

# Cold Fusion at SRI

## An 18 Year Retrospective (and brief Prospective)

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**1989**

A Series of Unanswered Questions

**Q1** *Is there unexplained heat?*

**Q2** *Is the heat output sensibly correlated with inputs?*

**Q3** *Is the heat derived from a nuclear process?*

**Q4** *Nuclear ash correlated with the excess heat?*

**Q5** *Are there other nuclear effects?*

**Q6** *What is the nuclear process?*

**Q7** *What is the future?*

**1992**

**Q1 *Unexplained heat source?* YES!!!**

- Effect Evidenced on numerous occasions (*>70 at SRI*)
- Typical  $P_{xs}$  3 - 30% ( $\pm 0.5\%$ ) of Total  $P_{in}$  (*340%*)
- Up to  $90\sigma$  observation of excess power effect
- Duration several hours to 1 week
- Sustained, unidirectional heat burst exhibit an integrated energy at least 100 times greater than conceivable energy storage effects
- Heat production observed for over half the operation time of one cell (C1).
- Similar heat production observed using 4 different calorimetric methods.

**1995**

**Q2 *Sensibly correlated with inputs?* YES!!!**

- Necessary conditions:

Maintain High Average D/Pd Ratio

*(Loading )*

For times  $\gg 20-50 \times \tau_{D/D}$

*(Initiation)*

At electrolytic  $i > 250-500 \text{ mA cm}^{-2}$

*(Activation)*

With an imposed D Flux

*(Disequilibrium)*

- Heat correlated with:

- electrochemical current or current density

- D/Pd loading

- $V_{\text{ref.}}$  surface potential

- Pd metallurgy

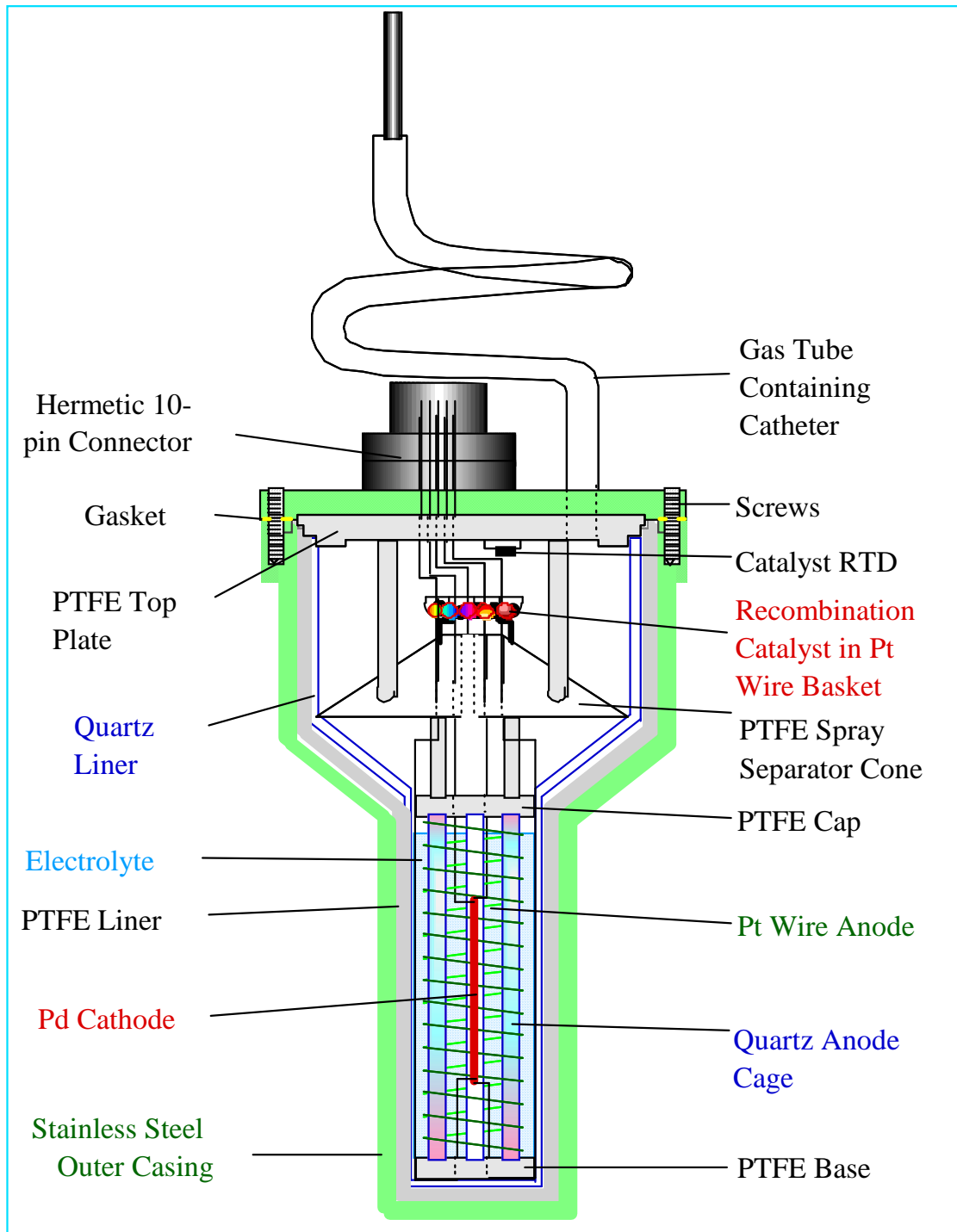
- Laser stimulus

- For 1mm dia. Pd wire cathodes:

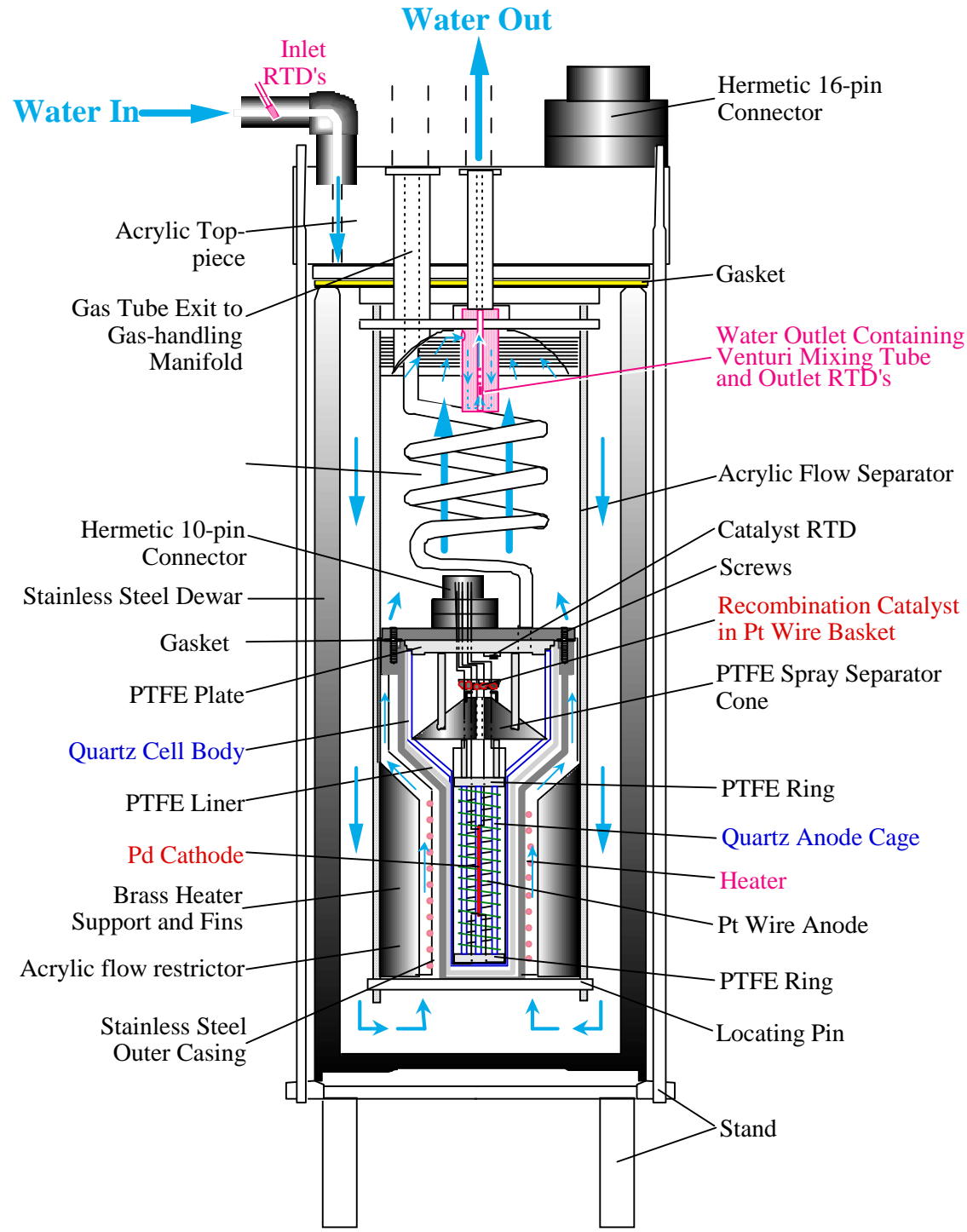
$$P_{\text{XS}} = M (x-x^{\circ})^2 (i-i^{\circ}) |i_{\text{D}}|$$

