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 their other nuclear effects?*

Q6 *What is the nuclear process?*

Q7 *What is the future?*

1992

<u>**Q1**</u> *Unexplained heat source?* **YES!!!**

- Effect Evidenced on numerous occasions (*>70 at SRI*)
- Typical P_{xs} 3 - 30% (±0.5%) of Total P_{in} (340%)
- Up to 90σ 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 >> 20-50 x $\tau_{D/D}$	(*Initiation*)
At electrolytic i >250-500mA cm^{-2}	(*Activation*)
With an imposed D Flux	(*Disequilibrium*)

- Heat correlated with:

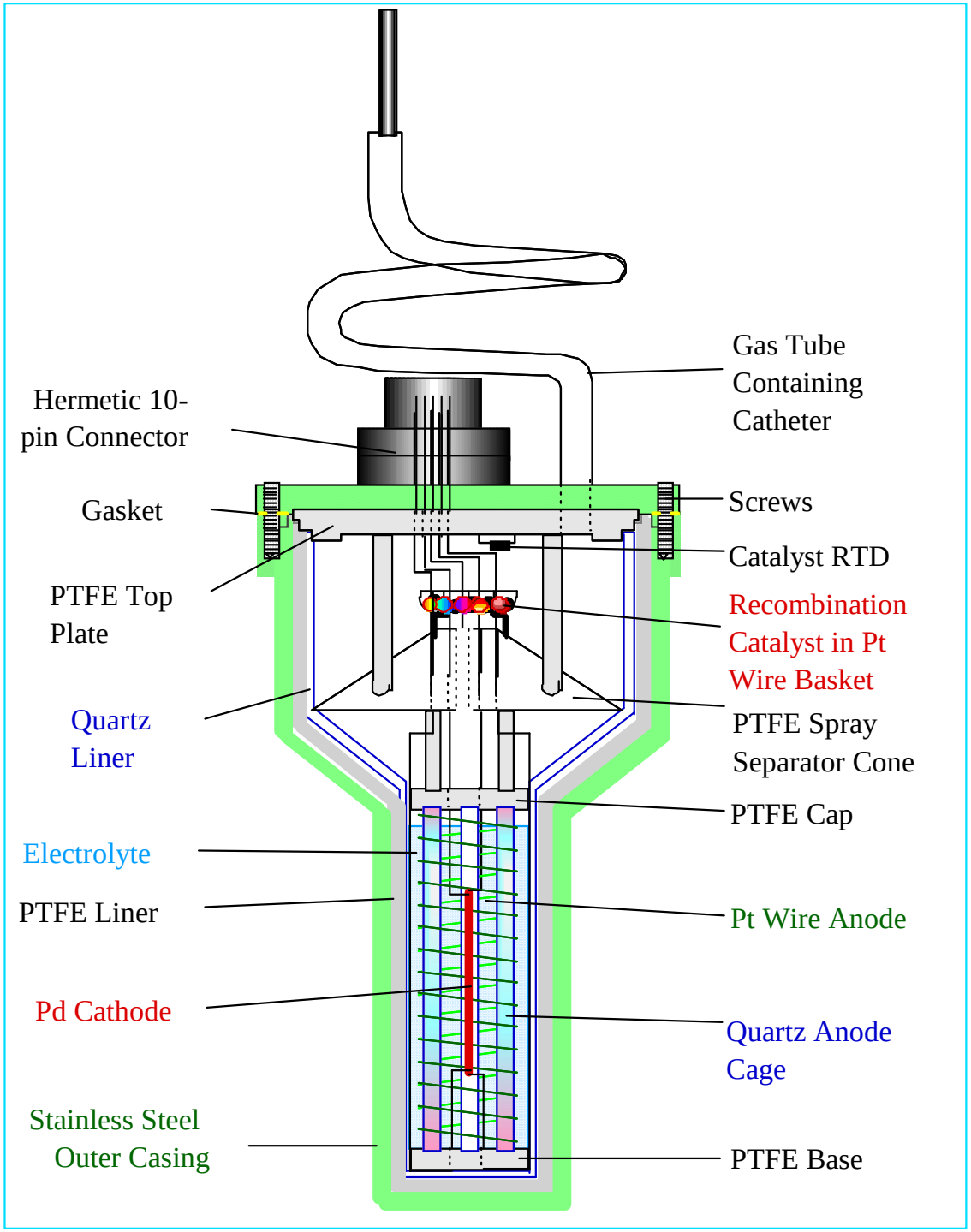
  - electrochemical current or current density
  - D/Pd loading
  - $V_{ref.}$ surface potential
  - Pd metallurgy
  - Laser stimulus

- For 1mm dia. Pd wire cathodes:

