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

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 >> 20-50 x $\tau_{D/D}$ (Initiation)
  - At electrolytic $i > 250-500$ mA 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:

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

$x^\circ \sim 0.875$, $i^\circ = 50$-400 mA cm$^{-2}$, $i_D = 1$-10 mA cm$^{-2}$, $t^\circ > 200 \tau_{D/D}$
SRI Quartz Calorimeter and Degree of Loading (DoL) Cell
SRI Labyrinth (L and M) Calorimeter and Cell
Simultaneous Series Operation of Light & Heavy Water Cells;

Excess Power & Current Density vs. Time

\[ I (A/cm^2) \quad P_{xs} D_2O (W) \quad P_{xs} H_2O (W) \]
P13/14 Simultaneous Series Operation of Light & Heavy Water Cells;
Excess Power vs. Current Density

Electrochemical Current Density (A/cm²)
C1: Excess Power vs. D/Pd
McKubre et al (similar to Kunimatsu et al) ICCF3, Nagoya.
Figure 1  Maximum loading, D/Pd, attained in experiment; determined by R/R°.
Excess Power vs. Maximum Loading (2)

70 Experiments
1989 - 2006

Maximum loading [D/Pd.]

X_{Max}
**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:

• $^{4}\text{He}$ closely time and quantity correlated with excess heat
• $^{3}\text{H}$ observed in some cases only. Not quantity correlated with excess heat ($\sim 3 - 4$ 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 $\sim 10$ 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**: $^3$He and $^4$He (Amarillo, PNNL & Clarke)

Results:

- Correlated heat and $^4$He.
- Unequivocal evidence of Tritium production.

M4: Excess Energy - $^4$He Correlation

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

Formula:
\[ P_{xs} = M \left( x \div x^\circ \right)^2 \left( i - i^\circ \right) \frac{\ddot{X}}{\ddot{I}} \]

Constants:
- \( x^\circ = 0.833 \)
- \( i^\circ = 0.425 \)
- \( r = 0.853 \)
- 73%
M4: Correlation of Heat with Helium

Time (hours)

[4He] % of 24MeV

<-Extended period of thermal and compositional cycling->

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

Gradient $y = 18.36x$
$R^2 = 0.99$

Differential $y = 18.89x$
$R^2 = 0.95$

Gradient Q = 31±13 MeV/atom

Differential Q = 32±13 MeV/atom
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.

Arata/Zhang “DS” Cathode:
6cm long, 14mm dia., 3.5mm wall
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

Input Power (W)

Excess Power (W)

$y = 0.0001x \pm 1.3W$

$P_{xs}$/Pin and Uncertainty
Max. = $9.9 \pm 1.5\%$

Pxs H2O  Pxs D2O  fit  %XS  %XS  Linear (Pxs H2O)
AZ1: Radial Distribution of $^3$He (and $^3$H)

Arata/Zhang “DS” Cathode: 6cm long, 14mm dia., 3.5mm wall

Electrolyte 0.3M LiOD

$^3$He Million Atoms/mg
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$^2$, 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$^3$, $P_{\text{Out}}/P_{\text{In}} > 3.7$, $E_{\text{Out}}/E_{\text{In}} > 6.7$, >1000 eV/ Pd Atom.

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

- **DARPA - Energetics - SRI - ENEA - NRL - MIT**
  Replication effort established August 2005.
$E_{\text{Out}} = 1.14 \text{ MJ}$

$E_{\text{In}} = 40 \text{ kJ}$

$E_{\text{Out}} / E_{\text{In}} = 25$