$x^{\circ} \sim 0.875$ ,  $i^{\circ} = 50-400 \text{ mA cm}^{-2}$ ,  $i_{\text{D}} = 1-10 \text{ mA cm}^{-2}$ ,  $t^{\circ} > 200 \tau_{\text{D/D}}$

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

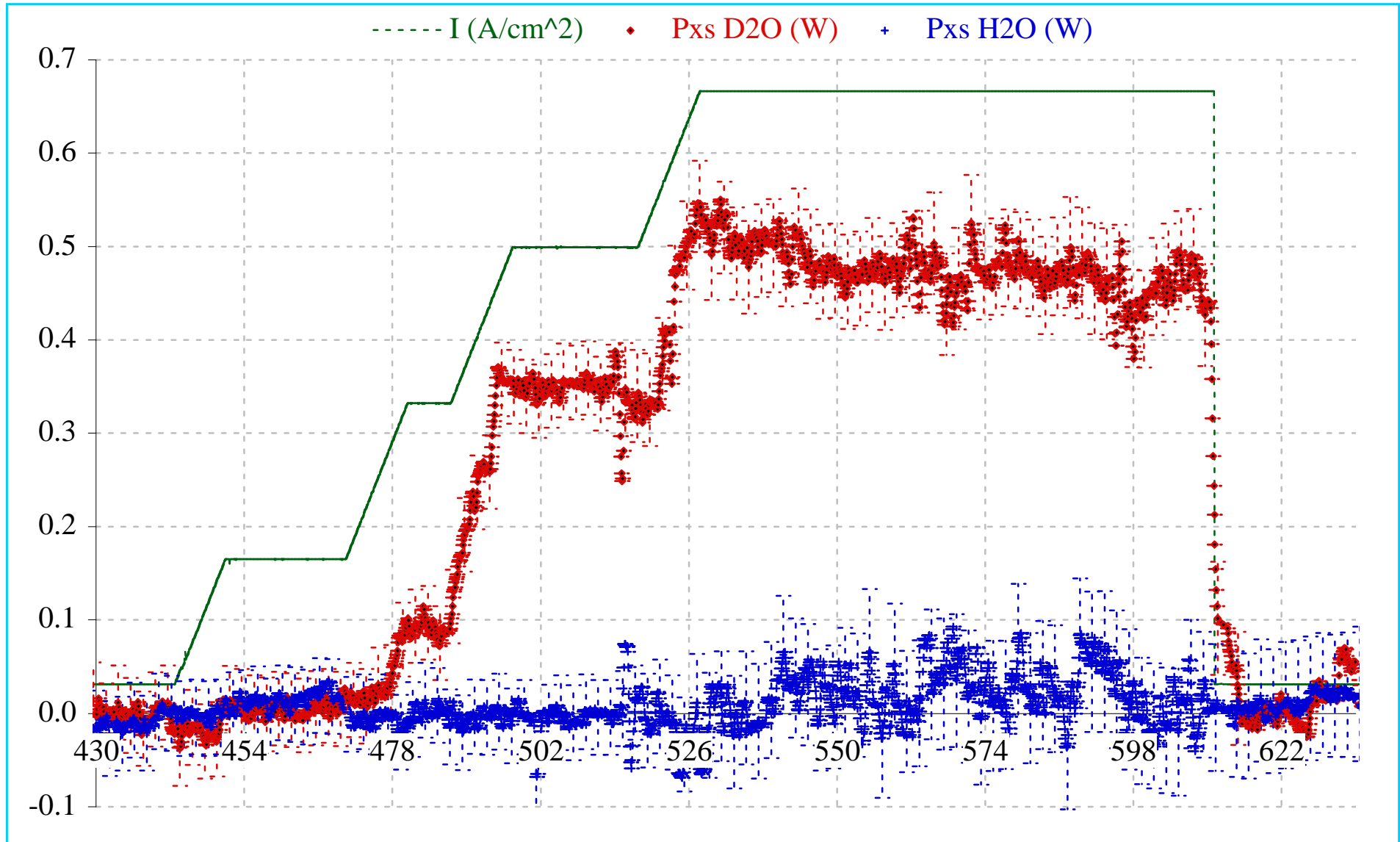


# SRI Labyrinth (L and M) Calorimeter and Cell



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

D<sub>2</sub>O

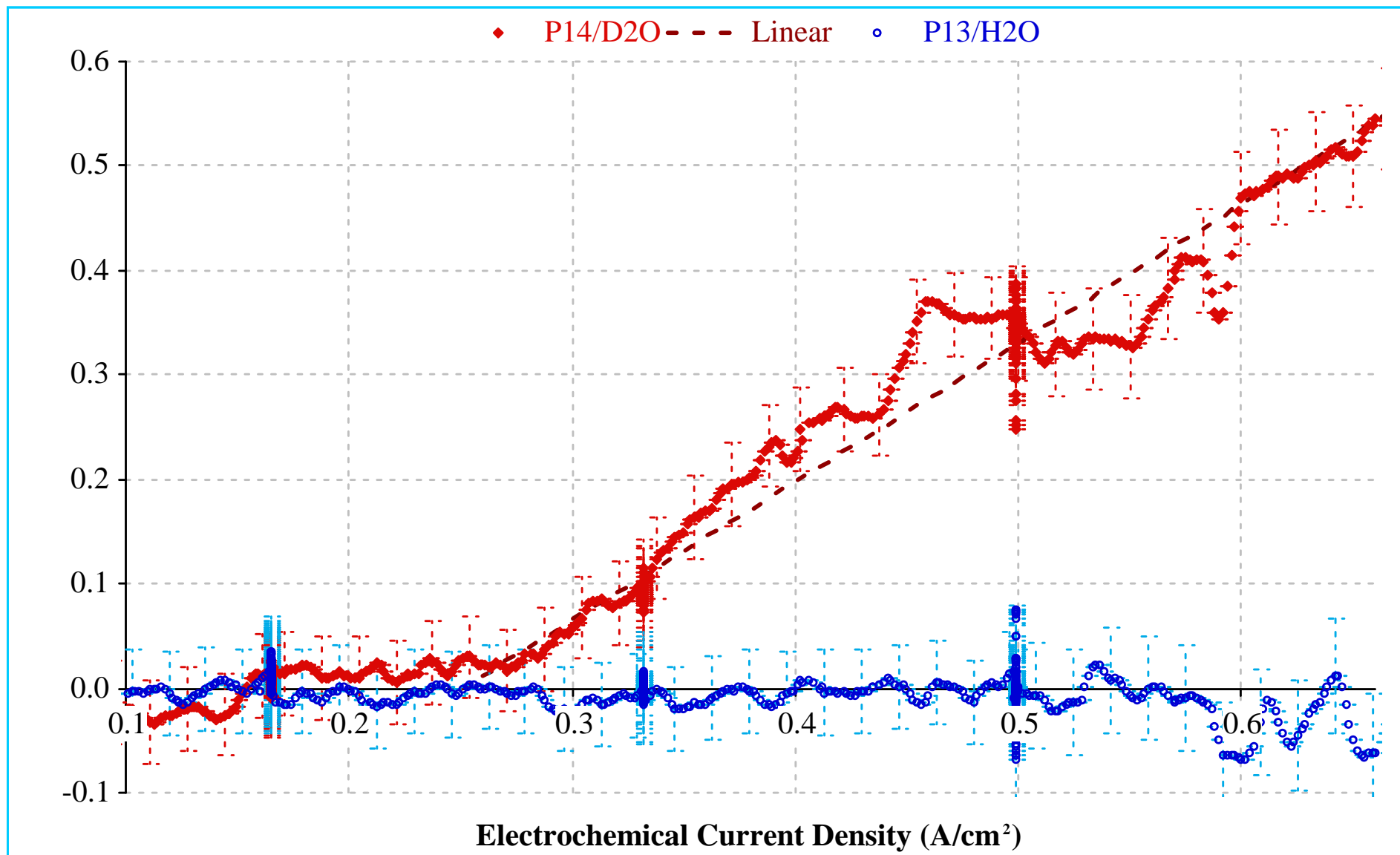


# P13/14 Simultaneous Series Operation of

Light & Heavy Water Cells;