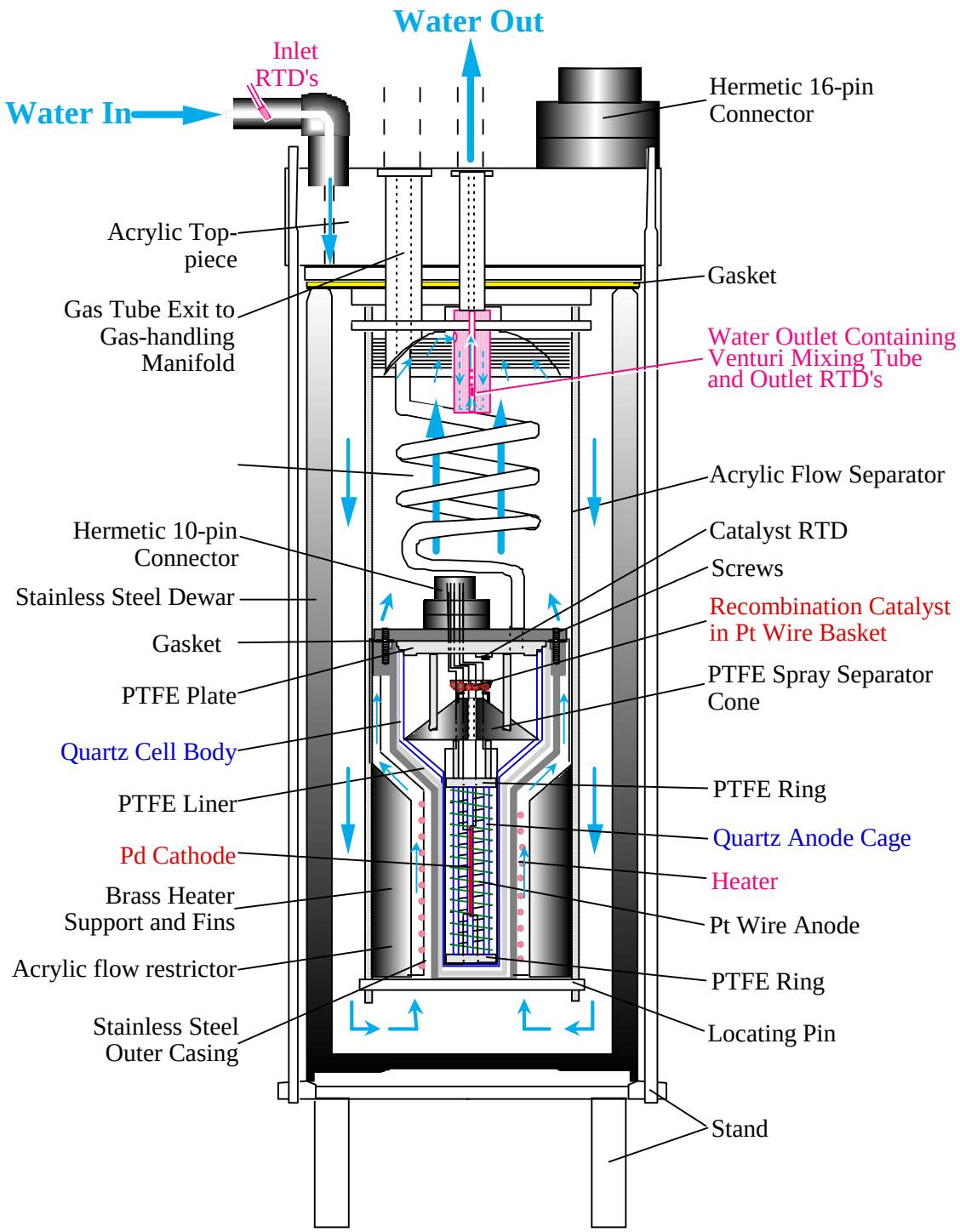
$$P_{xs} = M\,(x-x°)^2\,(i-i°)\,|i_D|$$

$x°$~0.875, $i°$=50-400mA cm^{-2}, i_D=1-10 mA cm^{-2},$t°$>200 $\tau_{D/D}$

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

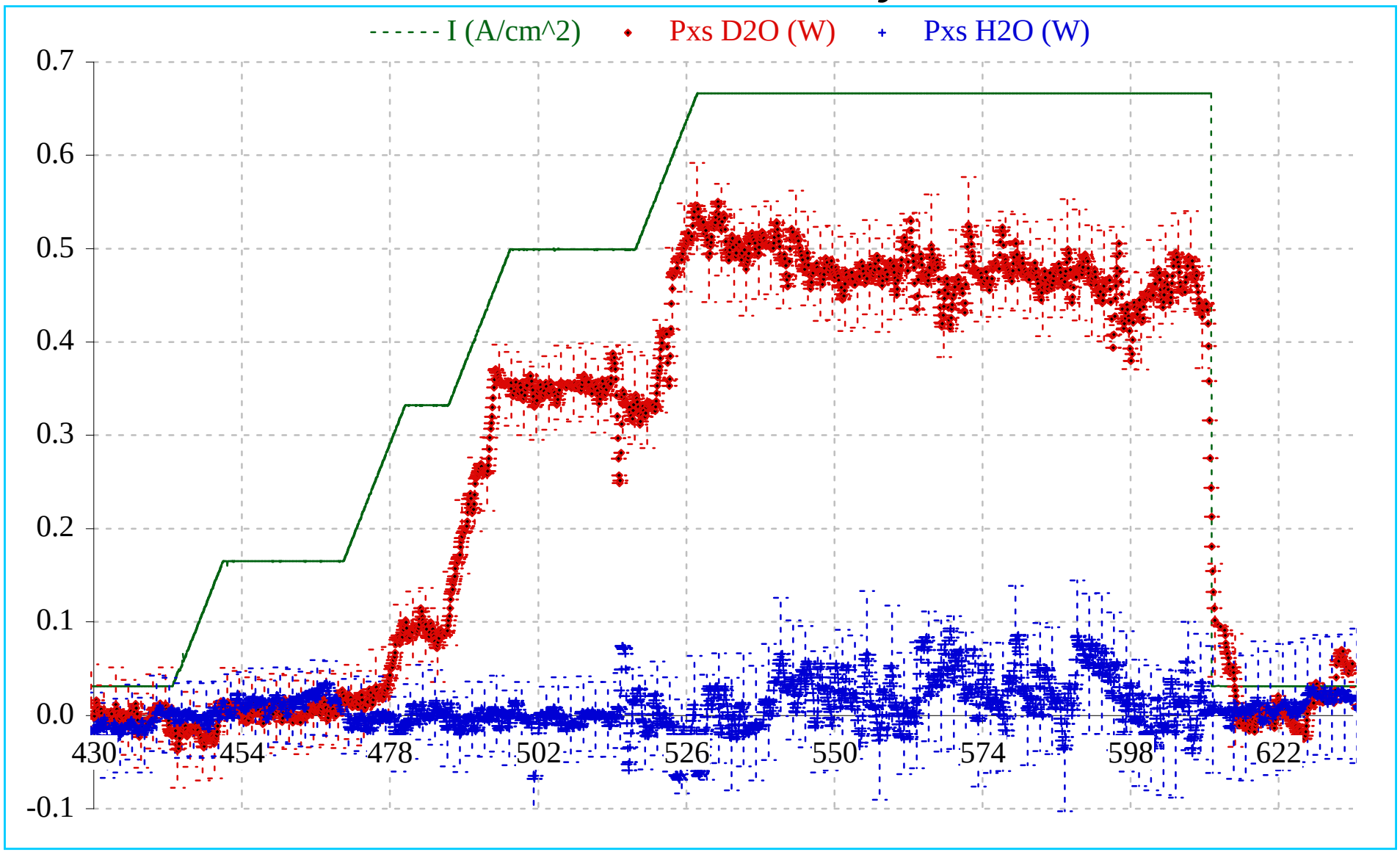


SRI Labyrinth (L and M) Calorimeter and Cell



P13/14 Simultaneous Series Operation of Light & Heavy Water Cells; D_2O

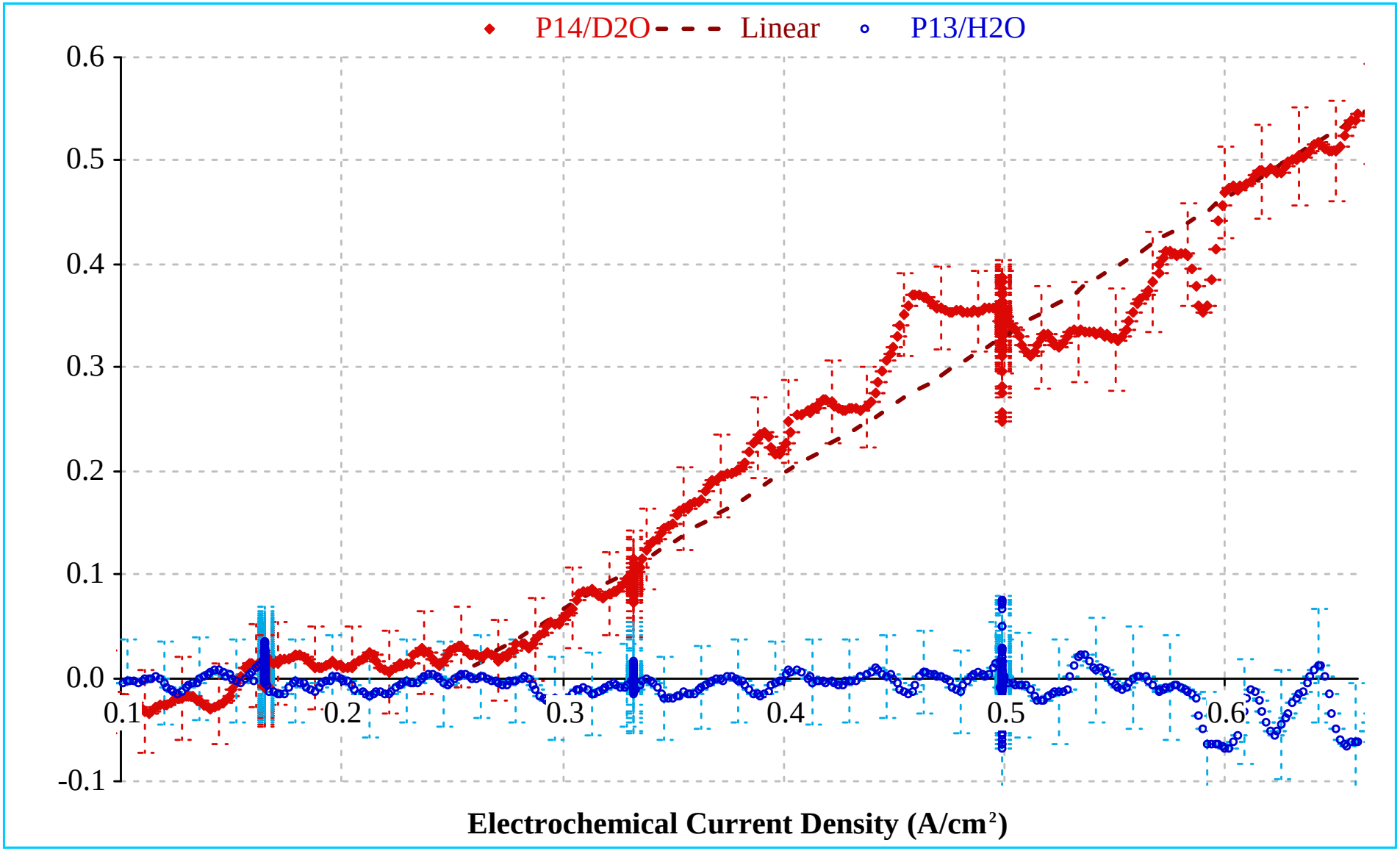
Excess Power & Current Density vs. Time



P13/14 Simultaneous Series Operation of Light & Heavy Water Cells;

