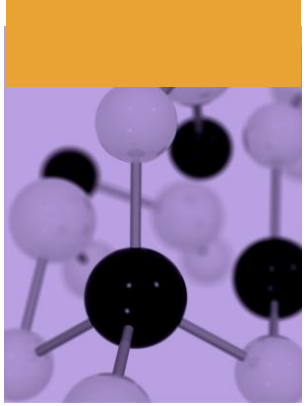
SRI International



# 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

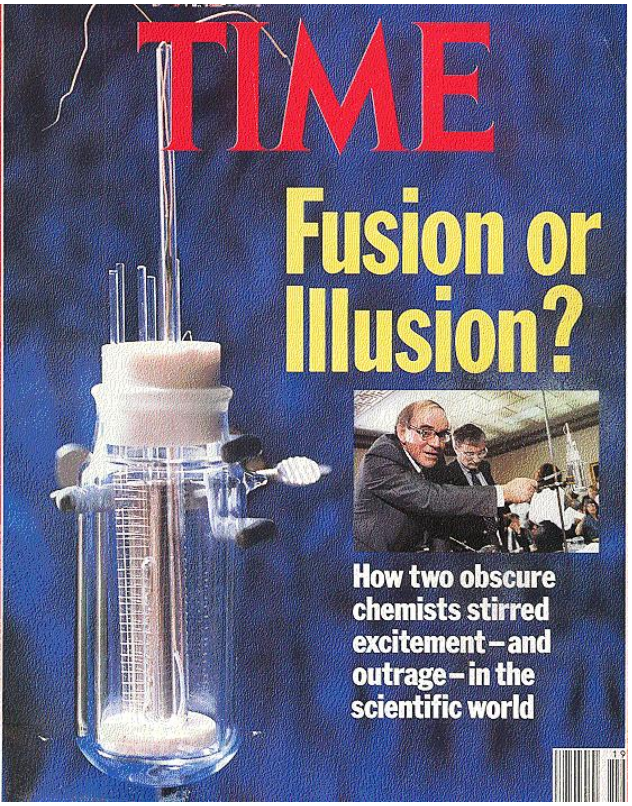
# Problems

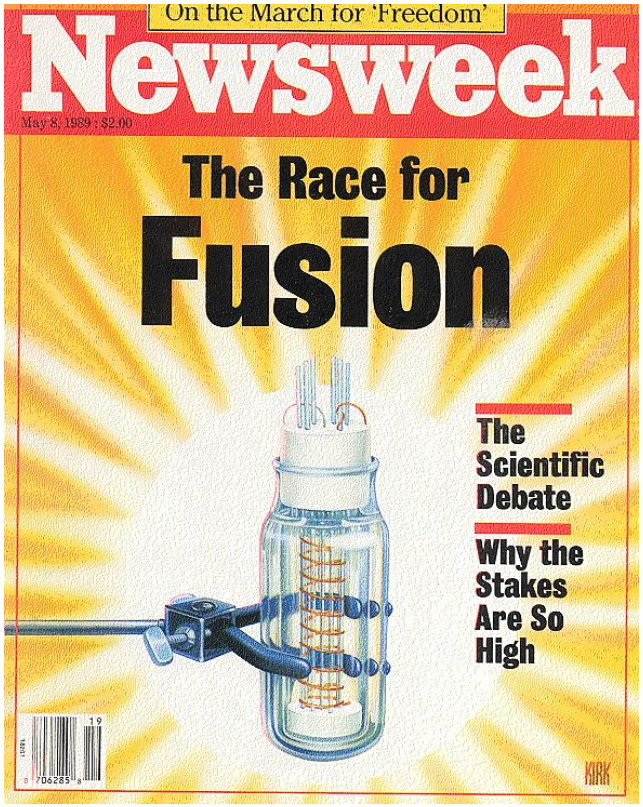
- Potential Importance for Energy
- Polarization of Scientists
- Diverse Mistakes
- Technical Complexity
- Flows of Money and Information

  - disrupted early and remain poor

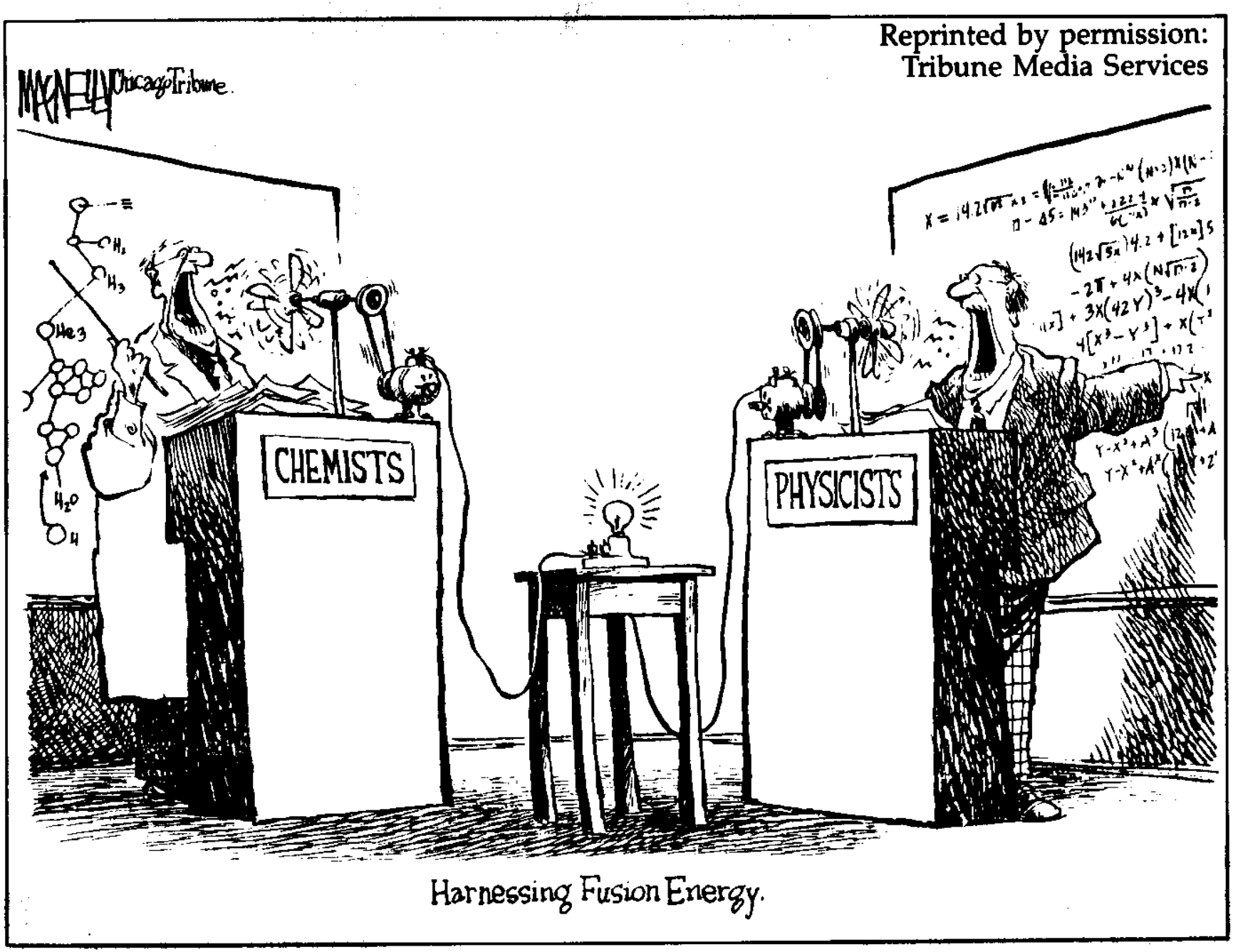
# Magazine Cover Stories

*May 1989*



**Truly Extraordinary Interest**

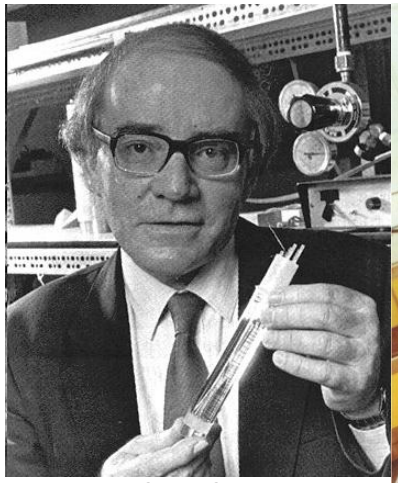



**Research and Development Magazine (July 1989)**

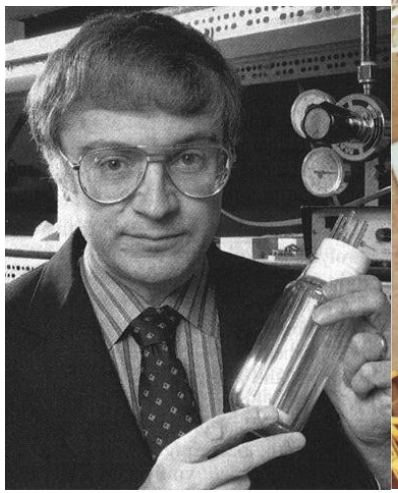
# Tokomak Fusion Test Reactor [TFTR]

