An Outsider's View of the Fleischmann - Pons Effect

October 5, 2009

ICCF 15

Rome, Italy

Rob Duncan

University of Missouri

A Long History of ‘Cold Fusion’

- **First report of a possible nuclear fusion in palladium loaded with heavy hydrogen: Berlin, Germany, September 17, 1926 by Professors Paneth and Peters, later retracted. (83 years old)**
- **Some patent activity in and after 1927**
- **Detection of confirmed nuclear fusion in liquid heavy hydrogen at -422 F (-252 C) in Russia, Berkeley and other places from 1954 to 1959. This fusion is catalyzed by naturally occurring muons**
- **FP in March, 1989**

Hydrogen Fusion Reactions

D + D → **$^{3}He + n + 3.3$ MeV**

$p + T + 4.0$ MeV

$^{4}He + \gamma + 23.8$ MeV (rare)

D + T → **$^{4}He + n + 17.6$ MeV**

p + D → **$^{3}He + \gamma + 5.5$ MeV**

Can Pd somehow catalyze these reactions in the solid-state?

Cold (Muon-Catalyzed) Fusion

PHYSICAL REVIEW VOLUME 106, NUMBER 2 APRIL 15, 1957

Catalysis of Nuclear Reactions between Hydrogen Isotopes by μ^- Mesons

J. D. JACKSON*
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received January 10, 1957; revised manuscript received February 4, 1957)

μ^- mesons are 207 times more massive than an electron, have a 2.2 μs half-life, and shower the earth at an average rate of one per cm^2 per minute near the speed of light

D-μ-D forms in a fraction of a microsecond at liquid D_2 densities, D to D spacing is only 0.5% of D_2, and has a vibration period of $5x10^{-18}$s. Each vibrational close approach gives a substantial probability of tunneling through the coulomb barrier to create fusion.

Each muon will catalyze about 10 D+D nuclear fusions before it combines with a positively charged fusion product (^{3}He, p, or t) or decays. It can catalyze about 100 D+T fusions.

Notice… COLD FUSION!, but no energy technology impact, since muons are so expensive to create artificially, and since their natural luminosity is far too low.

'Cold Fusion', but now in the 'Age of Mass Media'

- Fleischmann and Pons (PF), University of Utah Press Conference, March, 1989
  - Very bad media strategy, in my opinion
  - A very negative reaction by the physics community especially within the United States
  - Real science with possible engineering consequences, suddenly becomes a 'pariah science'
  - Fleischmann's two regrets from 60 Minutes, 4/09
- About 200 'excess heat' results from many independent labs repeat FP results, from 1989 to 2009 (Edmund Storms book, more since then)

What is Different Now from 1990?

We know now that the loading [D]/[Pd] must exceed 0.88 for excess heat

(Data from Michael McKubre, SRI)

- **Hard to achieve in electrochemical loading**
- **A little easier to achieve in D+ ion bombardment**
- **Readily achieved in gas diffusion loading of nanoparticles, or in co-deposition of Pd + D**

The 60 Minutes Story, 4/19/09

- Visit to Energetic Technologies in Omer, Israel, in October, 2008:
  - Observed excess heat while I was there
  - Three different cell designs, all very different, all have reported excess heat
  - Five cells have reported excess heat exceeding 1,000,000 J from a 0.3g Pd foil electrode
    - Chemical heat release would have been about 100 - 800 J
    - (Heat out) / (Electrical energy in) = 25, 15 (rarely), 8, and less
  - Quite similar results from many other labs in Italy, Russia, China, Germany, and the USA (mainly SRI and Navy)

ET’s schematic of their Electrolytic Cell, Isoperibolic Calorimeter design (With and without ultrasound)