Excess Power vs. Current Density

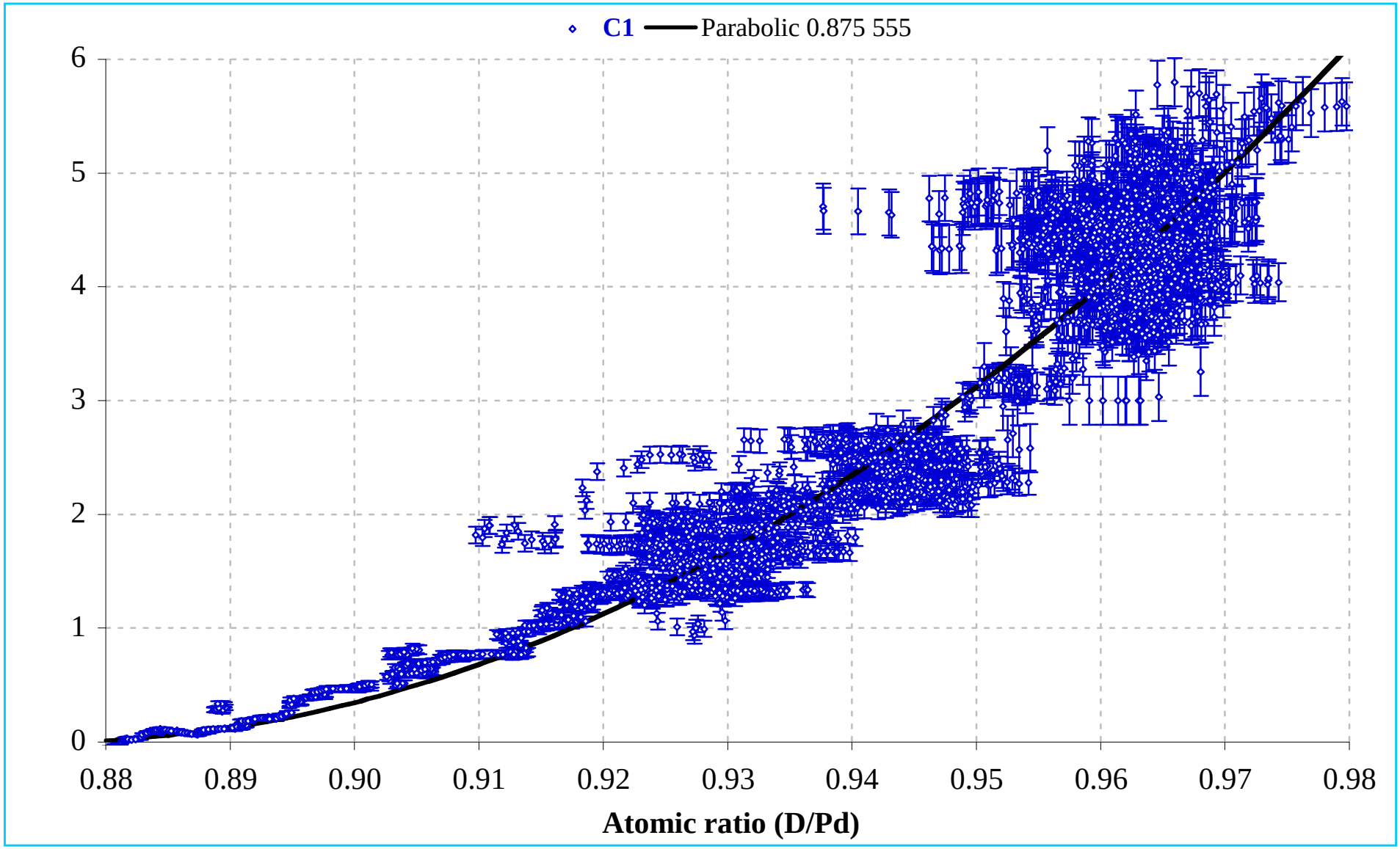
I or i



C1: Excess Power *vs.* D/Pd

D/Pd

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



Excess Power *vs*. Maximum Loading (1)

49 Experiments 1989 - 1994

X_{Max}

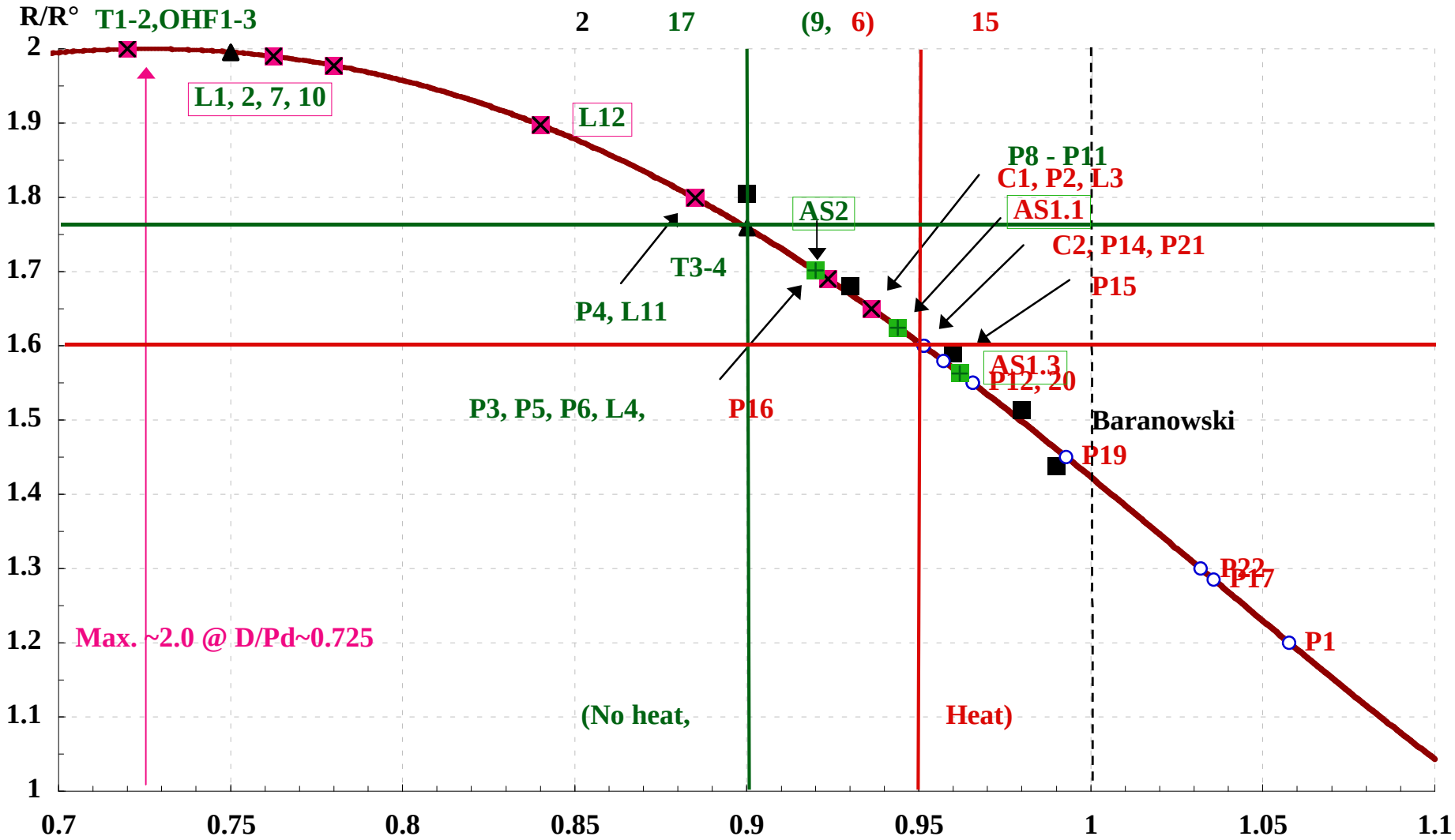
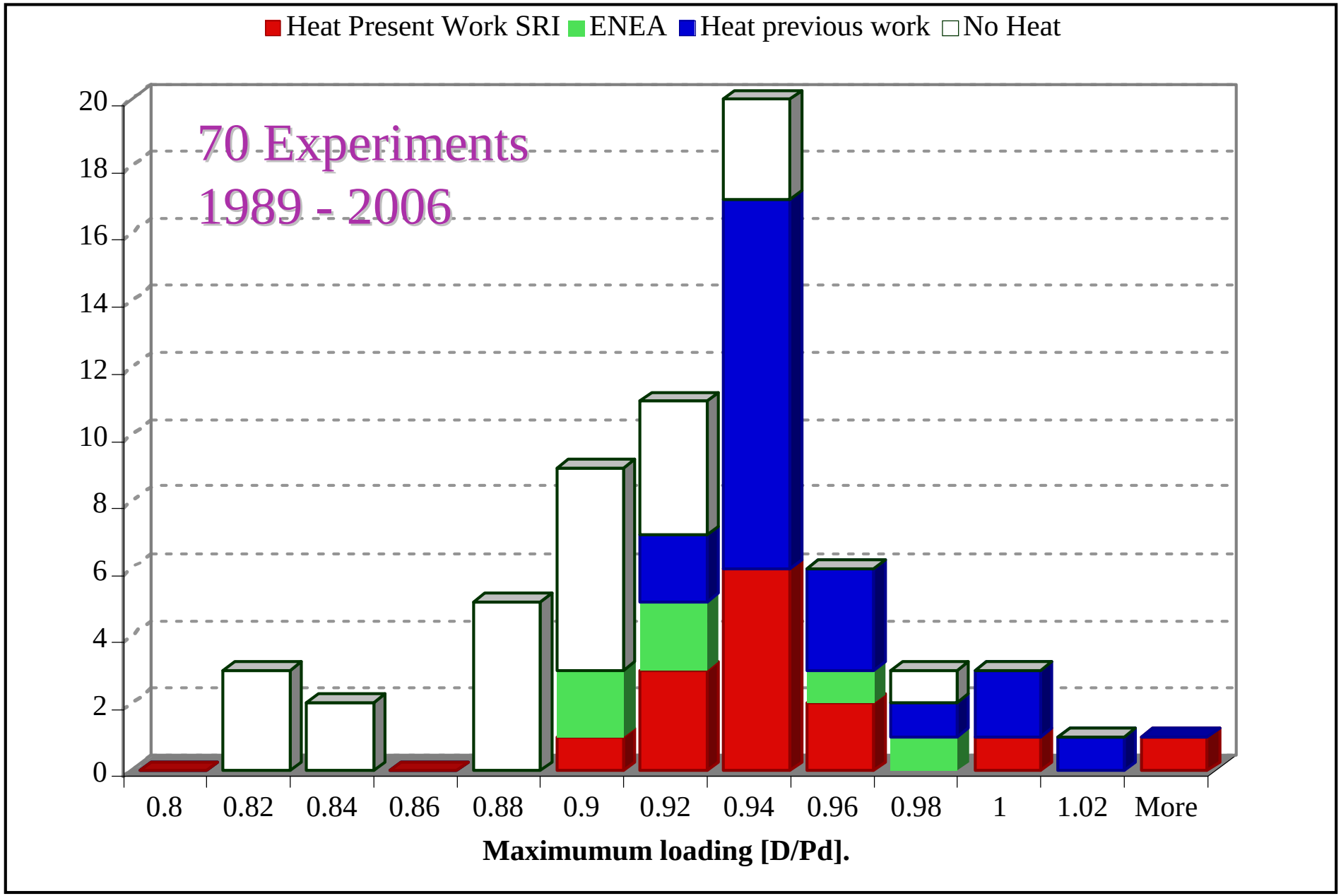