I or i

*Excess Power vs. Current Density*

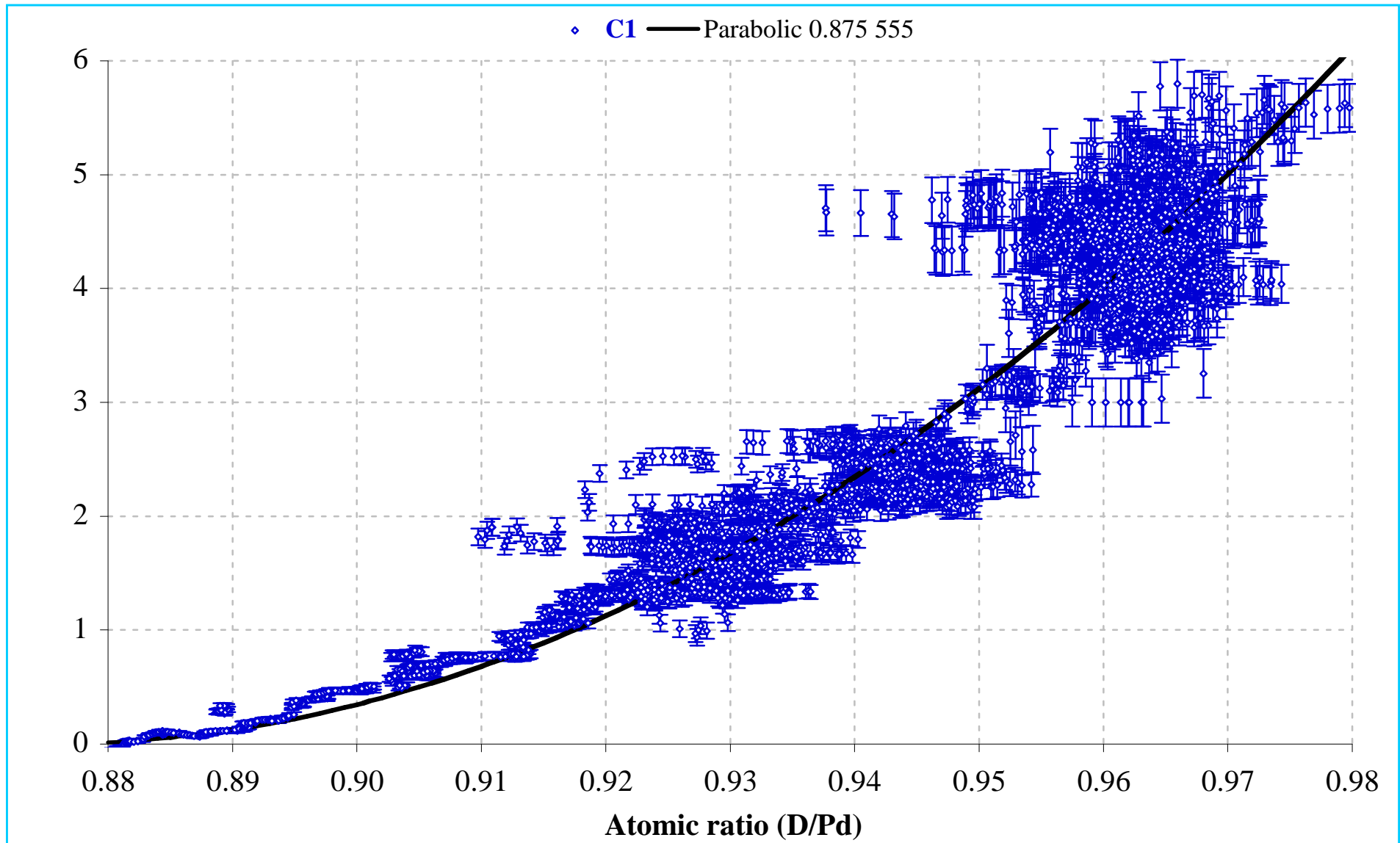




# C1: Excess Power vs. D/Pd

McKubre *et al* (similar to Kunimatsu *et al*) ICCF3, Nagoya.

D/Pd



# Excess Power vs. Maximum Loading (1)

49 Experiments 1989 - 1994

$X_{Max}$

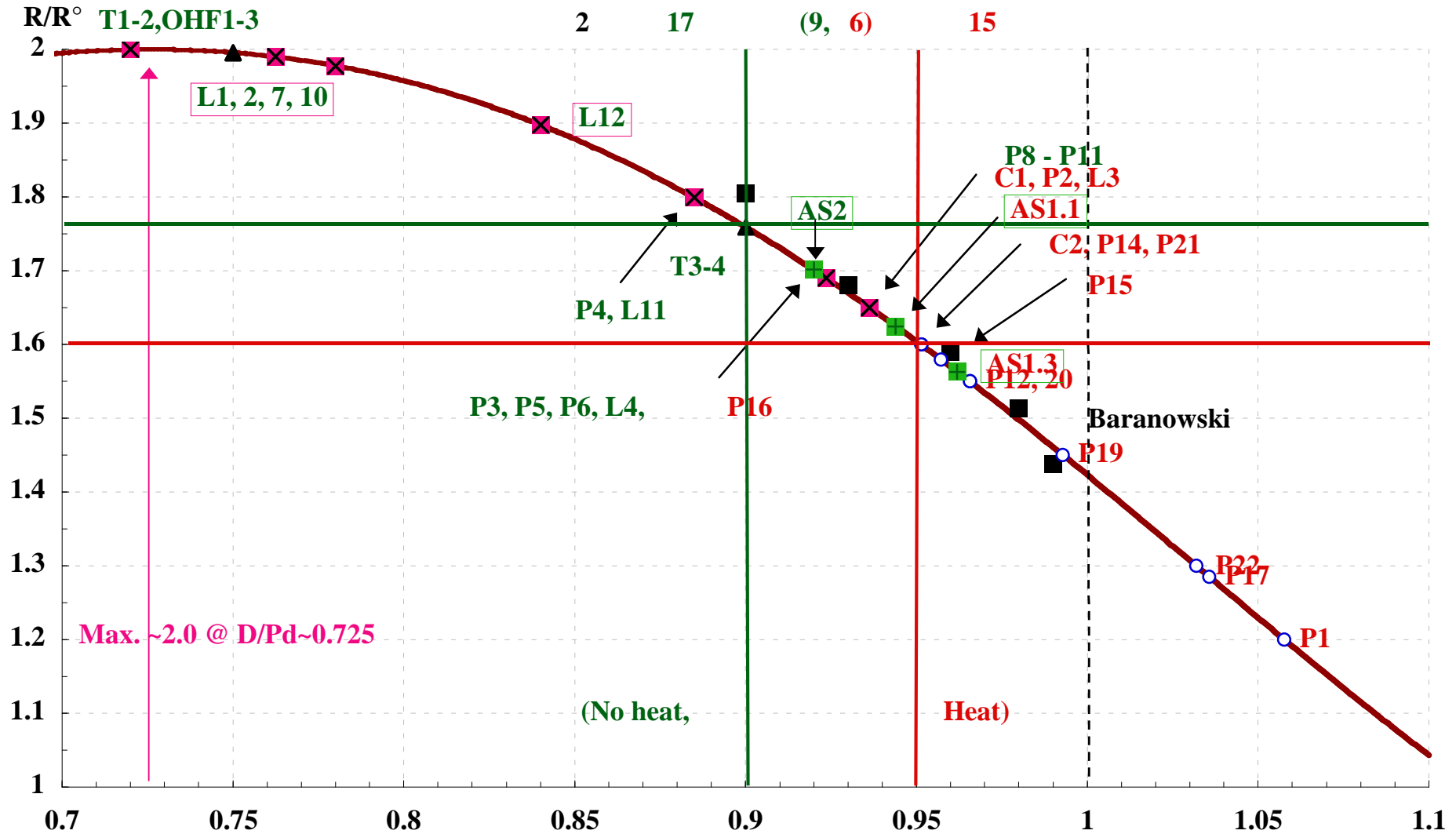
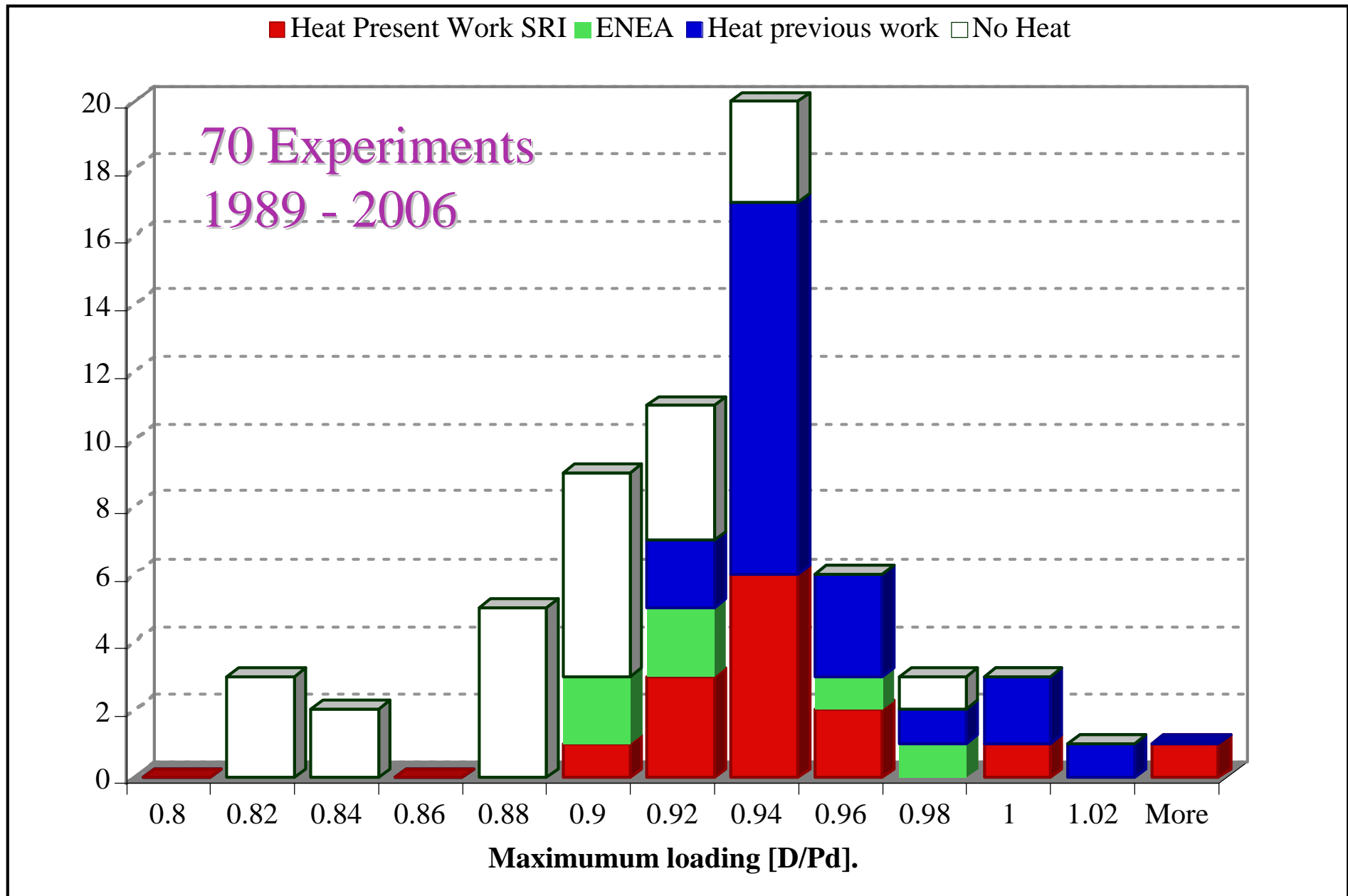