$P_{in} = I * V$

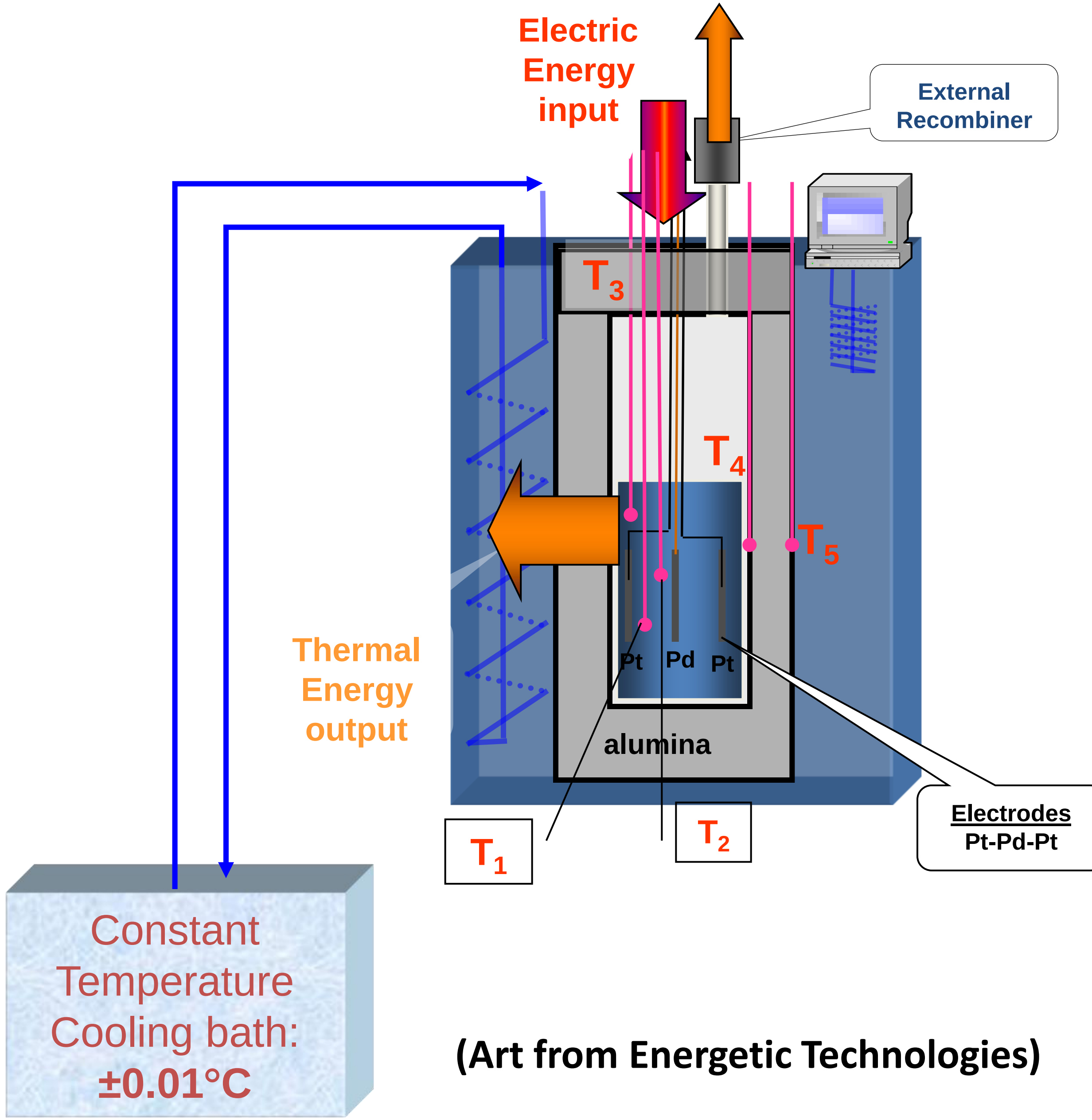
(Recombiner losses were ignored)

Cartoon is not to scale

$P_{out} = k * (T_4 - T_5)$

$P_{excess} = P_{out} - P_{in}$

Excess Heat = $\sum P_{excess} \Delta t$



(Art from Energetic Technologies)