Figure 1 Maximum loading, D/Pd, attained in experiment; determined by R/R°.

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

McKubre *et al*, ***"Development of Advanced Concepts…",*** EPRI, TR-104195 (**1994**)

2000

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

Q5 *Uncorrelated nuclear products?* Yes!

Compelling Evidence:

- **^{4}He** closely time and quantity correlated with excess heat
- **^{3}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: α, β, 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:

- 2π, real time, "*in situ*" X-ray detector (Lockheed)
- Gamma and X-ray spectrometer (Wolf)
- Neutron spectrometer (Wolf & Lockheed)
- Charged particles: α, β, p^+ (MIT)
- Residual isotopics effects (SRI & other)
- **Tritium (SRI & Clarke)**
- **Helium: ^{3}He and ^{4}He (Amarillo, PNNL & Clarke)**

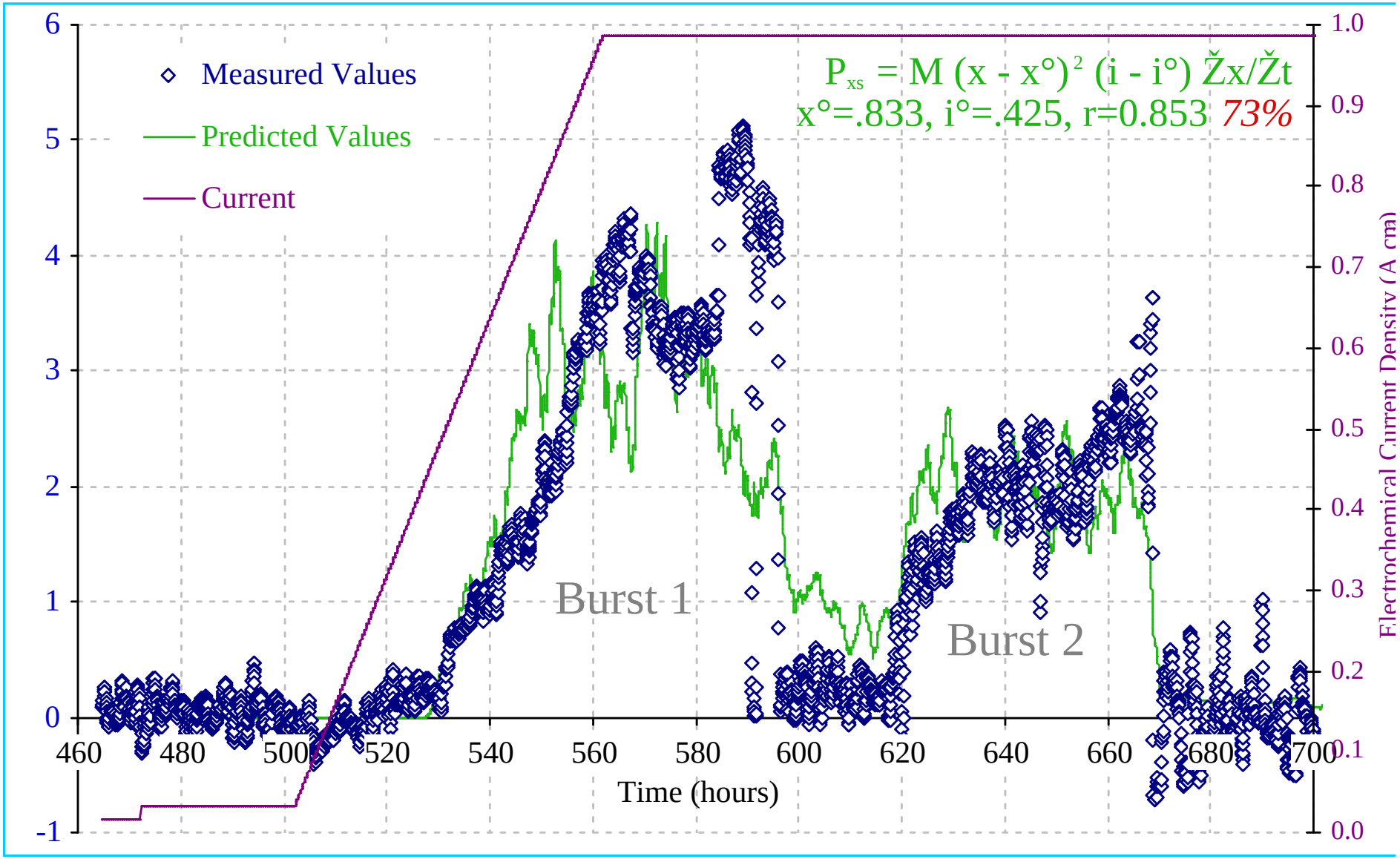
Results:

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

McKubre *et al*, ***"Emergence of a coherent explanation…"***, Proc. ICCF8, Lerici (**2000**)

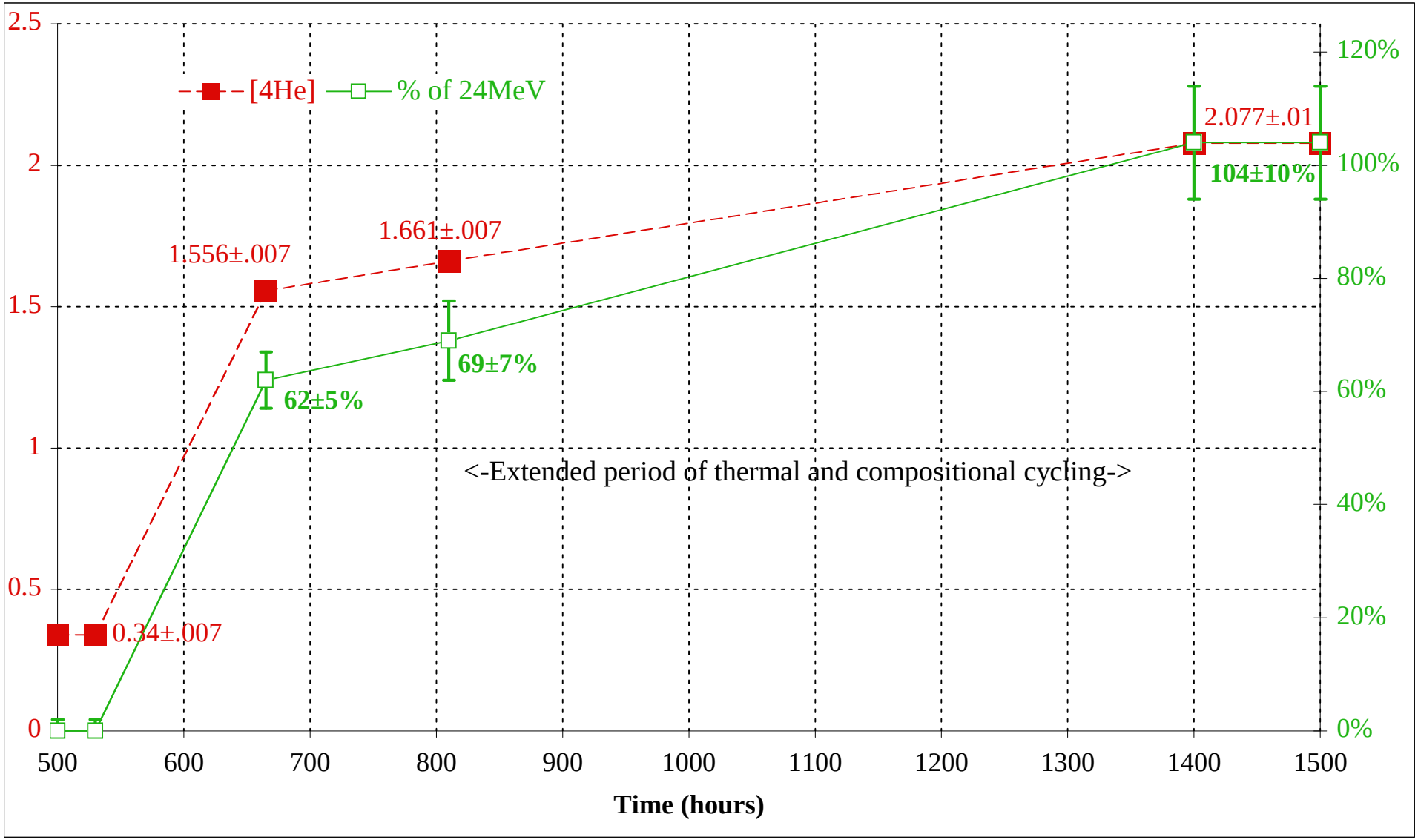
M4: Excess Energy - ^{4}He Correlation

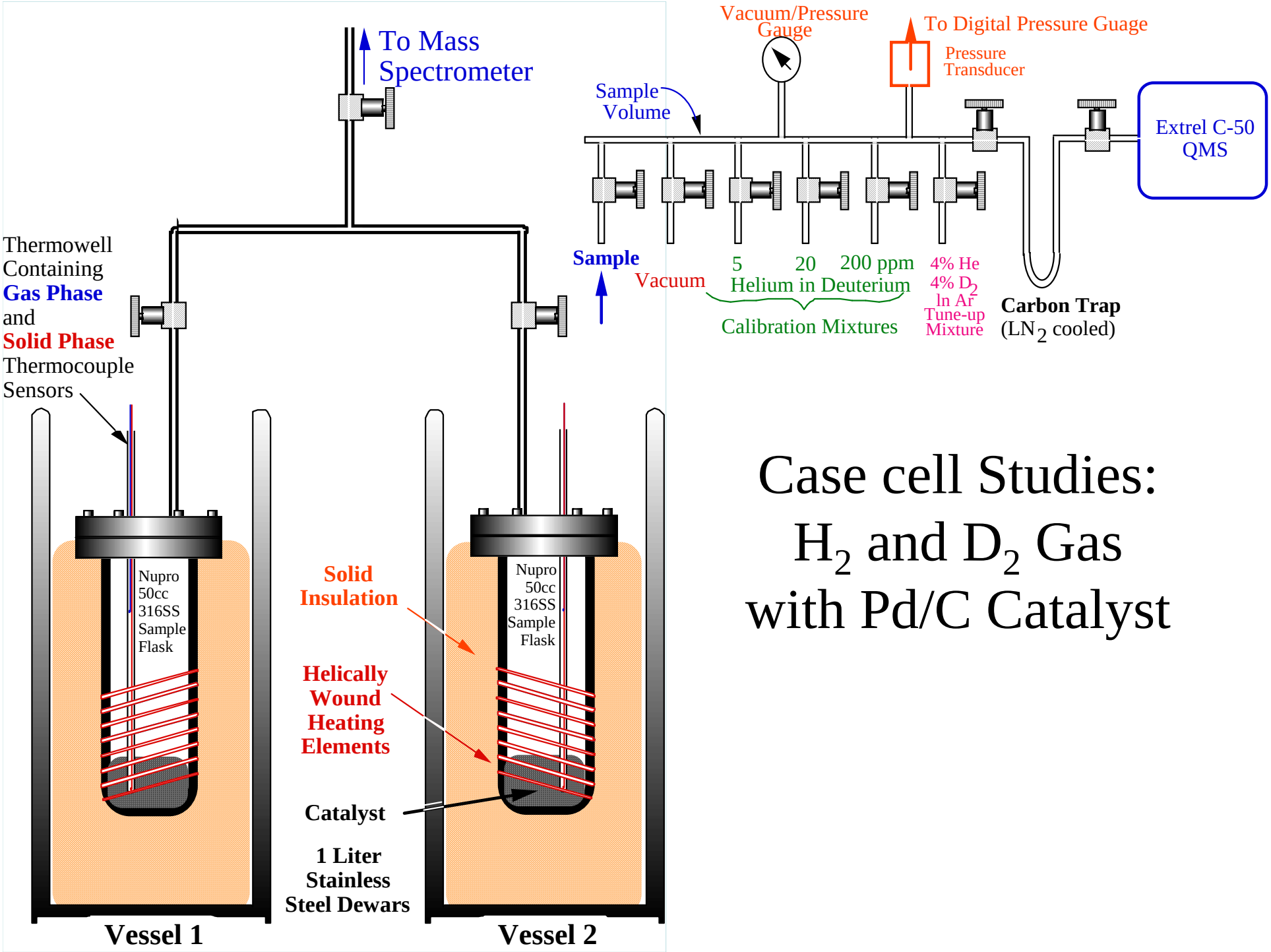
[Closed, He-leak tight, Mass-Flow Calorimeter, Accuracy ±0.35%]