Figure 1 Maximum loading,  $D/Pd$ , attained in experiment; determined by  $R/R^\circ$ .

# Excess Power vs. Maximum Loading (2)

$X_{Max}$



## 1994-1998

Q3 *Is the heat of nuclear origin?* Yes!

- 100's to 1000's of eV's / Pd (D) atom SRI 2080 eV/Pd,  
Energetics >4000 eV/Pd
- Sustained, unidirectional heat burst exhibit an integrated energy at least 10 times greater than the sum of all possible chemical reactions within a closed cell
- Heat effects are observed with D, but not H, under similar (or more extreme) conditions

**2000**

**Q4** *Nuclear ash correlated with the excess heat?* **Yes!**

**Q5** *Uncorrelated nuclear products?* **Yes!**

Compelling Evidence:

- **<sup>4</sup>He** closely time and quantity correlated with excess heat
- **<sup>3</sup>H** observed in some cases only. Not quantity correlated with excess heat ( ~ 3 - 4 O.M. down)
- Isotopics effects possibly at very low level
- Charged particles:  $\alpha$ ,  $\beta$ ,  $p^+$  possibly at even lower level
- Neutrons not observed at SRI (although I believe they can be found using more sensitive detectors at ~10 or more O.M. down from heat)

**2000**

**Q4** *Nuclear ash correlated with the excess heat?* **Yes!**

**Q5** *Uncorrelated nuclear products?* **Yes!**

Experiments:

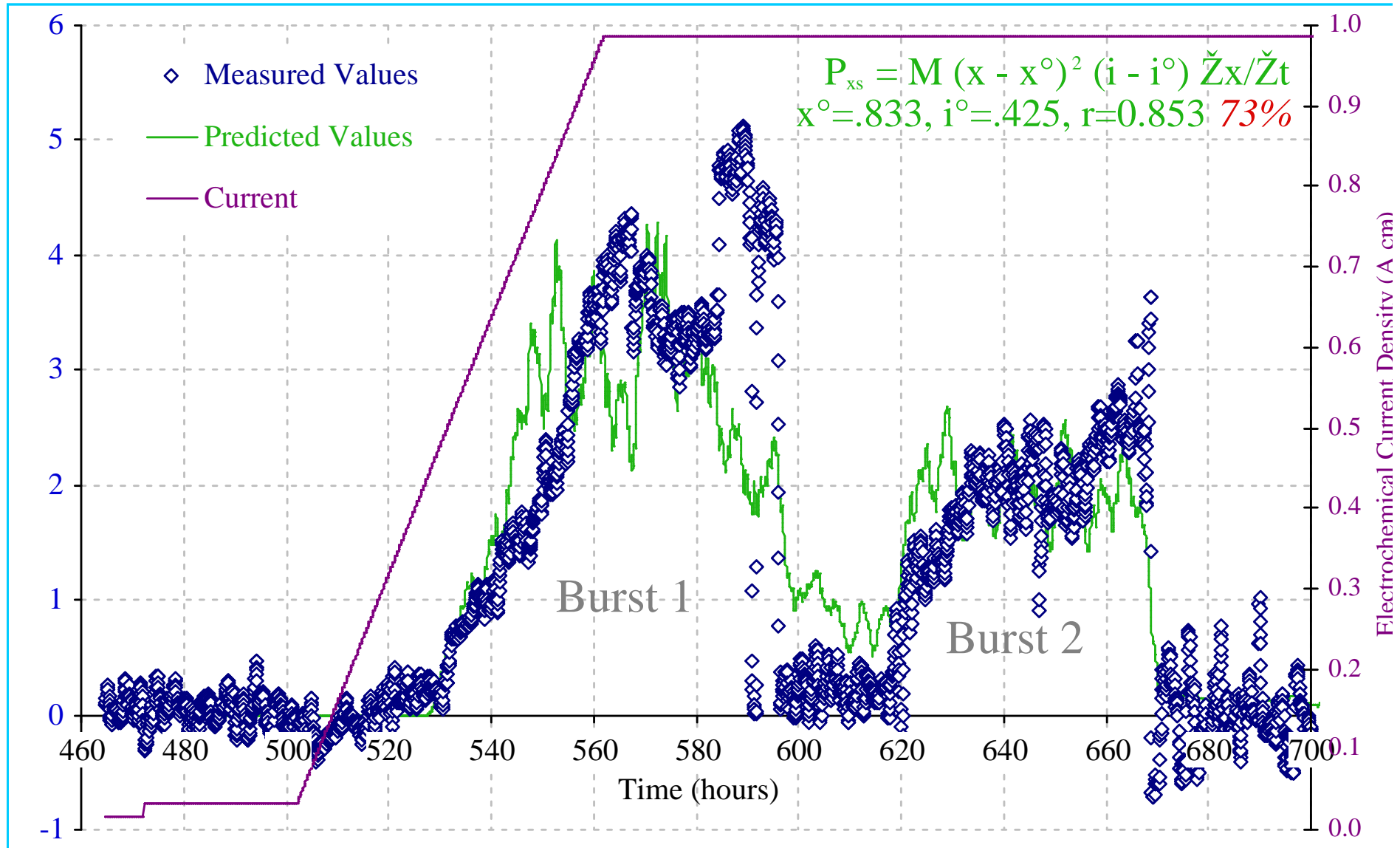
- $2\pi$ , real time, “*in situ*” X-ray detector (Lockheed)
- Gamma and X-ray spectrometer (Wolf)
- Neutron spectrometer (Wolf & Lockheed)
- Charged particles:  $\alpha$ ,  $\beta$ ,  $p^+$  (MIT)
- Residual isotopics effects (SRI & other)
- **Tritium (SRI & Clarke)**
- **Helium:  $^3\text{He}$  and  $^4\text{He}$  (Amarillo, PNNL & Clarke)**