*Princeton University*

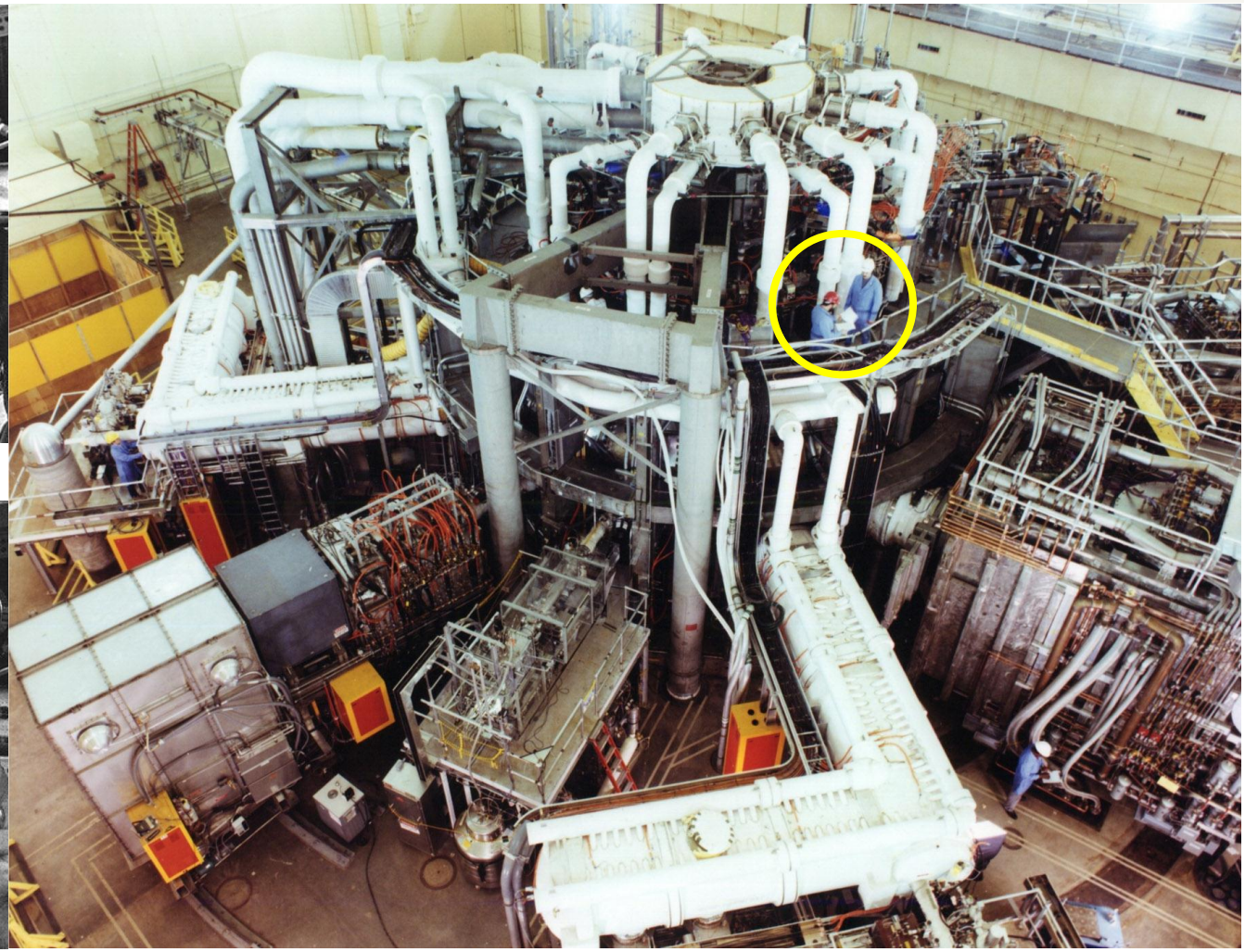
**1989**



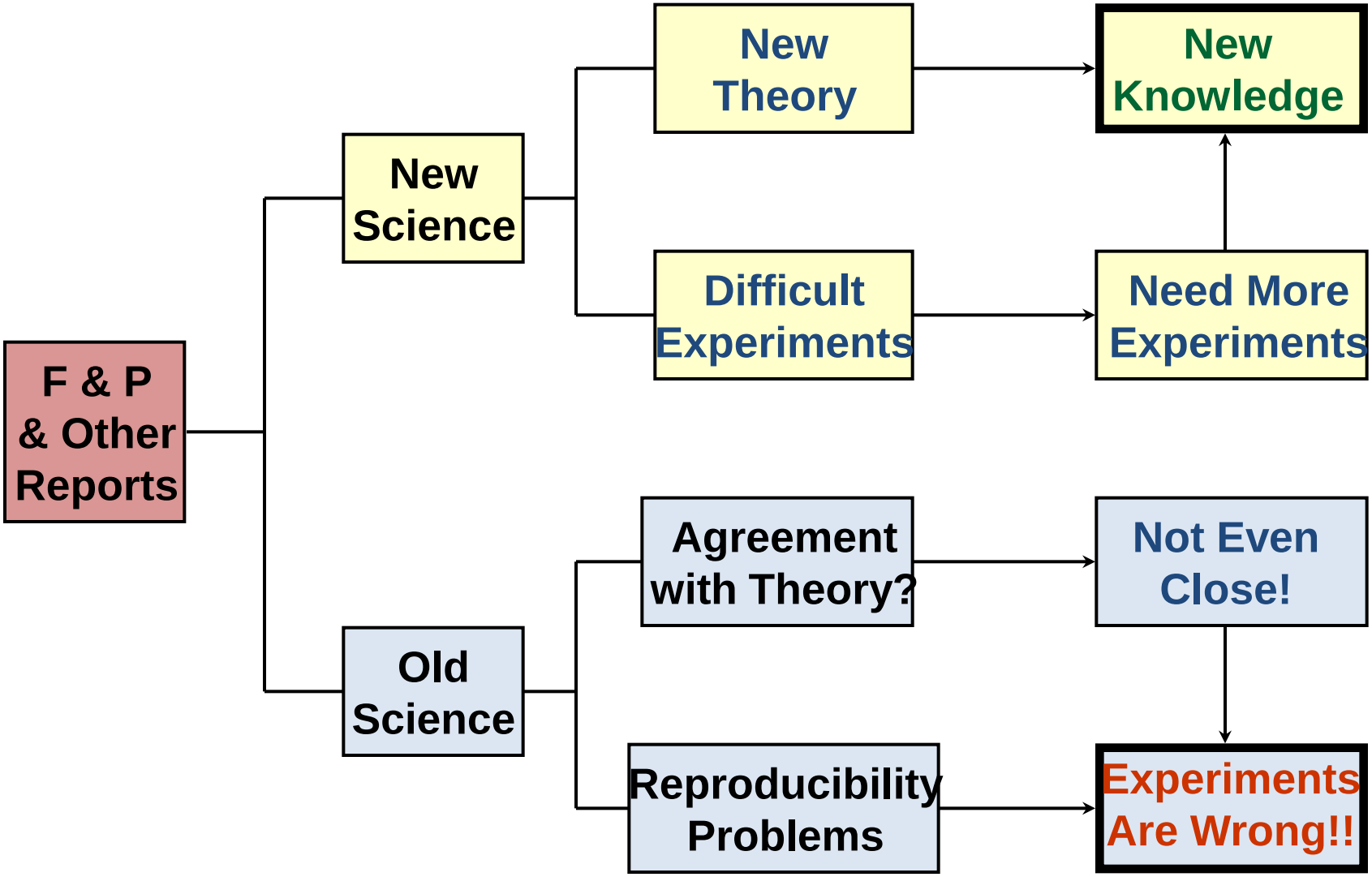
**Martin Fleischmann**



**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

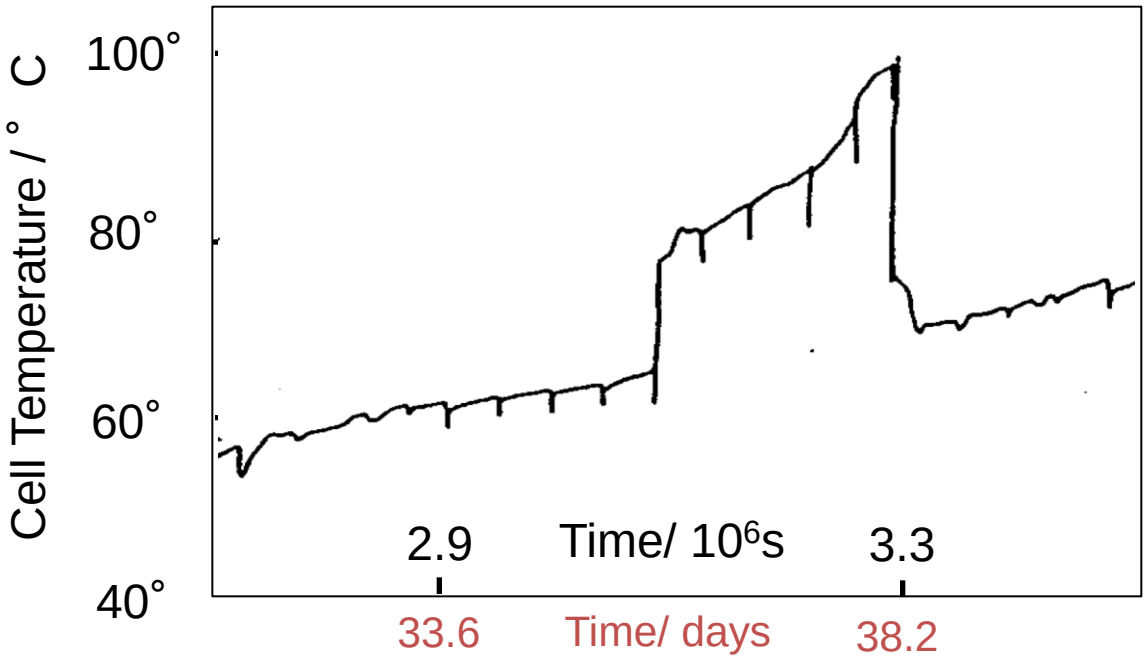
Fleishmann and Pons early results

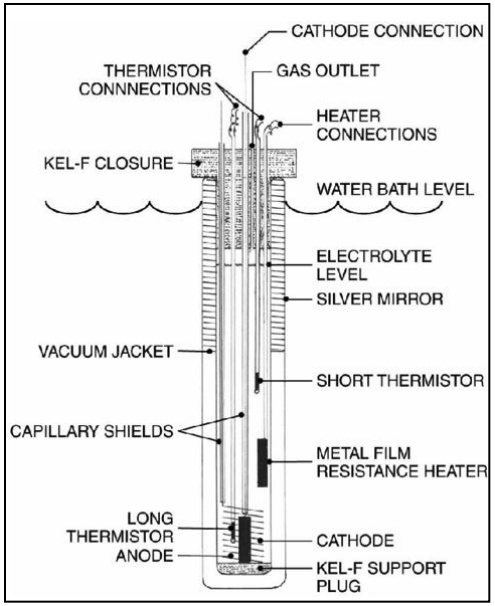
Calorimeters

Electrochemistry and loading

SRI cells and results

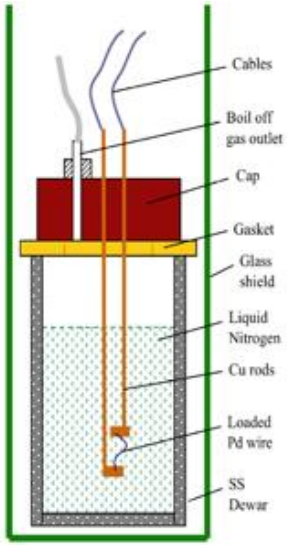
# Early Data on Cell Temperature

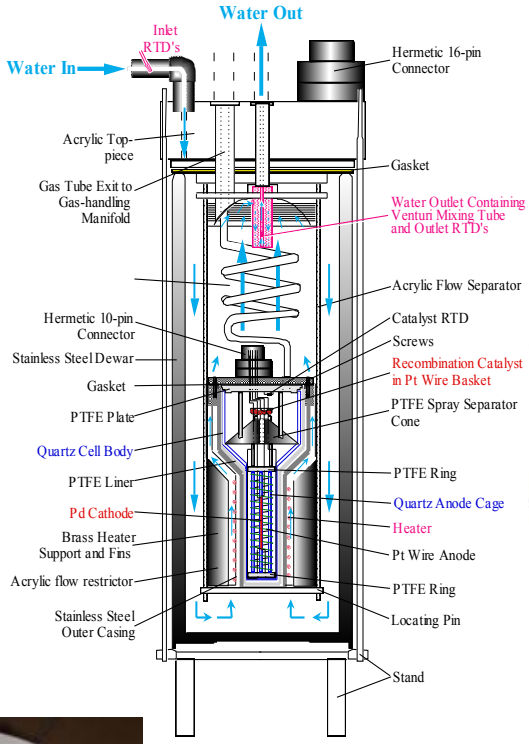