M4: Correlation of Heat with Helium

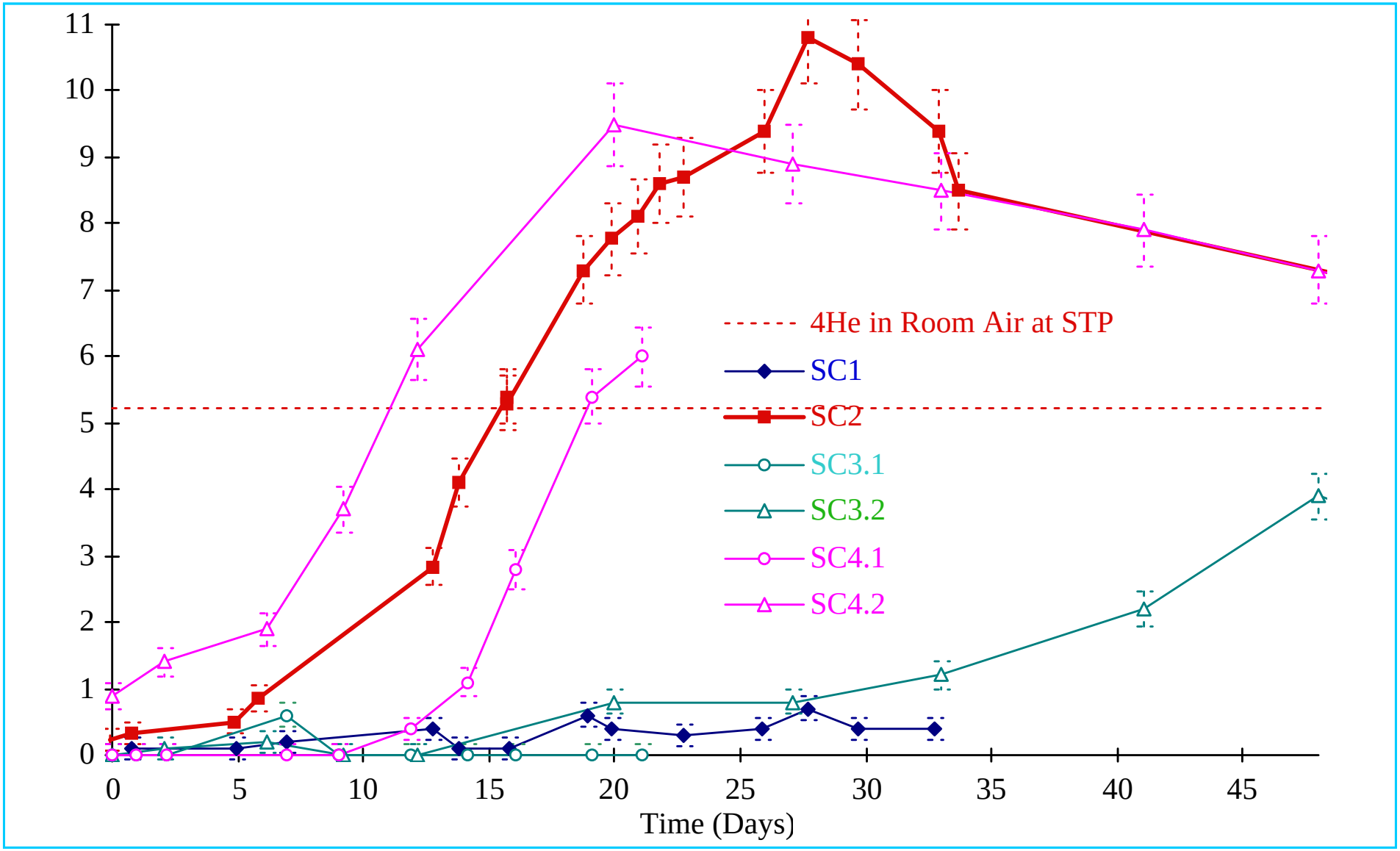
104±10%



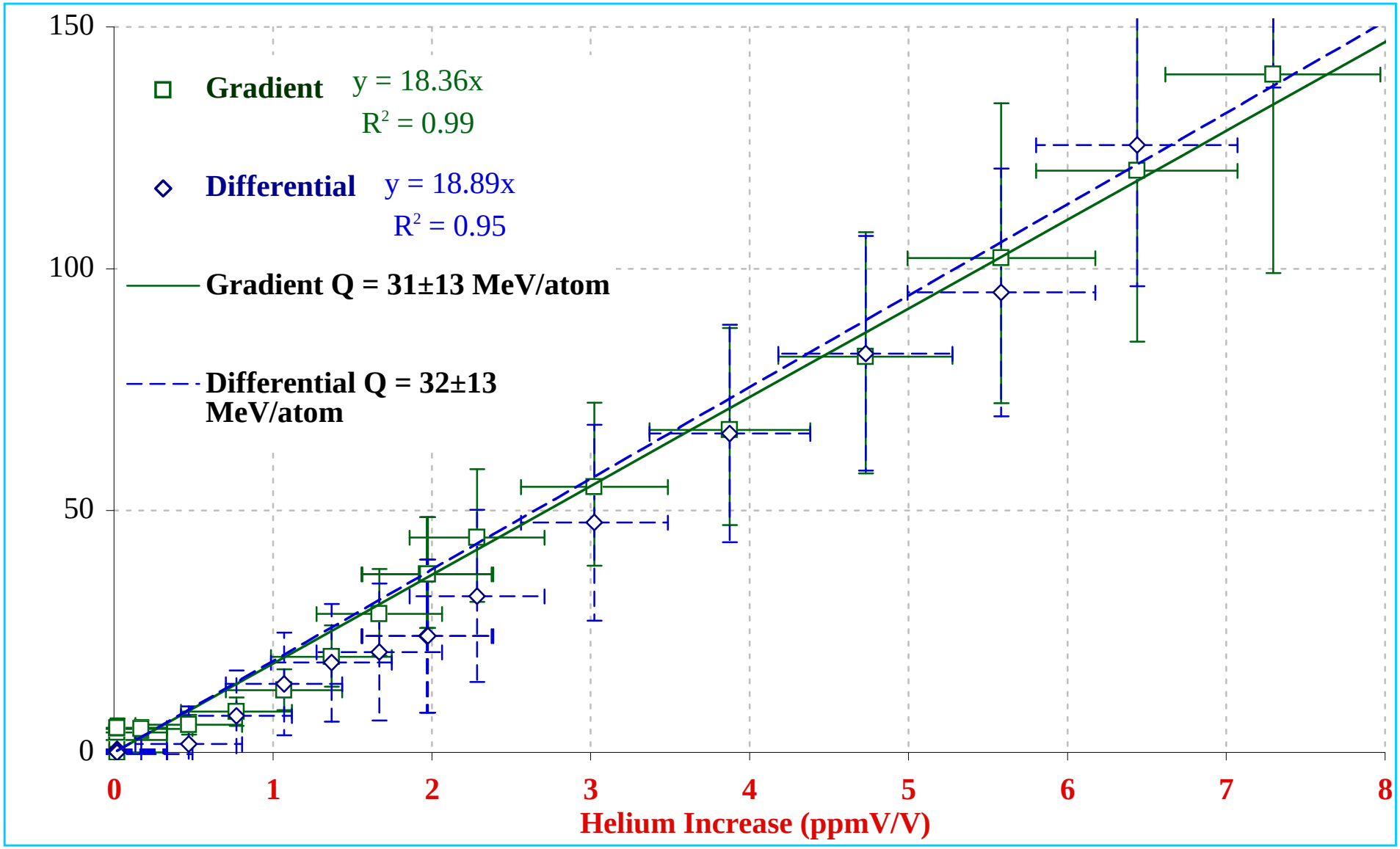


Case cell Studies: H_2 and D_2 Gas with Pd/C Catalyst

Case: ^{4}He *vs.* time



Case: “Q”-Value - Energy *vs.* ^{4}He