Results:

- **Correlated heat and  $^4\text{He}$ .**
- **Unequivocal evidence of Tritium production. \_**

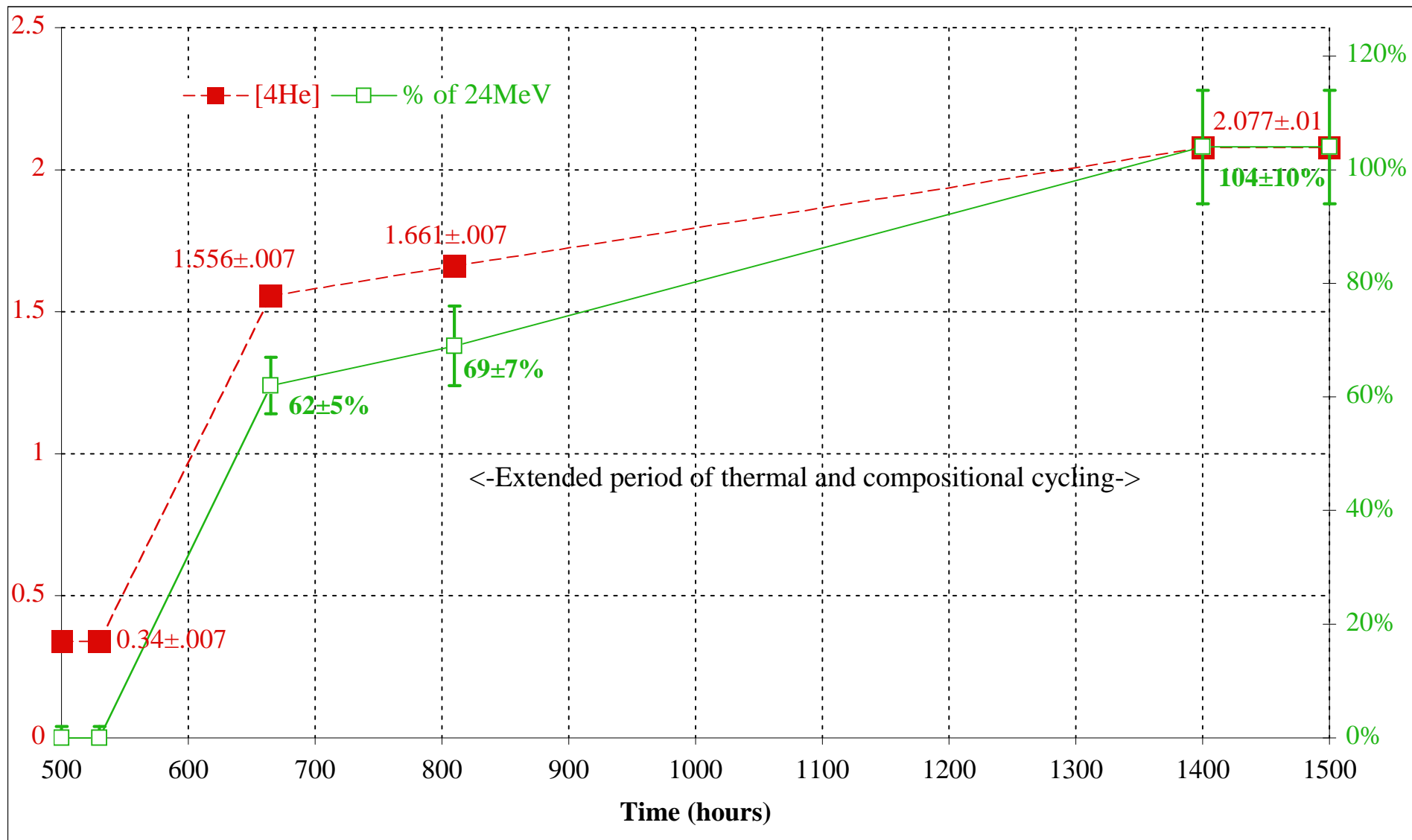
# M4: Excess Energy - $^4\text{He}$ Correlation

[Closed, He-leak tight, Mass-Flow Calorimeter, Accuracy  $\pm 0.35\%$ ]