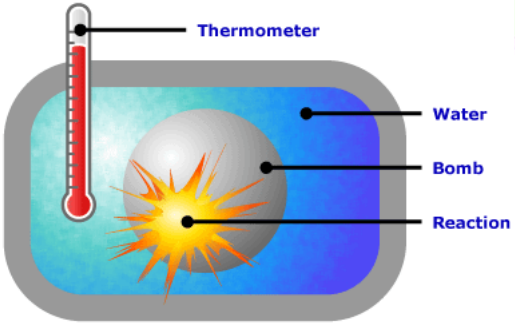

**S. Pons, M. Fleischmann, C. Walling and J. Simpson**
**International Patent Publication No. 90/10935 (1990)**

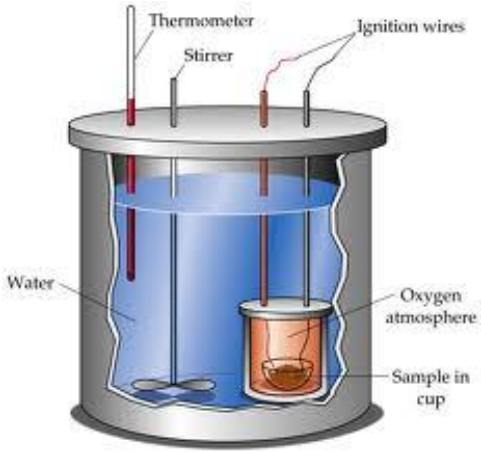
# Calorimeters

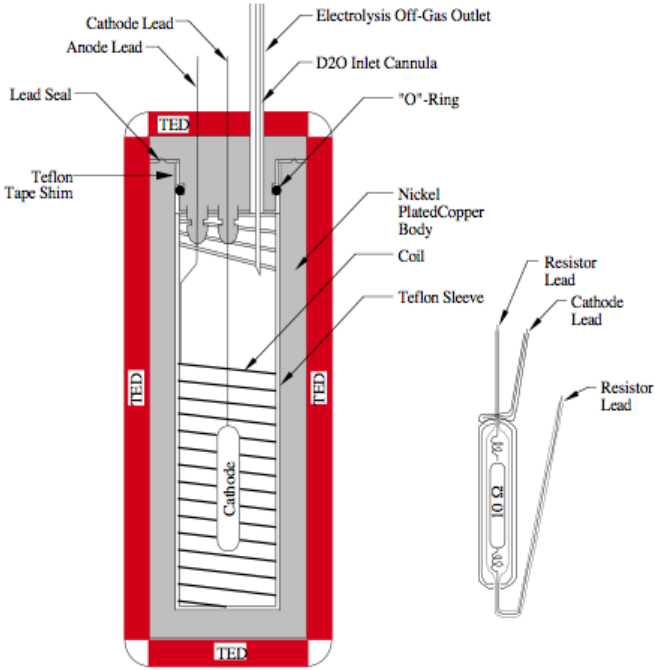




## Bomb Calorimeter



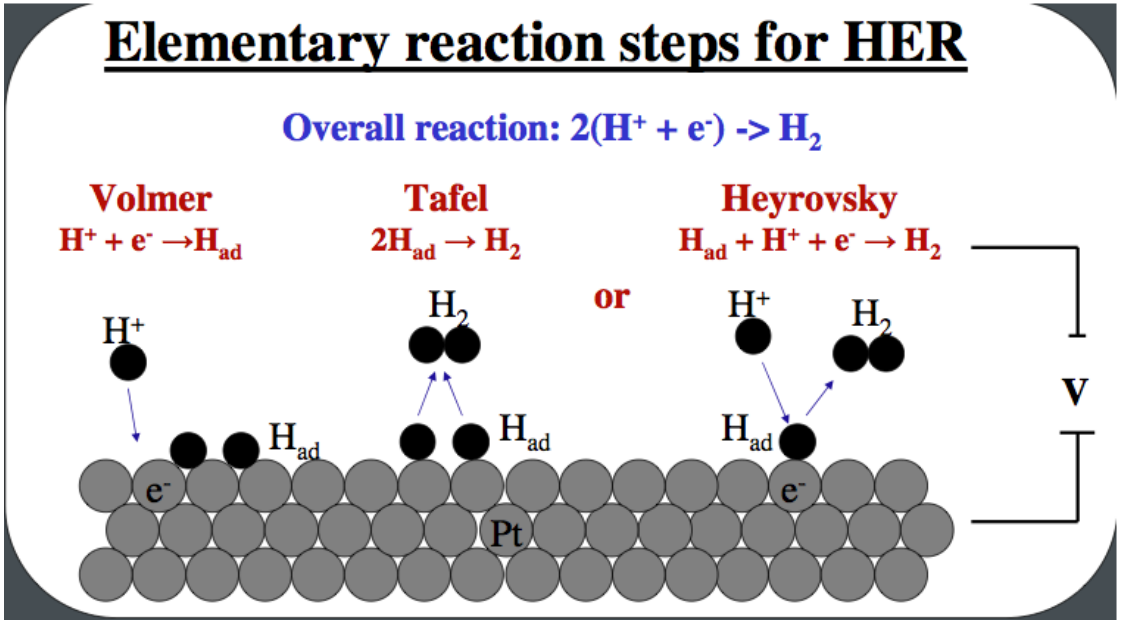





# Hydrogen Evolution Reactions [HER]

*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) |