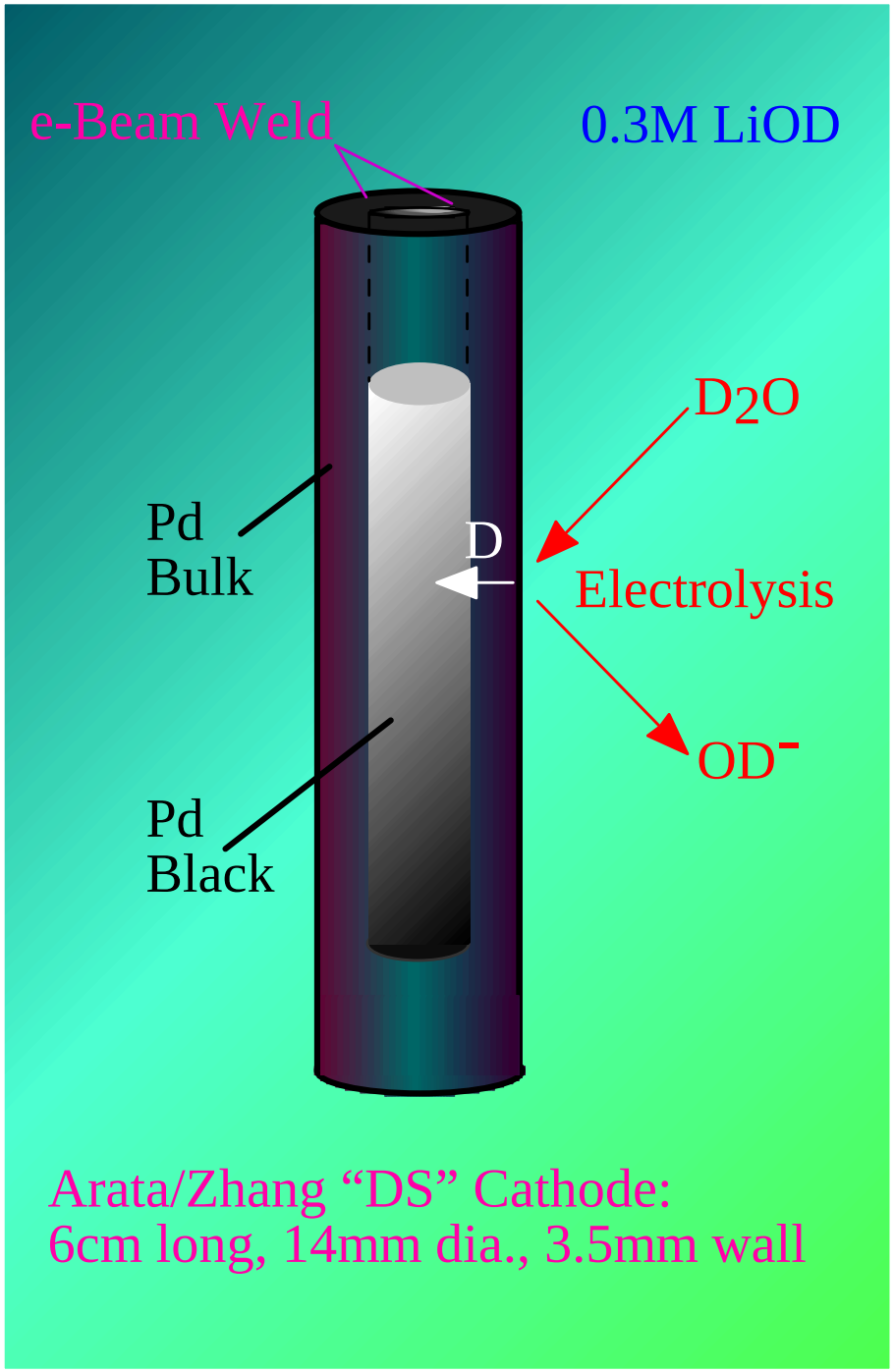
Production of Tritium in a Sealed Pd cavity

AZ1 0.3M LiOD,
AZ2 0.3M LiOH

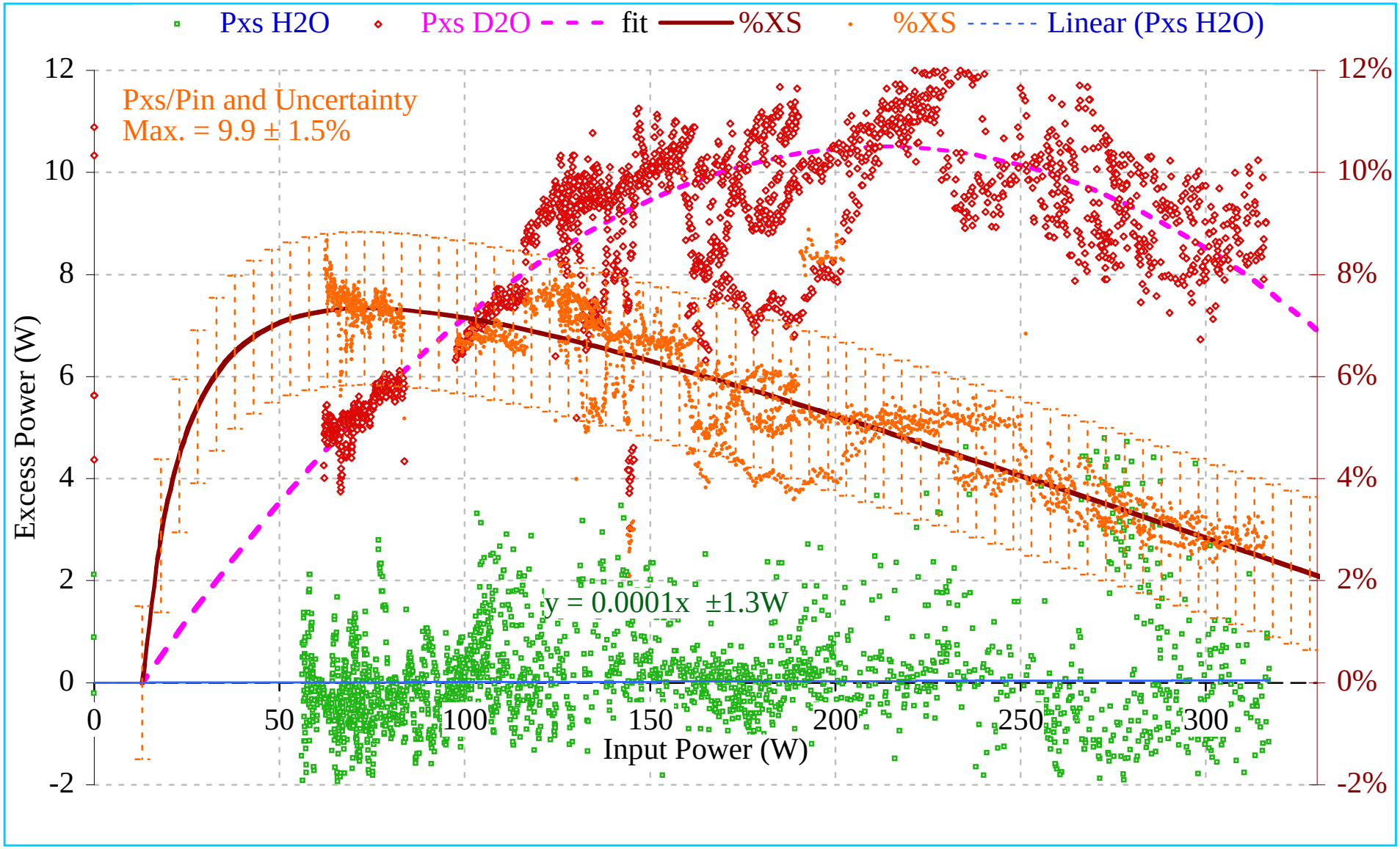
Cathodic Current 5 - 7.5A
Current Density 170-255mA cm^{-2}
P_{in} 50-317 W, Duration 120 Days