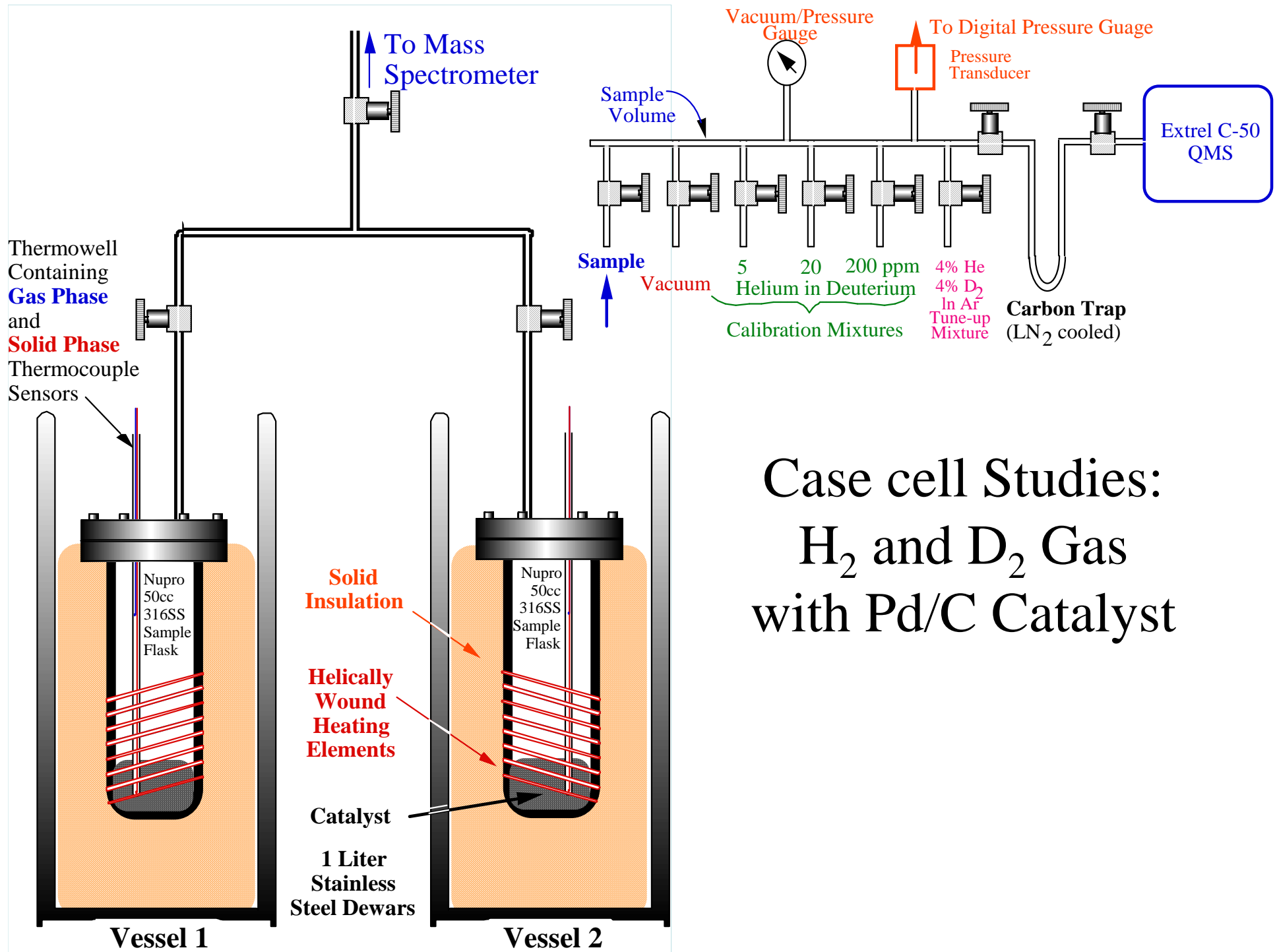


# M4: Correlation of Heat with Helium

104±10%

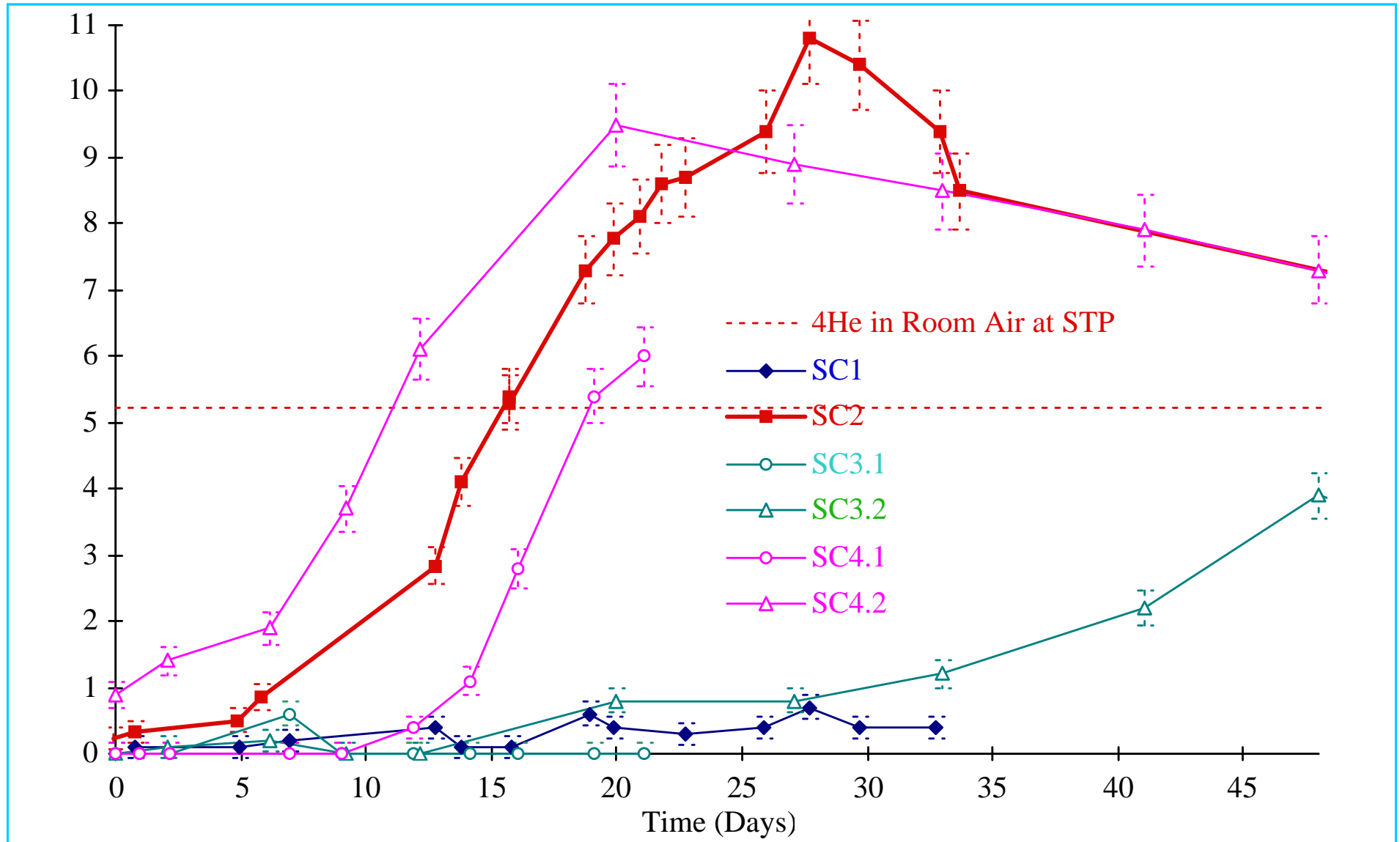




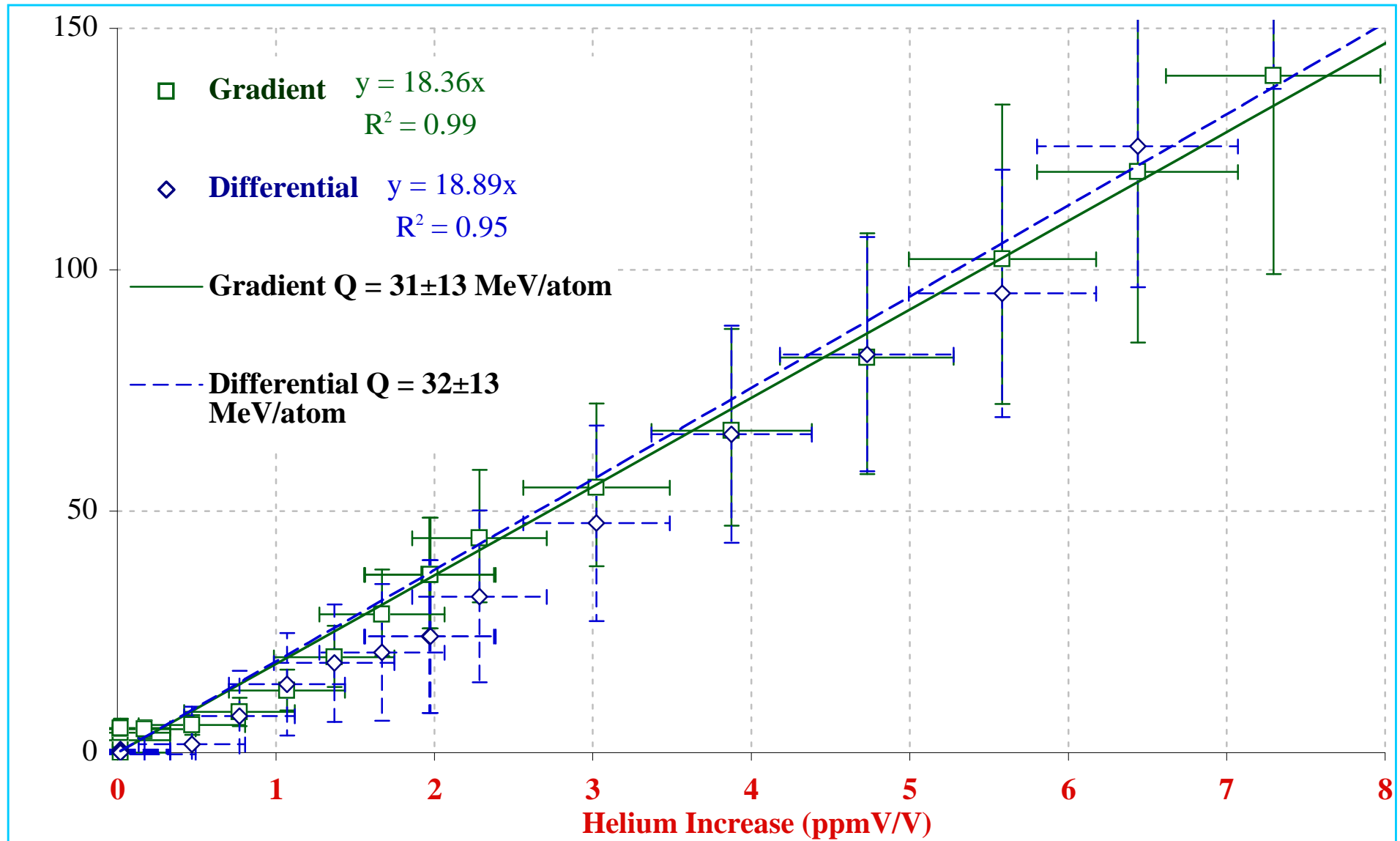


# Case cell Studies: H<sub>2</sub> and D<sub>2</sub> Gas with Pd/C Catalyst

# Case: $^4\text{He}$ vs. time



# Case: "Q"-Value - Energy vs. $^4\text{He}$



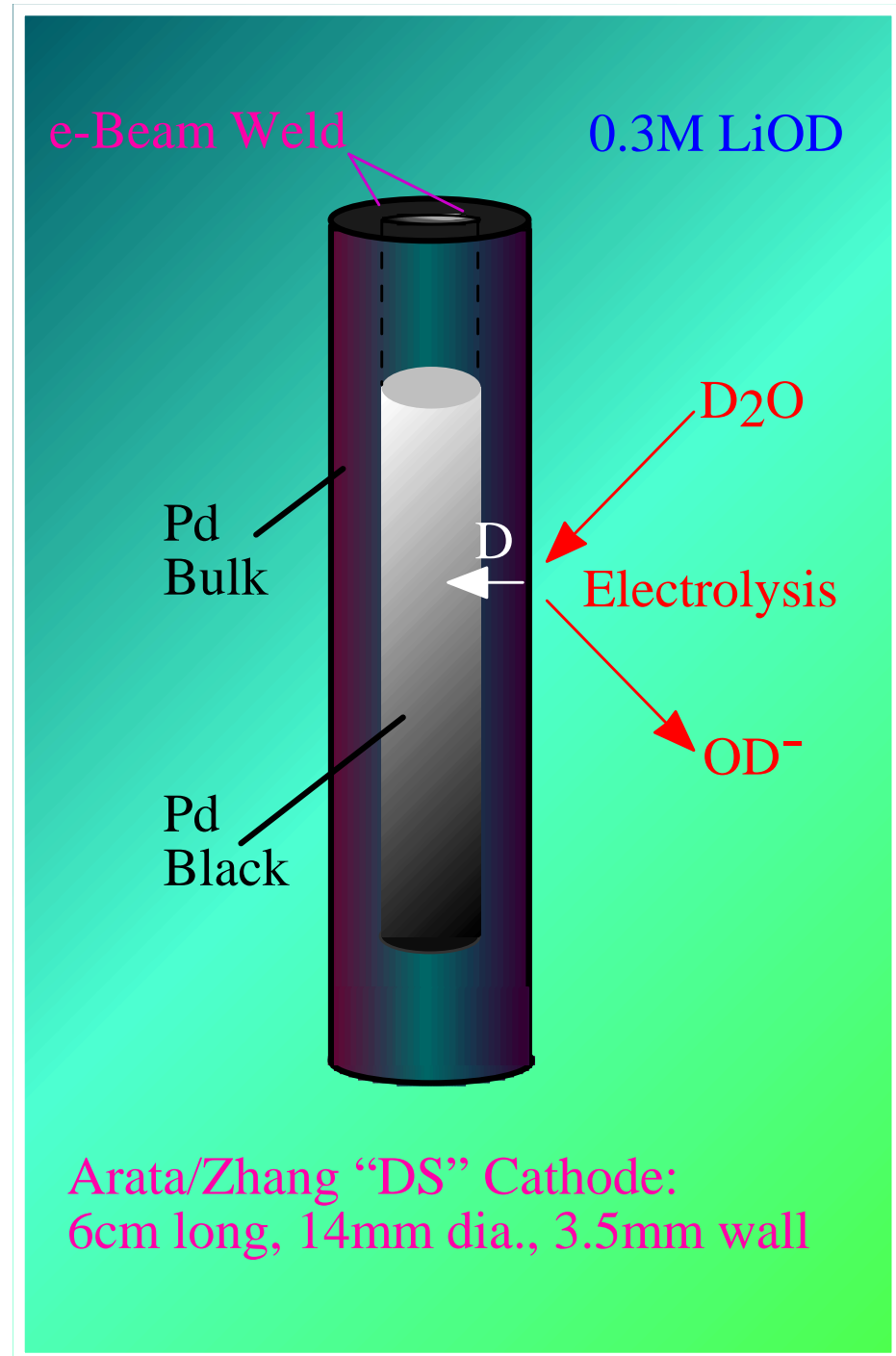
# Production of Tritium in a Sealed Pd cavity

AZ1 0.3M LiOD,  
AZ2 0.3M LiOH

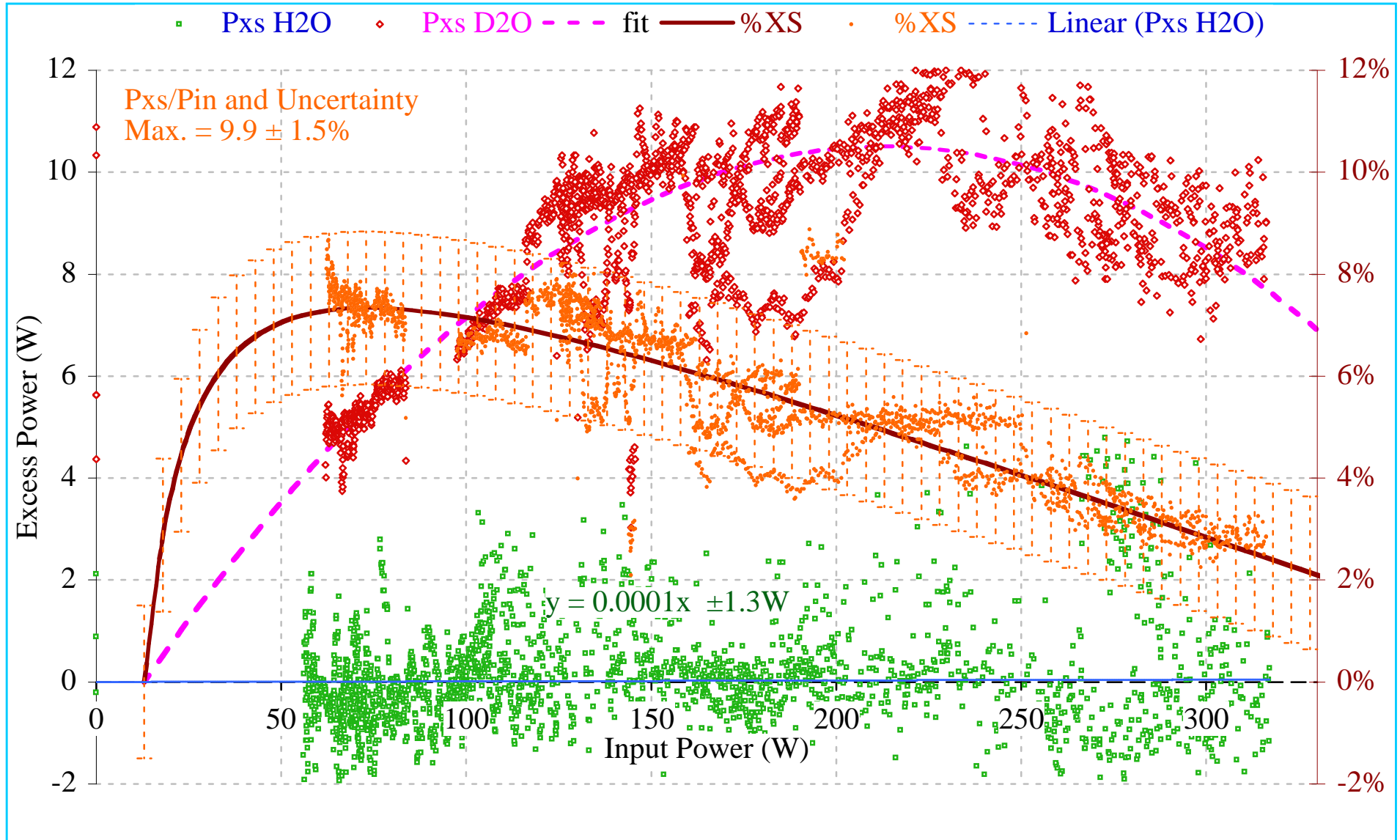
Cathodic Current 5 - 7.5A  
Current Density 170-255mA cm<sup>-2</sup>  
P<sub>in</sub> 50-317 W, Duration 120 Days