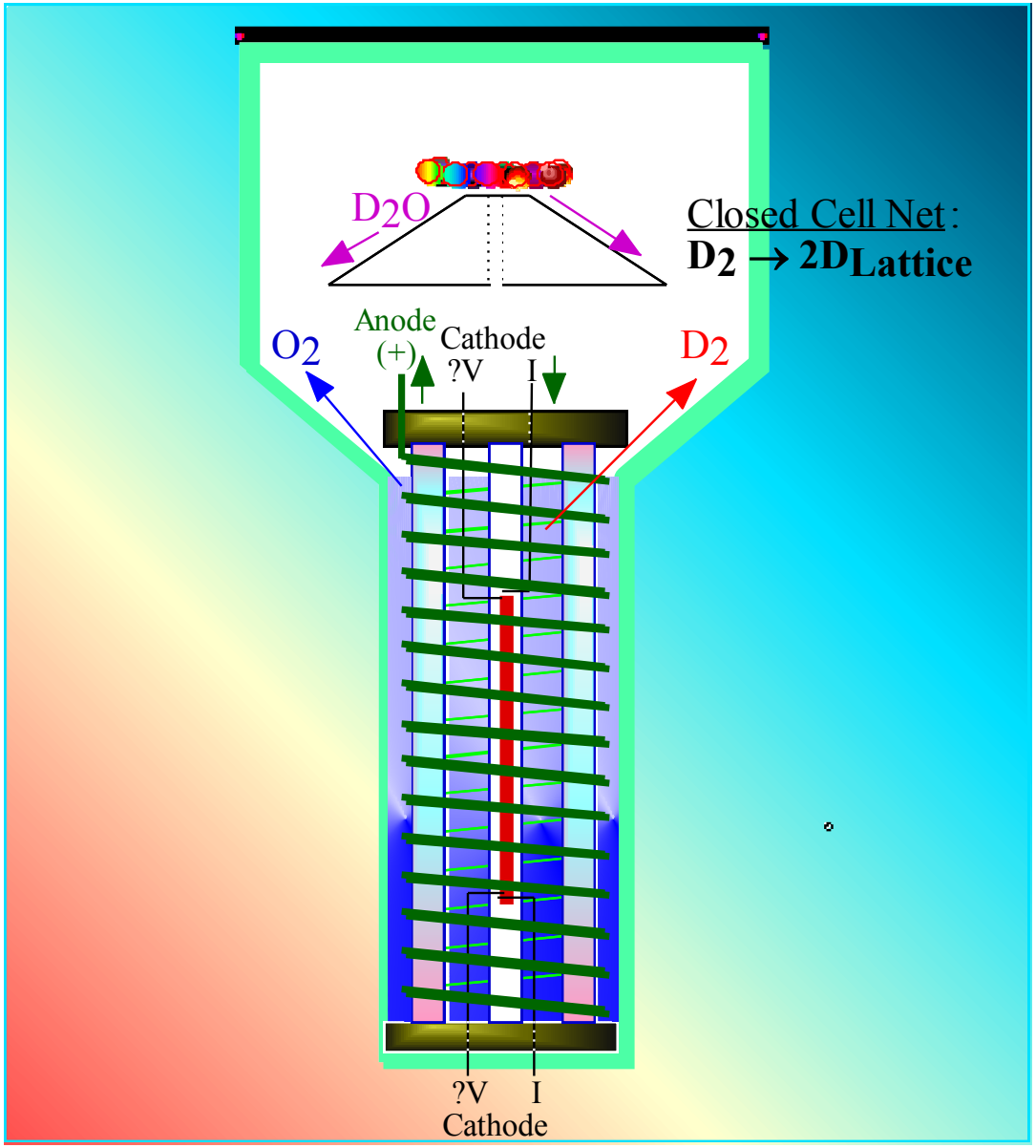
# Loading Cell and Reactions

**Wires:**

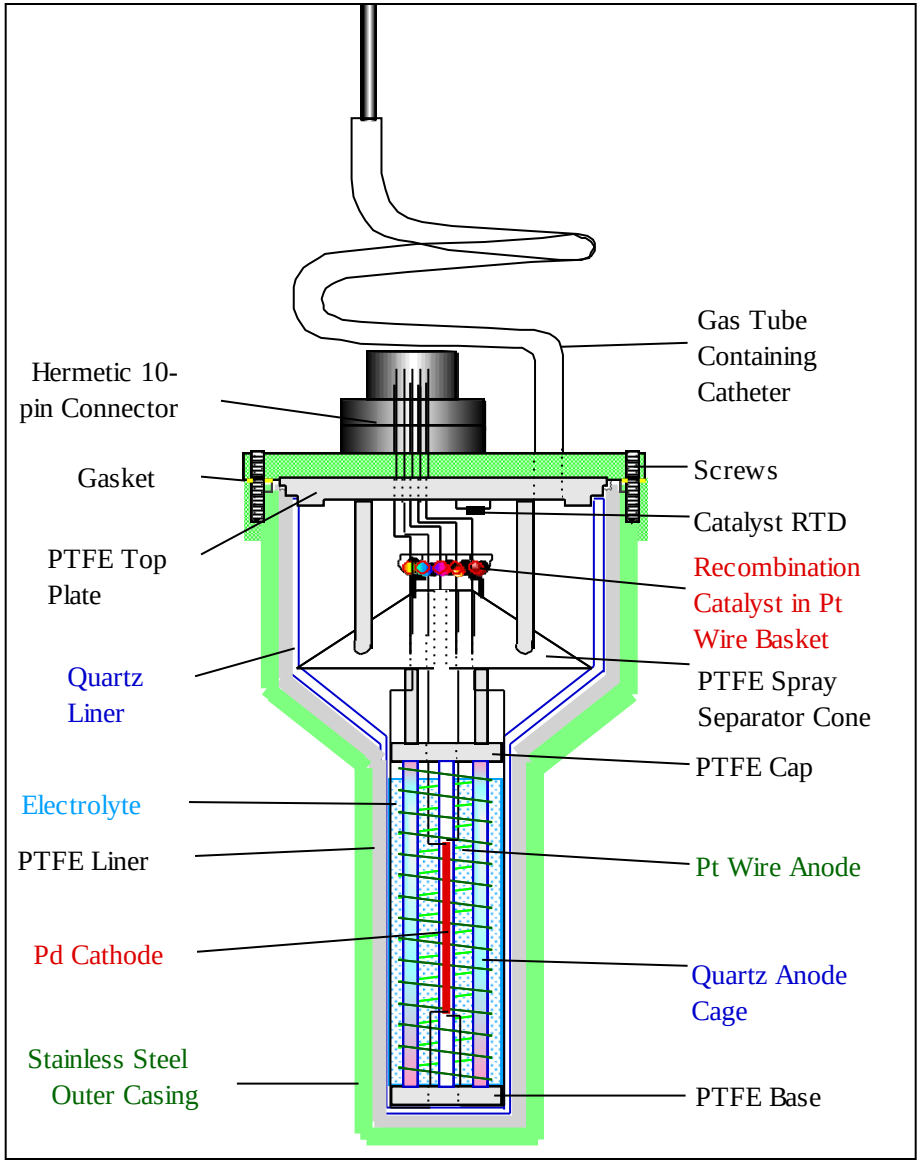
1 – 3 mm in diameter

3 – 5 cm in length

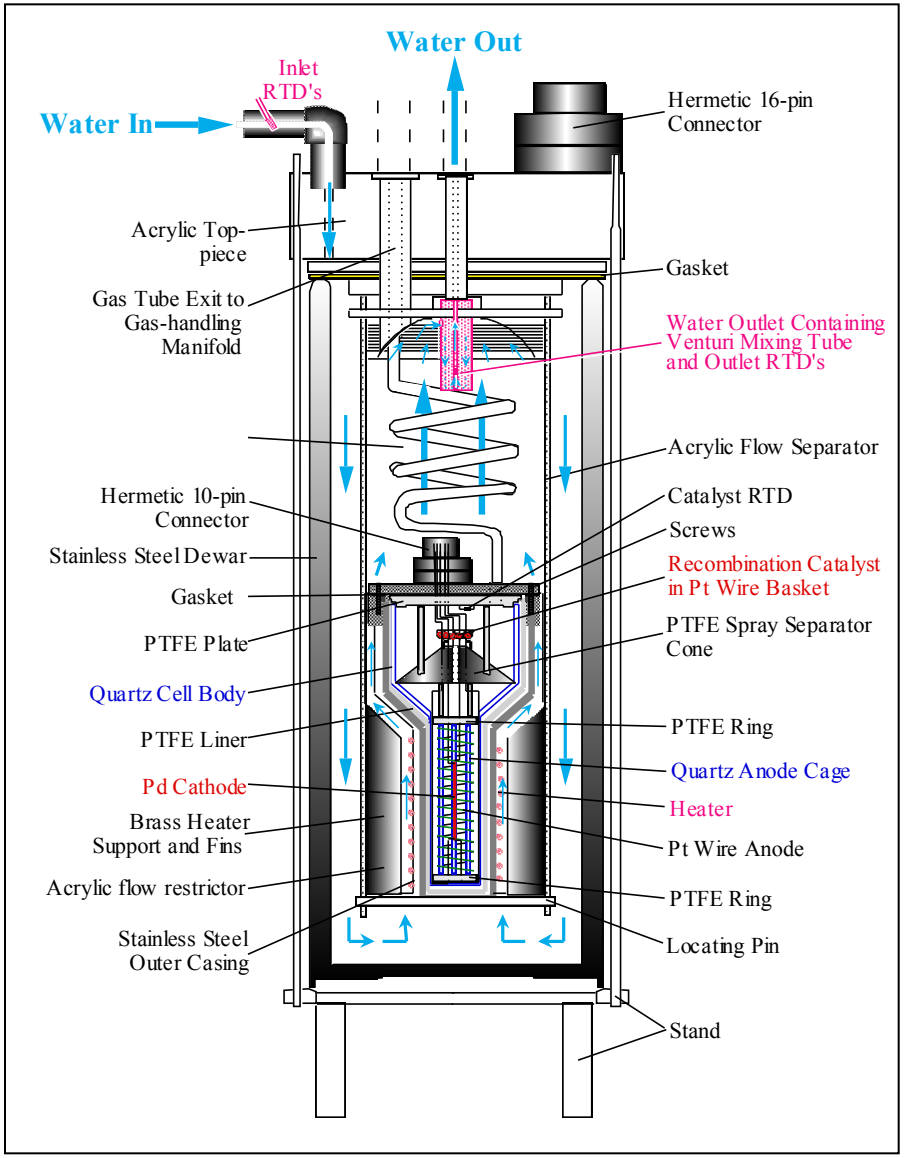
1M LiOD Electrolyte



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



# SRI Labyrinth (L and M) Calorimeter and Cell




Accuracy: ±0.35%

Operation:

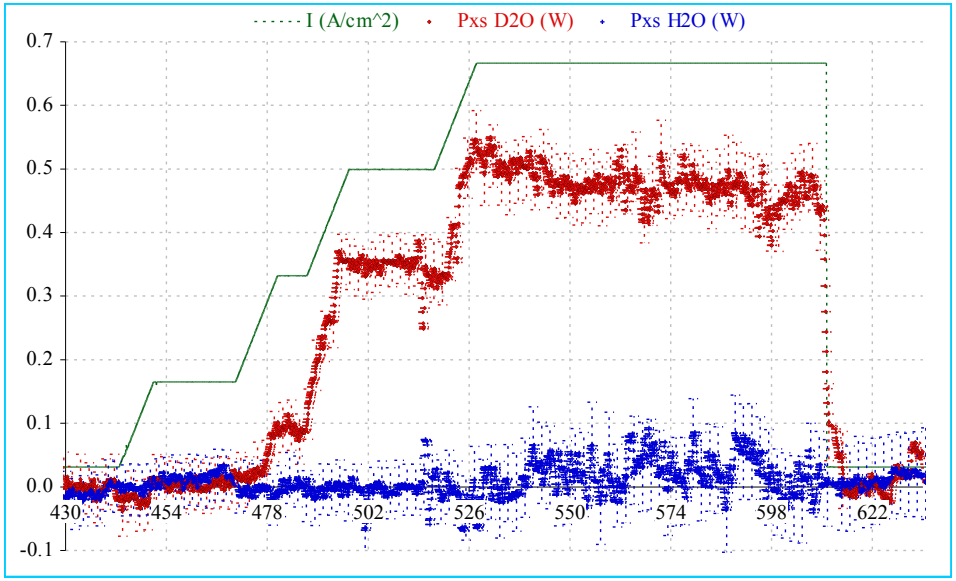
100 mW – 30W

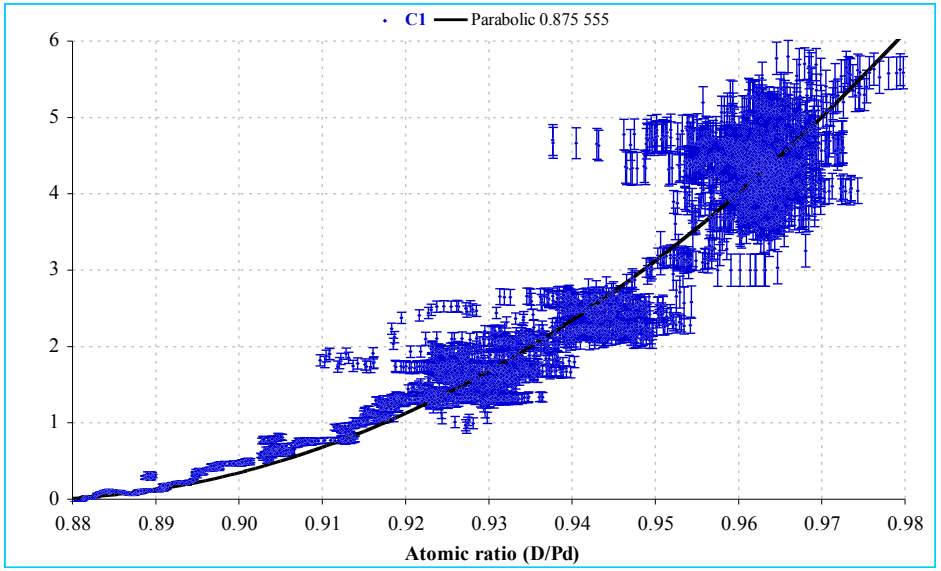
Stability:

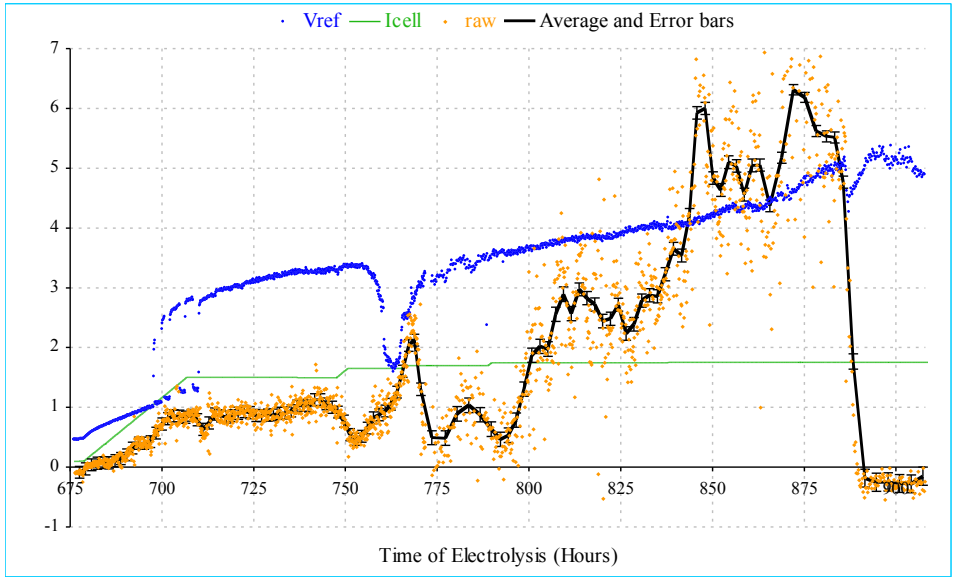
> 1000 hours

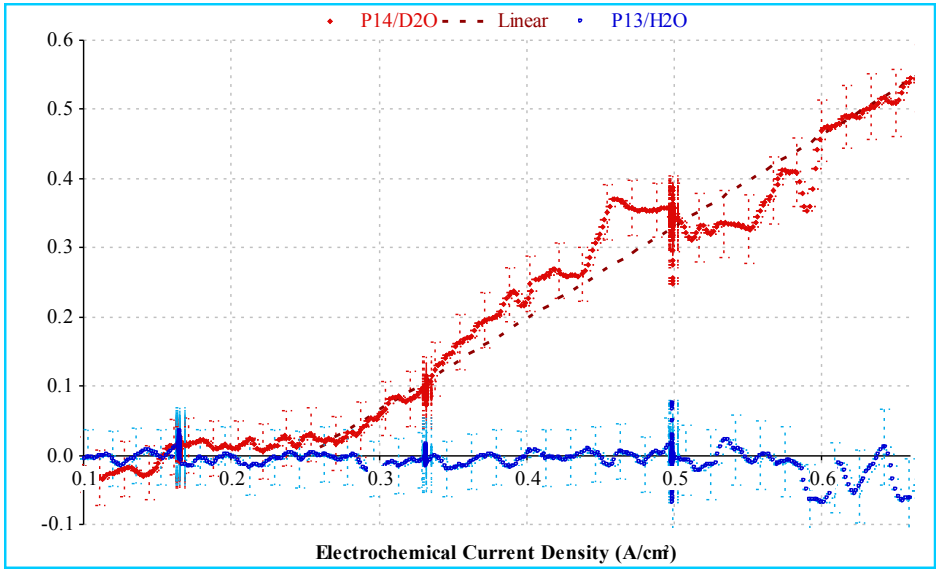
SRI >100,000 Hours of Precision Calorimetry using this and other Calorimeters

# DoE Review 2004



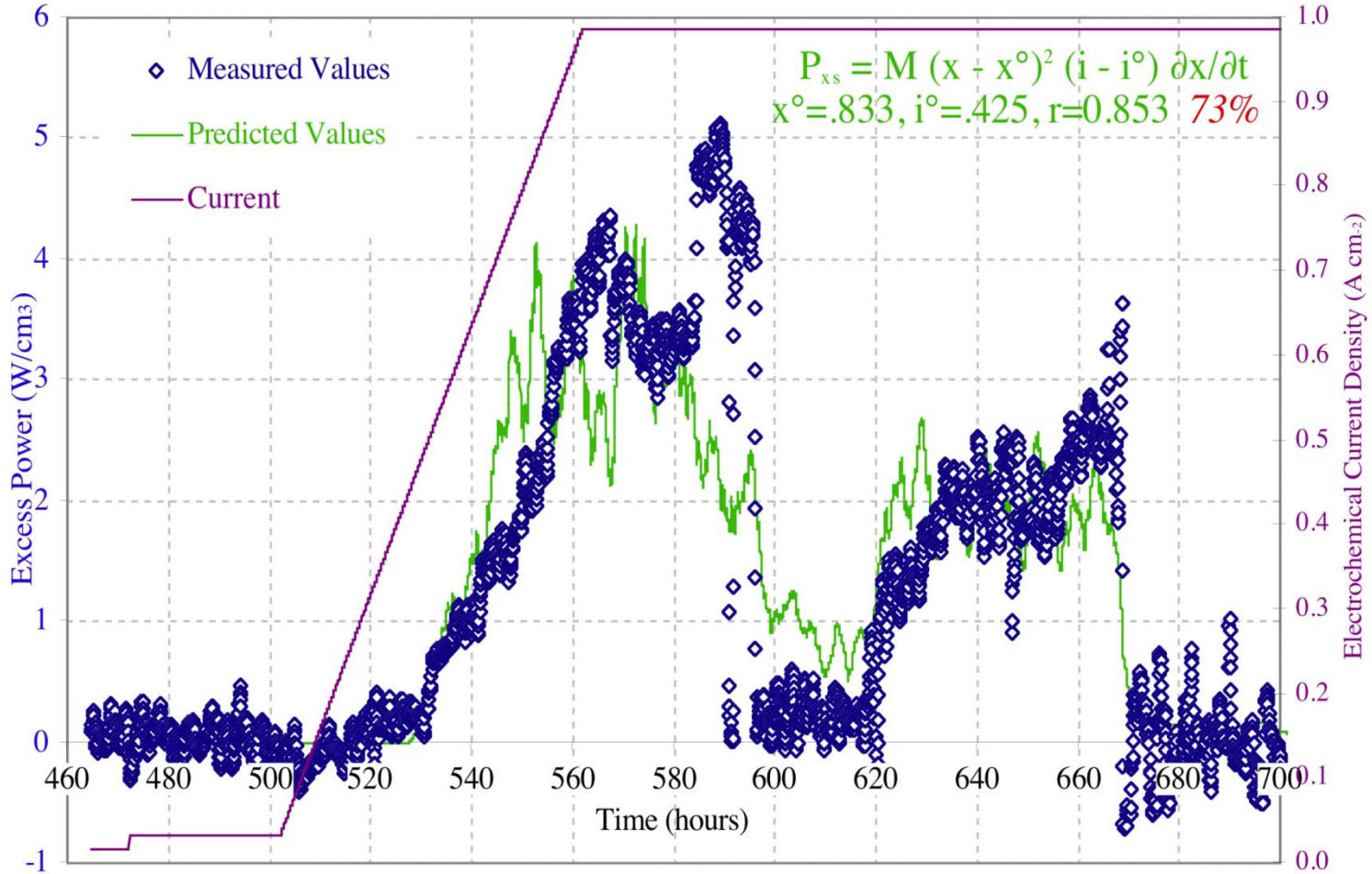



# A Predictive Equation

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

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



# Necessary but Not Sufficient….

- Necessary conditions:

| | |
|---|---|
| Maintain High <u>Average</u> D/Pd Ratio | (*Loading*) |
| For times >> 20-50 x $\tau_{D/D}$ | (*Initiation*) |
| At electrolytic i >250-500mA $cm^{-2}$ | (*Activation*) |
| With an imposed D Flux | (*Disequilibrium*) |

- Heat correlated with:

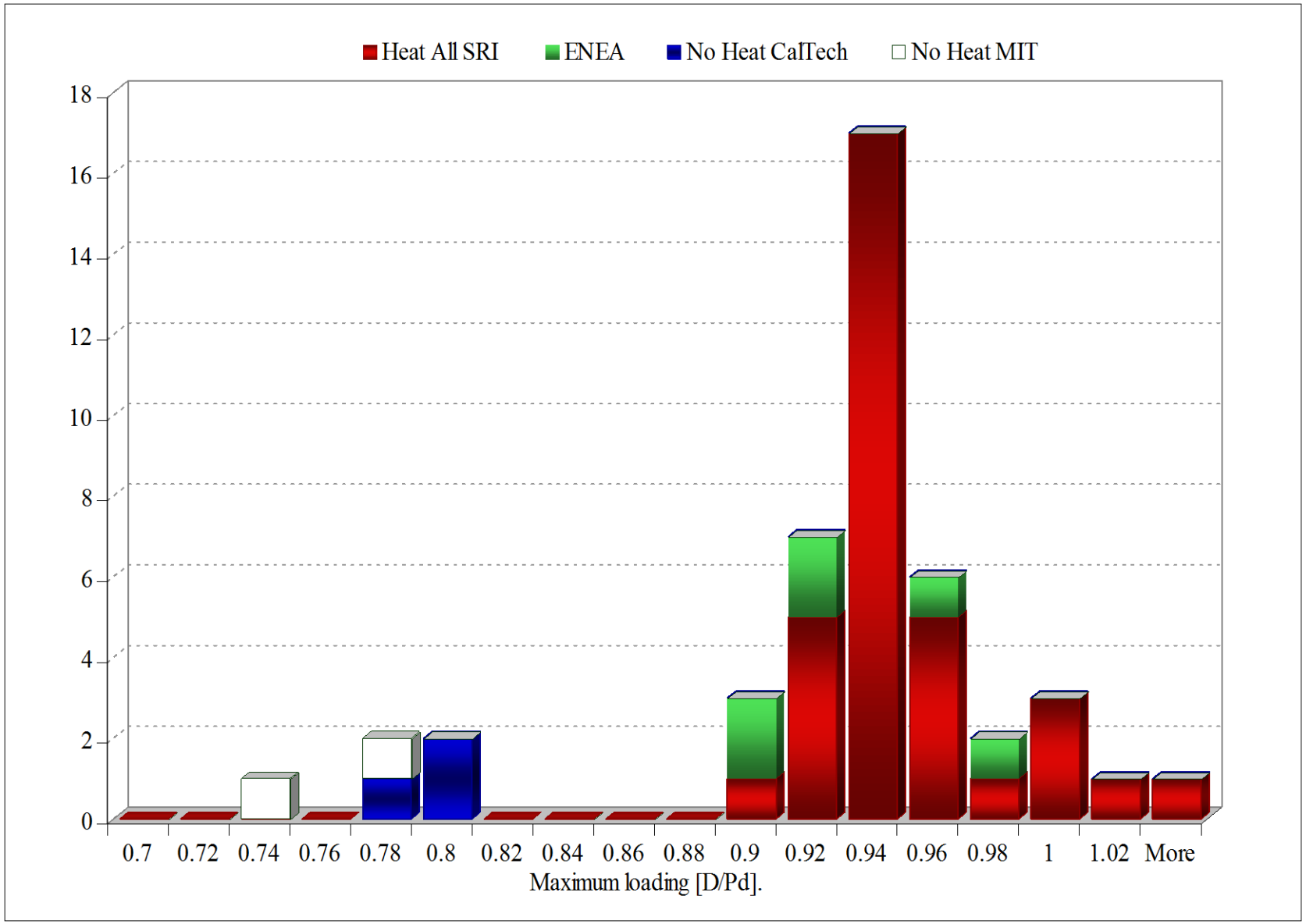
  - Electrochemical current or current density
  - D/Pd loading
  - $V_{ref.}$ surface potential
  - Pd metallurgy
  - Laser stimulus