$P_{xs,Max}$ = 10 ±1.5%,
P_{xs} = 0 ±1.5%,

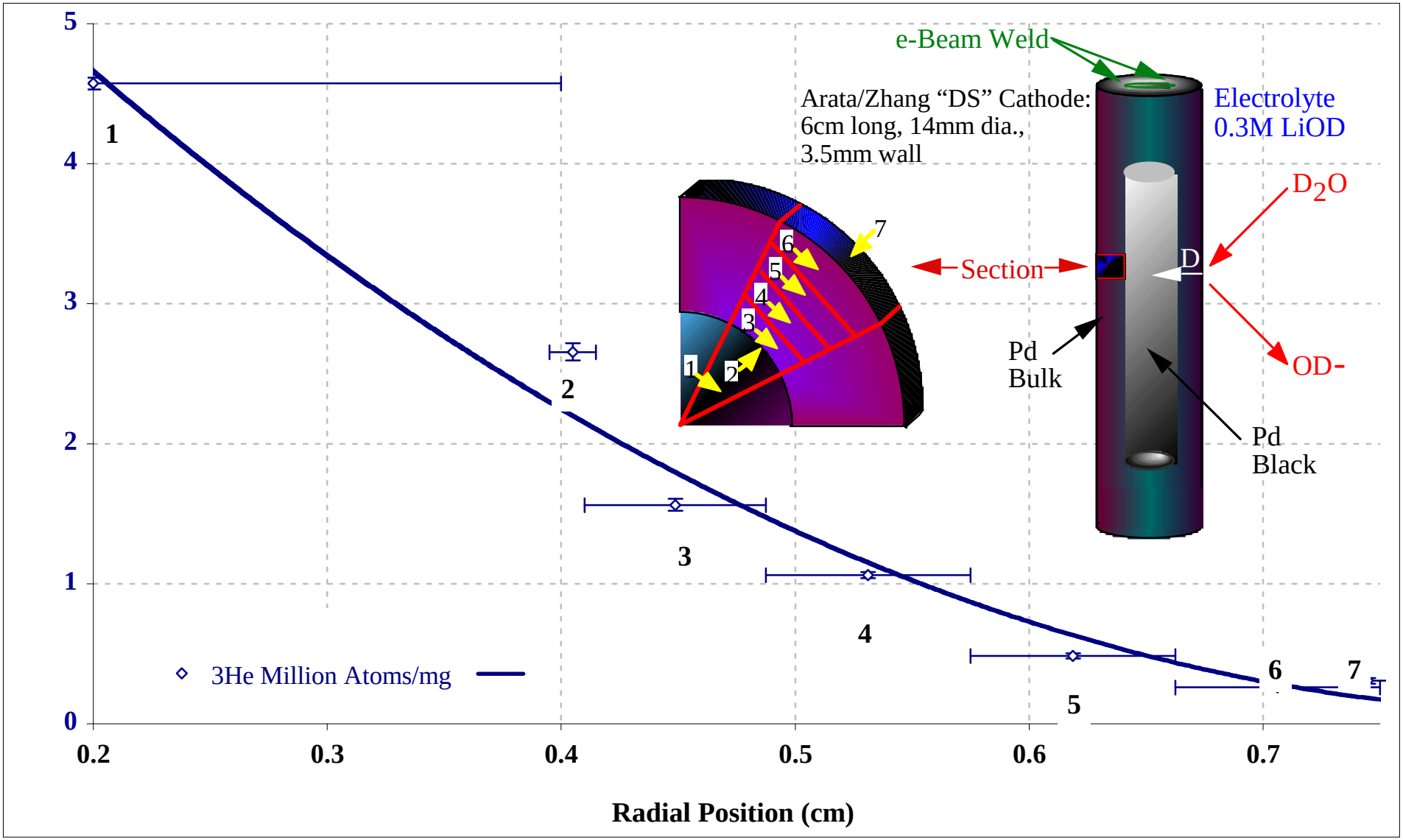
Deloaded:
open circuit and at 2V Anodic
for a further 100 Days.



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}He (and ^{3}H)



Present

<u>Q6</u> *What is the nuclear process?*

- Primary product ^{4}He with ~24 MeV/^{4}He

- Relevant theory under construction:
  Hagelstein, Chubb[2], *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

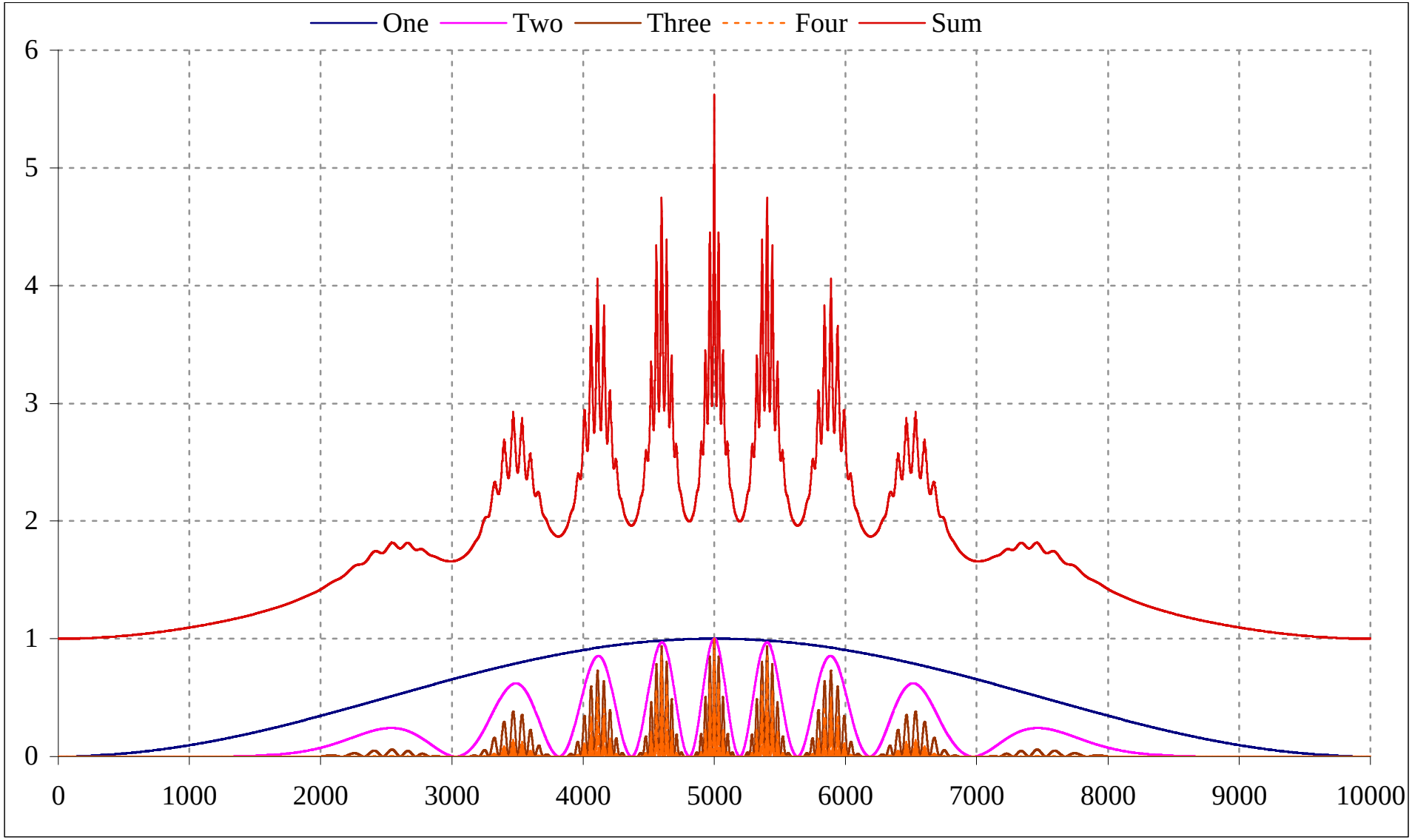
- Complex non-dc electrical perturbation results in:
  Increased Cathode absorption of H and D
  Enhanced Stimulation of Excess Heat Effects

- Glow Discharge Mass Flow Calorimeter: 600W/cm^3, $P_{Out}/P_{In} > 3.7$, $E_{Out}/E_{In} > 6.7$, >1000 eV/ Pd Atom.

- *FP* Electrolysis: P_{XS} >1kW/cm^3, $P_{Out}/P_{In} > 50$, $E_{Out}/E_{In} > 30$, $E_{XS} > 1.1$MJ ~3690 eV/ Pd Atom.

- DARPA - Energetics - SRI - ENEA - NRL - MIT
Replication effort established August 2005.

Energetics - SuperWaves



Dardik - ENERGETICS - Results: P_{XS}