P<sub>xs,Max</sub> = 10 ±1.5%,  
P<sub>xs</sub> = 0 ±1.5%,

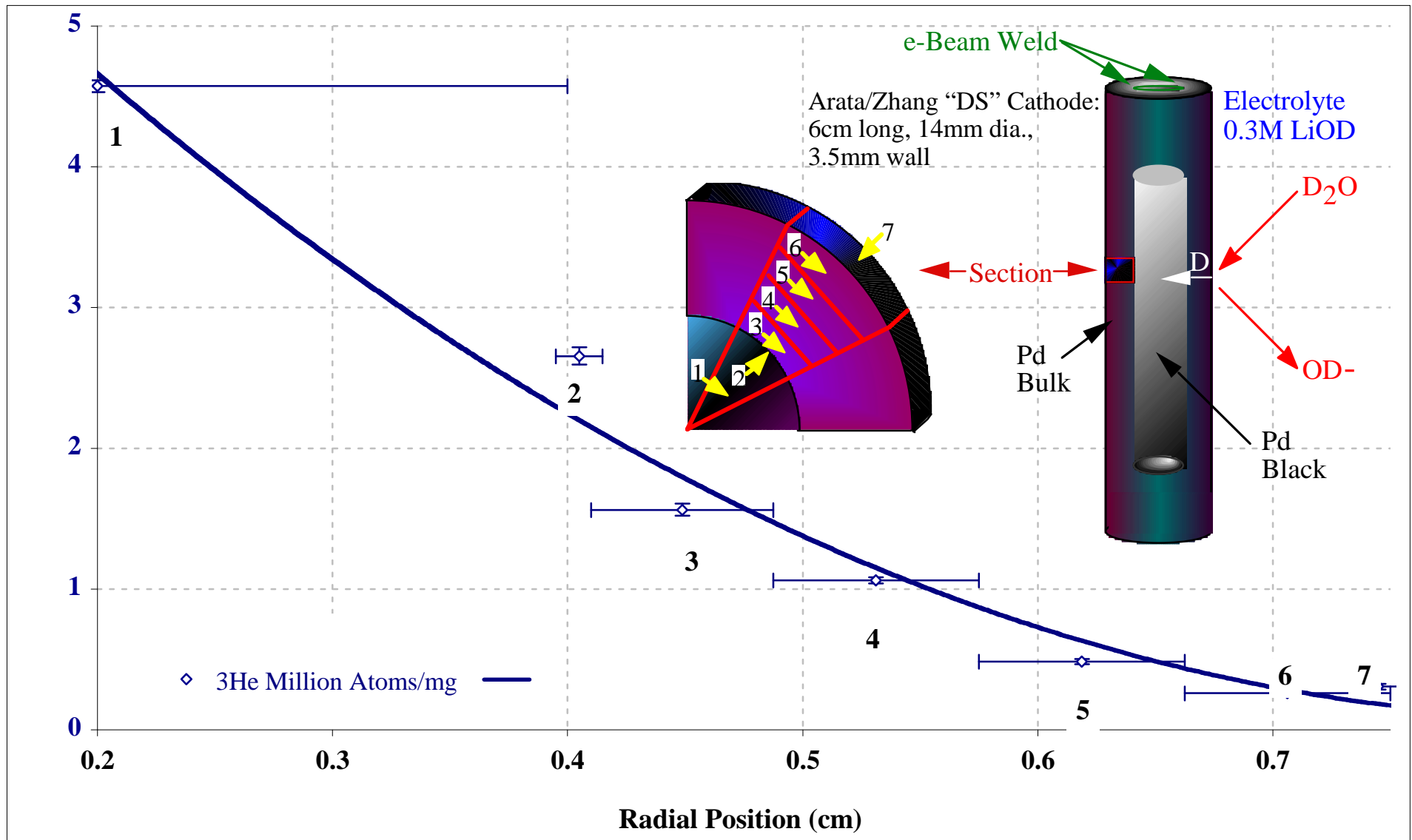
Deloaded:  
open circuit and at 2V Anodic  
for a further 100 Days.



# AZ1&2 0.3M LiOH & LiOD with Arata/Zhang “Double Structured” Cathode Largest SRI Total $P_{xs}$ (and Tritium Generation) Effects of Light and Heavy water electrolysis



# AZ1: Radial Distribution of $^3\text{He}$ (and $^3\text{H}$ )



## *Present*

Q6 *What is the nuclear process?*

- Primary product  ${}^4\text{He}$  with  $\sim 24 \text{ MeV}/{}^4\text{He}$
- Relevant theory under construction:  
Hagelstein, Chubb<sup>2</sup>, *Preparata, etc.*

## *Future*

### Q7 *What is next?*

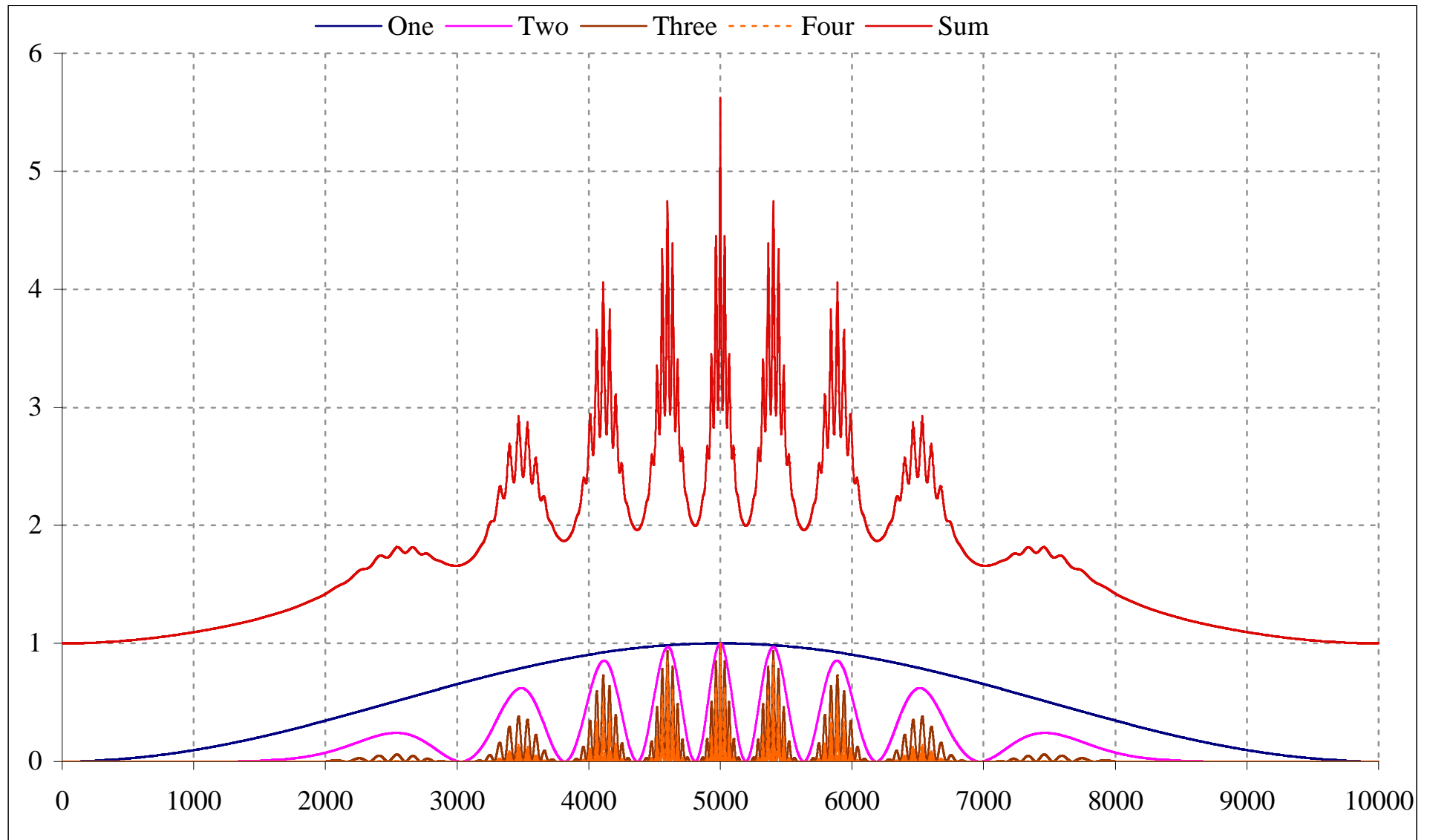
- Research consortia:  
*e.g. SRI/MIT/NRL/ENEA/Energetics*
- Technical development:
  - > 10 x Heat Out / Power In
  - Positive Temperature Coefficient?
  - Time for Engineering?



## *Dardik* - ENERGETICS

- Complex non-dc electrical perturbation results in:  
Increased Cathode absorption of H and D  
Enhanced Stimulation of Excess Heat Effects
- Glow Discharge Mass Flow Calorimeter:  $600\text{W}/\text{cm}^3$ ,  
 $P_{\text{Out}}/P_{\text{In}} > 3.7$ ,  $E_{\text{Out}}/E_{\text{In}} > 6.7$ ,  $>1000\text{ eV}/\text{Pd Atom}$ .
- *FP* Electrolysis:  $P_{\text{XS}} > 1\text{kW}/\text{cm}^3$ ,  $P_{\text{Out}}/P_{\text{In}} > 50$ ,  
 $E_{\text{Out}}/E_{\text{In}} > 30$ ,  $E_{\text{XS}} > 1.1\text{MJ} \sim 3690\text{ eV}/\text{Pd Atom}$ .
- DARPA - Energetics - SRI - ENEA - NRL - MIT  
Replication effort established August 2005.

# Energetics - SuperWaves



# *Dardik* - ENERGETICS - Results: $P_{XS}$