- For 1mm diameter Pd wire cathodes:

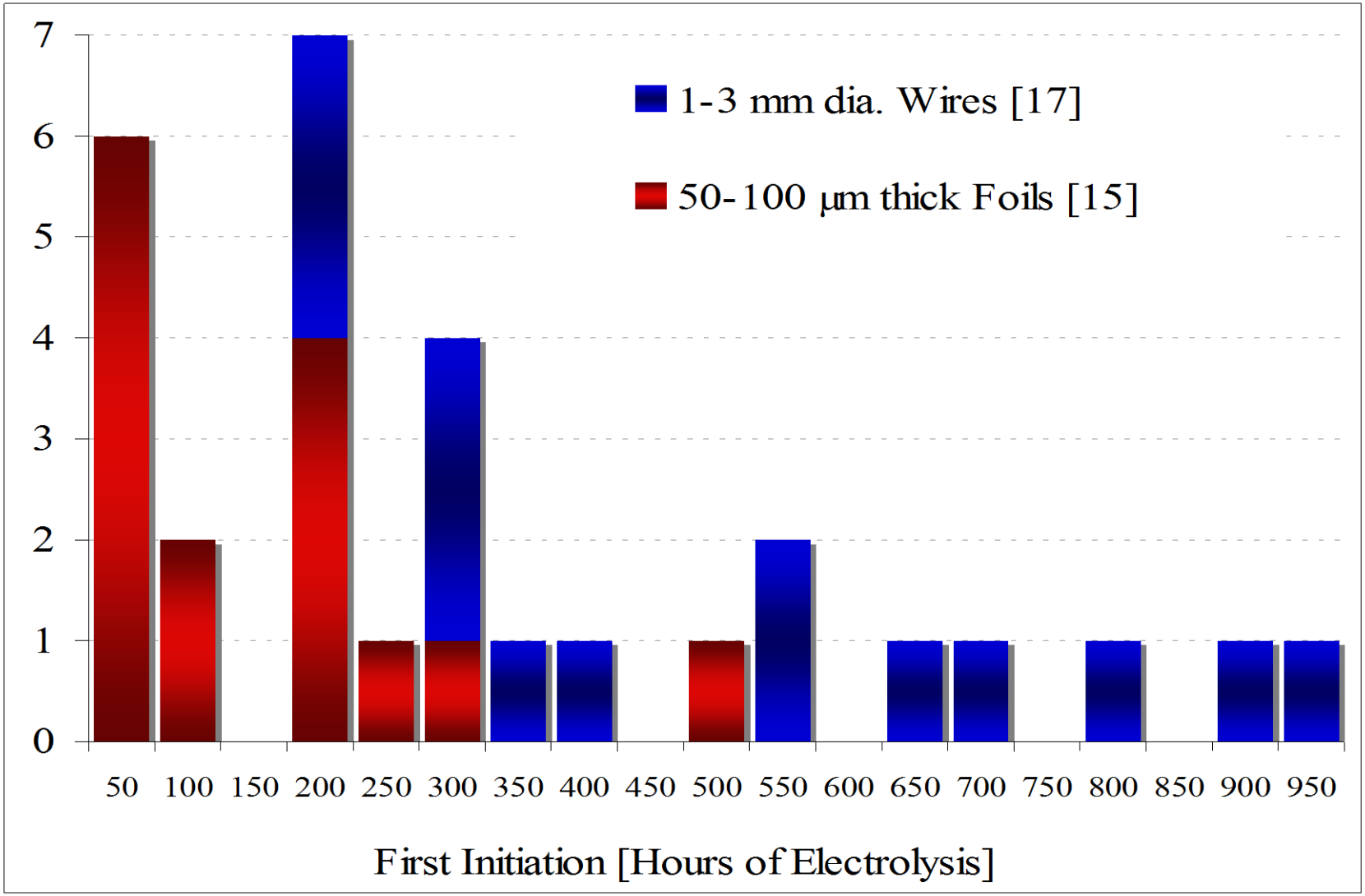
$$P_{xs} = M\,(x-x^{\circ})^2\,(i-i^{\circ})\,\partial x/\partial t$$

$x^{\circ}$ =0.84-0.88, $i^{\circ}$ =250-425mA $cm^{-2}$, $t^{\circ}$ >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

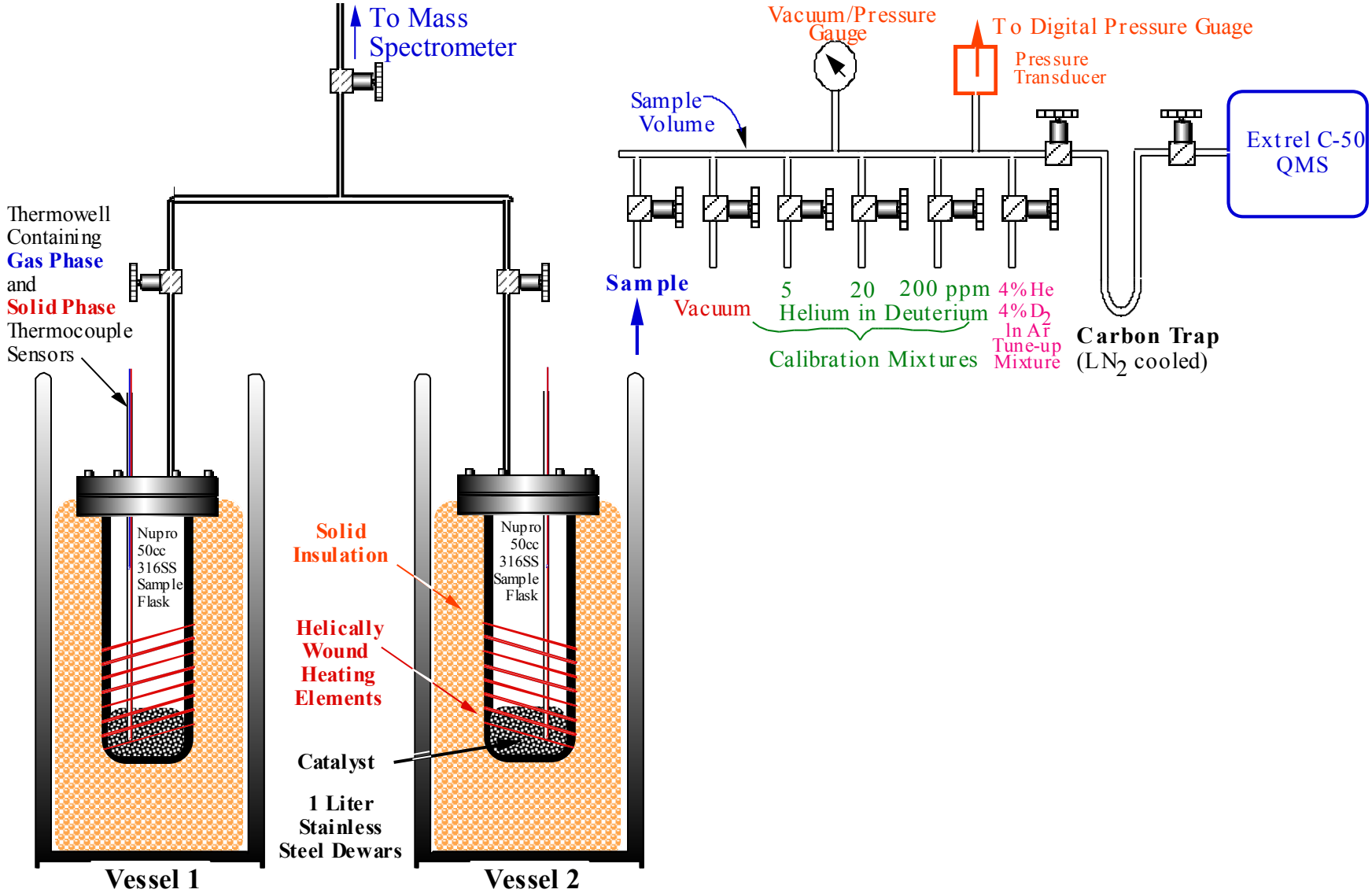
Heat and Helium

SRI gas calorimeter

Piantelli – Rossi – Commercialization?

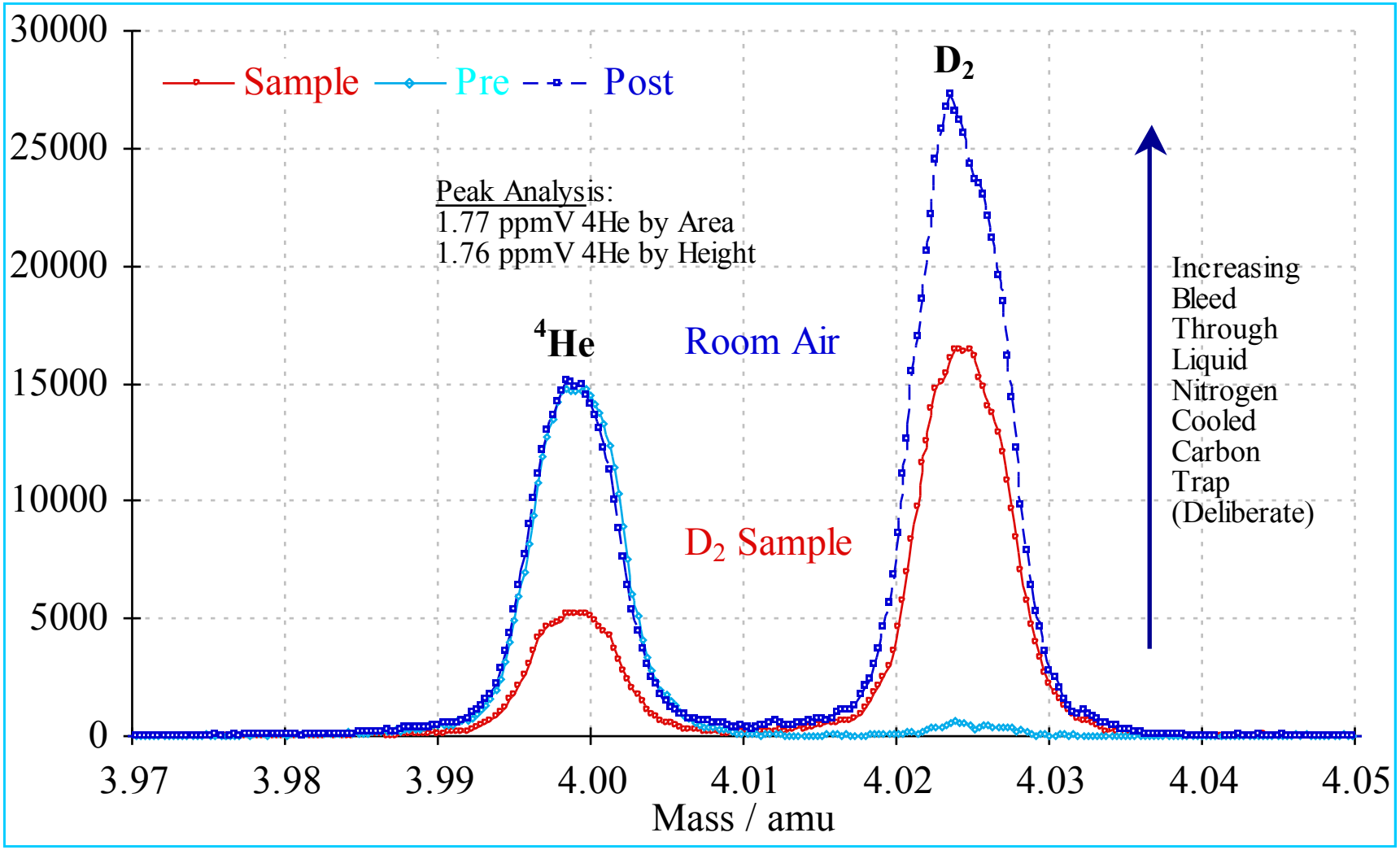
# Case Cell Studies:

## *$H_2$ and $D_2$ Gas with Pd/C Catalyst*



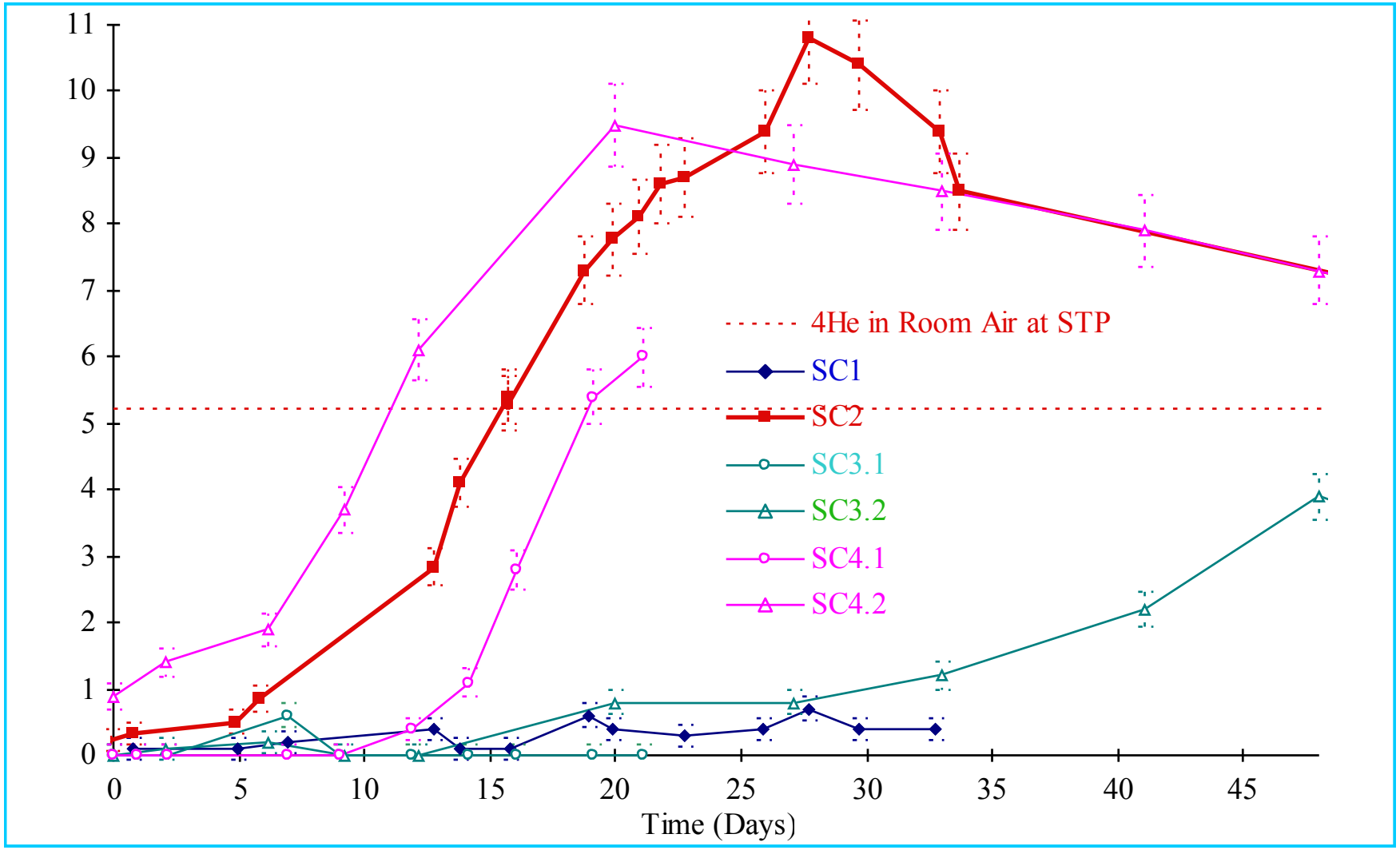
# Extrel QMS:

*Resolution of $D_2$ and $^4He$*



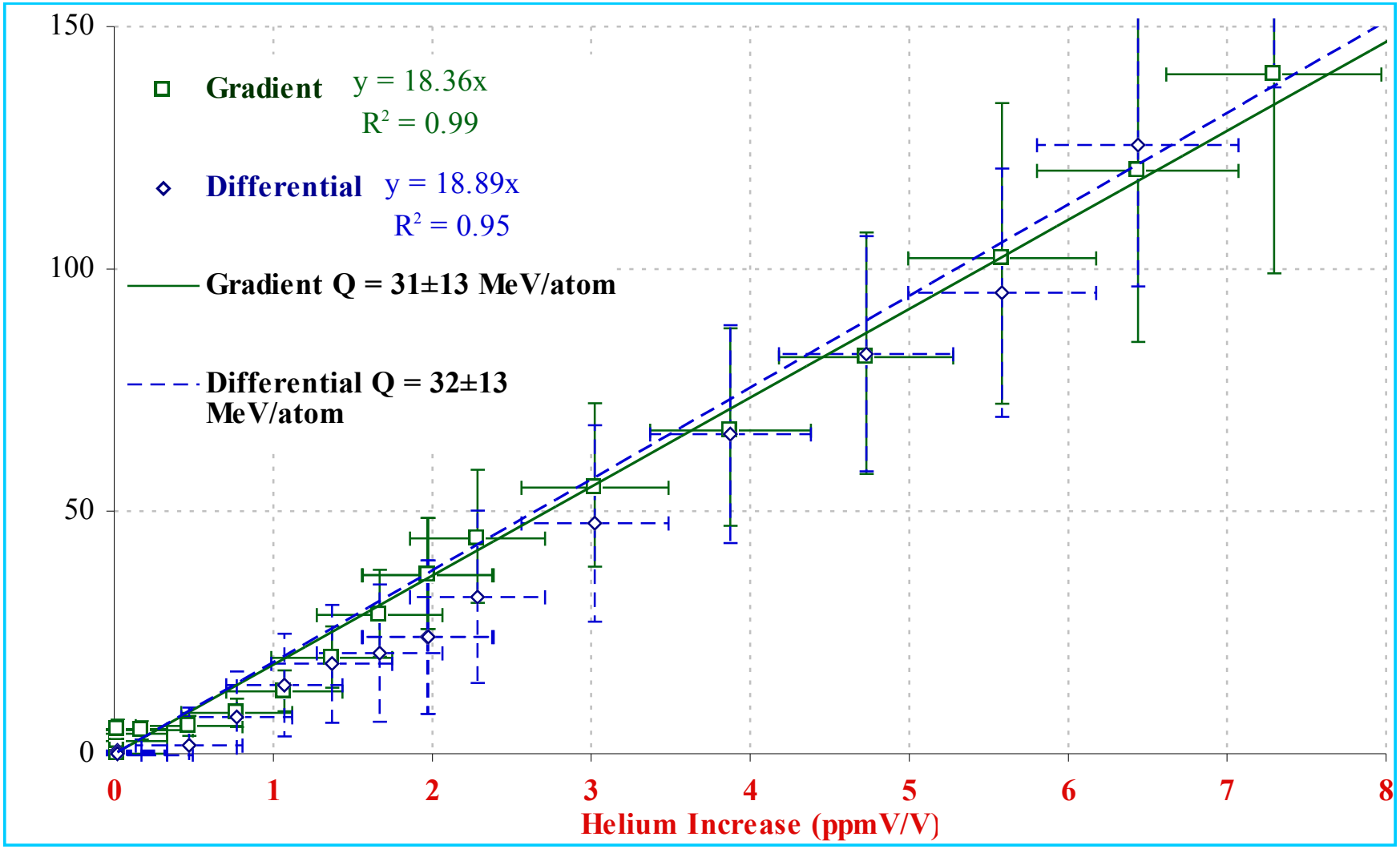
# Case:

## *$^{4}$He vs. Time*



# Case:

## *"Q"-Value - Energy vs. $^4He$*



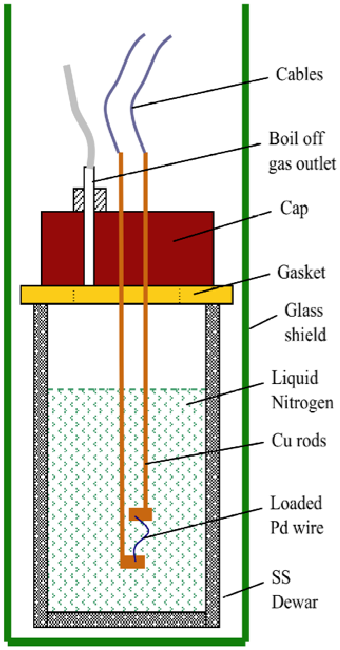
# Phase Change Calorimetry:

## *Liquid Nitrogen Boil-Off*

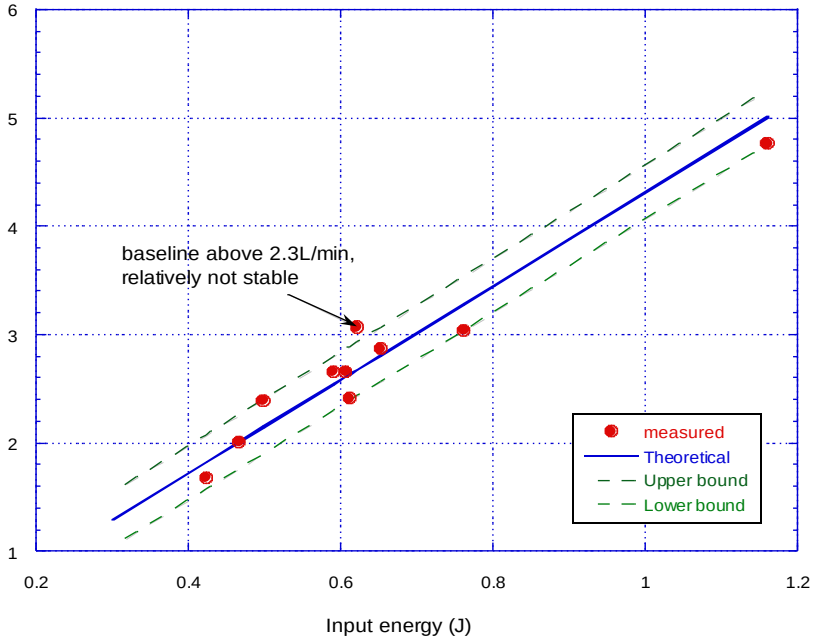
Measurements:

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

Apparatus



**mL $N_2$ gas**




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 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.

| Wire # | 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 |

**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 |

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

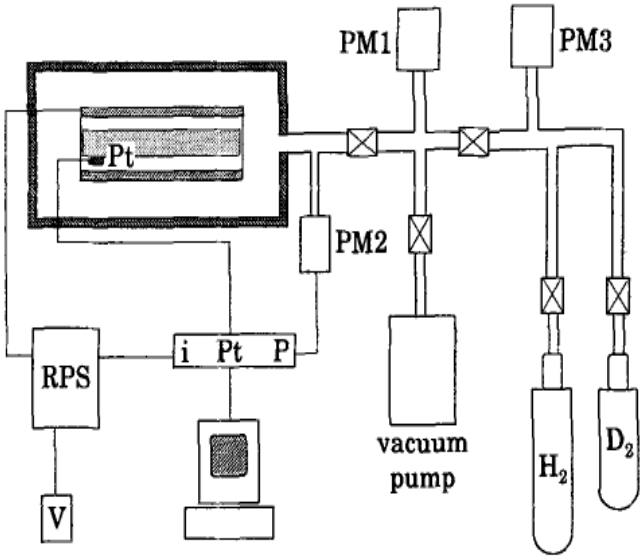
*University of Siena*

- 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

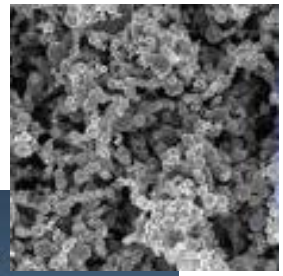


# Andrea Rossi E-Cat

*Energy Catalyzer*

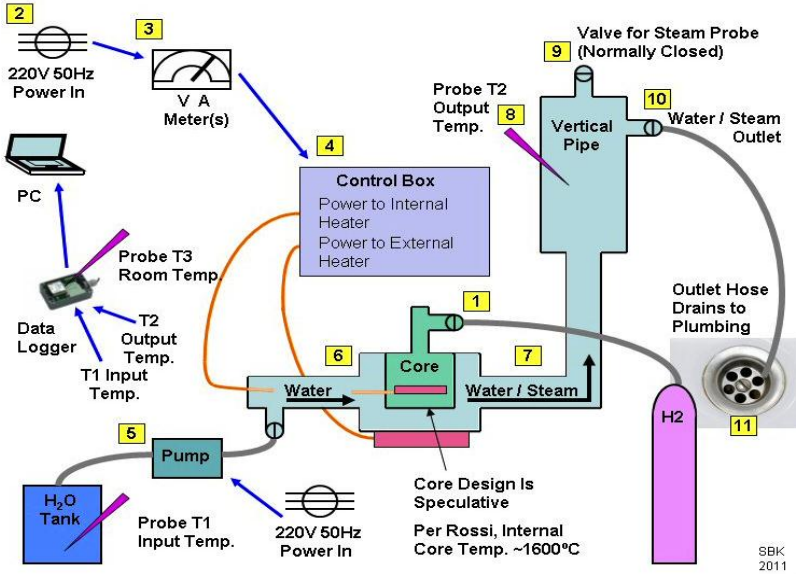
Rossi Core

nano-Ni powder



**Andrea Rossi's Energy Catalyzer**

(Draft schematic reviewed and confirmed by Rossi on June 14, 2011)



# 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

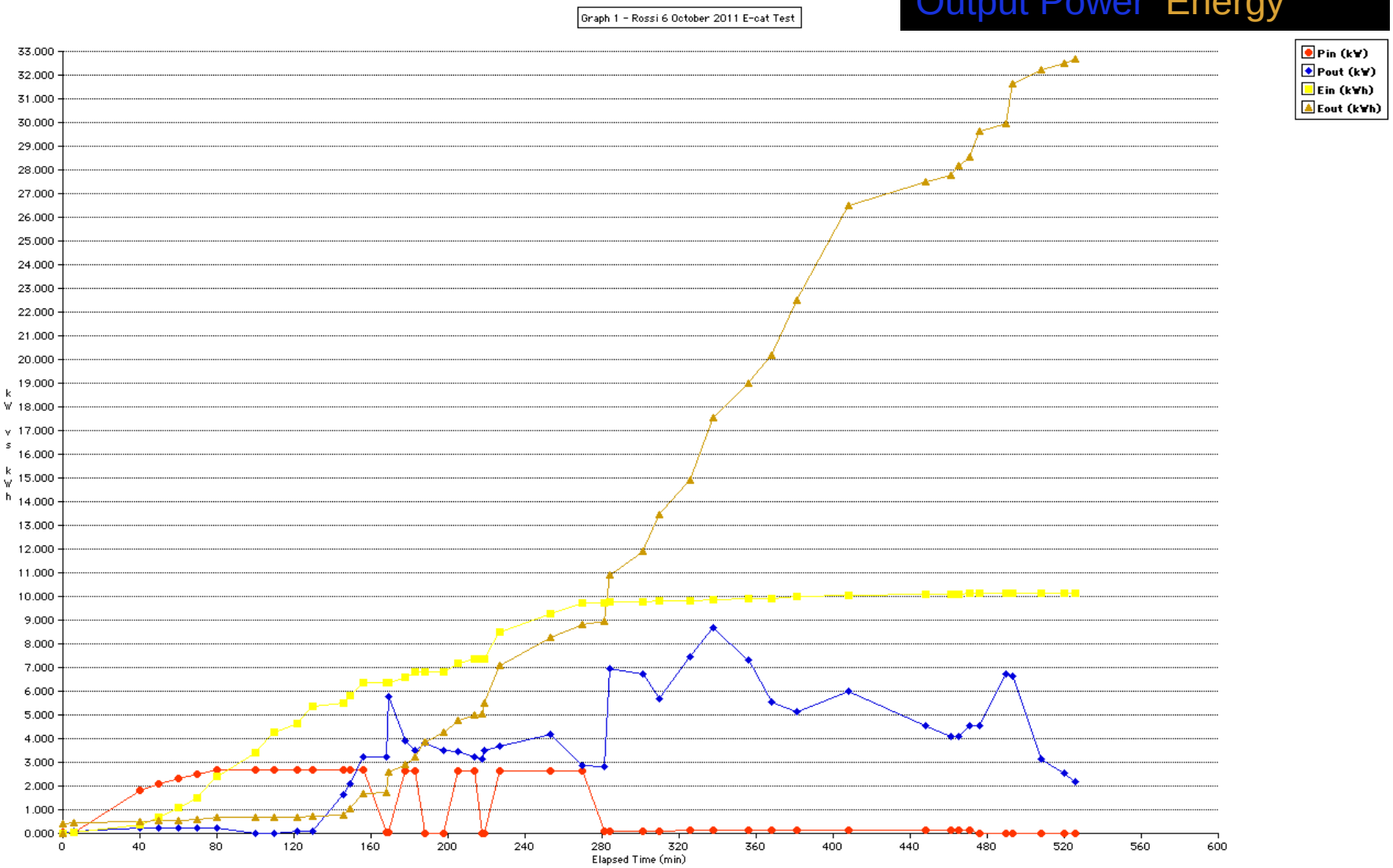
- **Bologna II Jan 14, 2011**
  - 45 minutes generating steam
  - Average $P_{In}$ ~1 kW, $P_{Out}$ 12 kW, Gain 12.7

- **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 $\gamma$-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!

SRI International

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| 10. Cambridge, Mass. | 11. Marseilles, France | 12. Yokohama, Japan |
| 14. Washington, D.C. | 13. Sochi, Russia | 16. India |
| | 15. Rome, Italy | 17. Korea Aug 2012 |

## Other Conferences

12 in Russia, 6 in Japan, 5 in Italy and
many sessions at various society conferences

# 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?