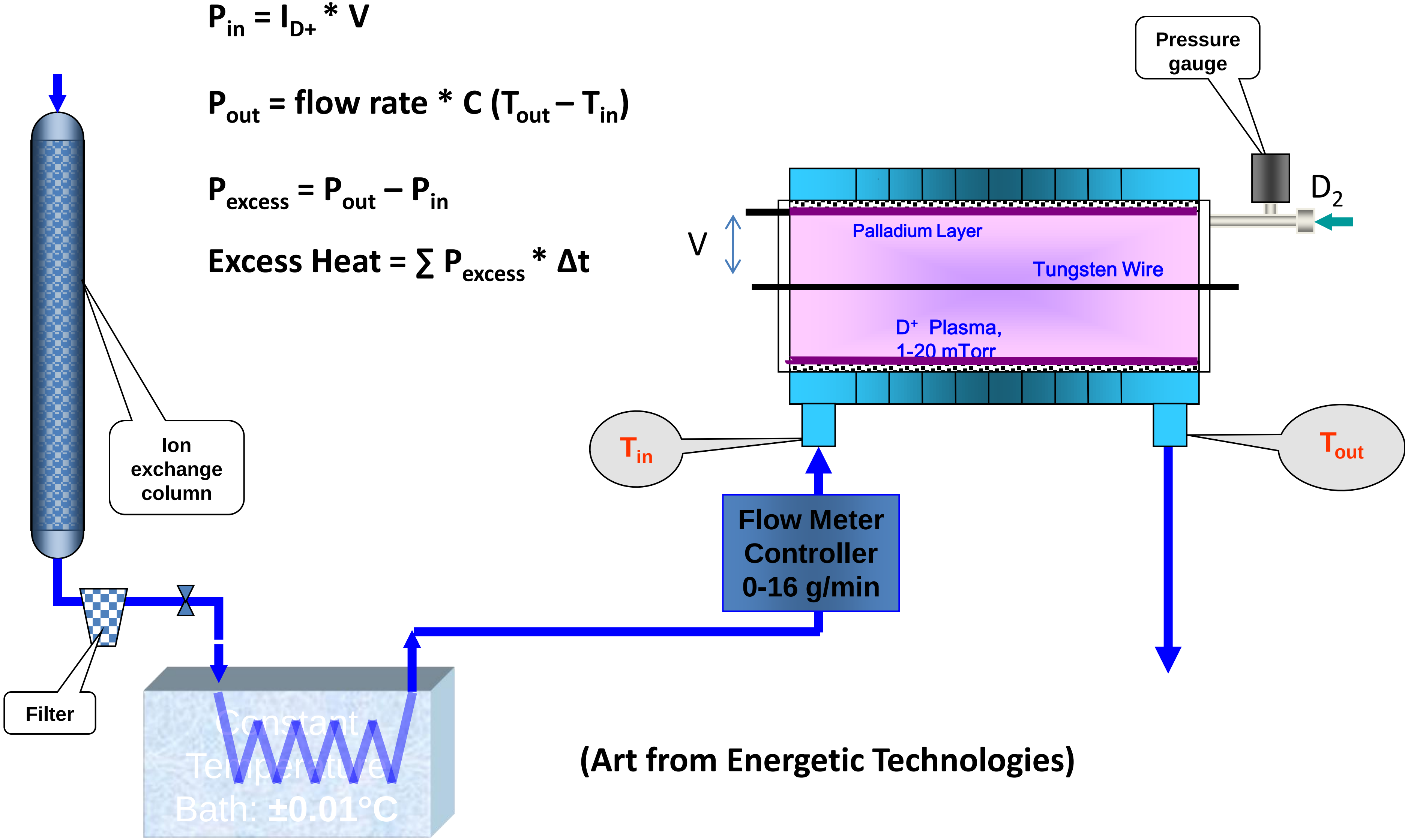
ET's Glow Discharge Cell Design with Water Flow Calorimeter

$P_{in} = I_{D+} * V$

$P_{out} = \text{flow rate} * C\,(T_{out} – T_{in})$

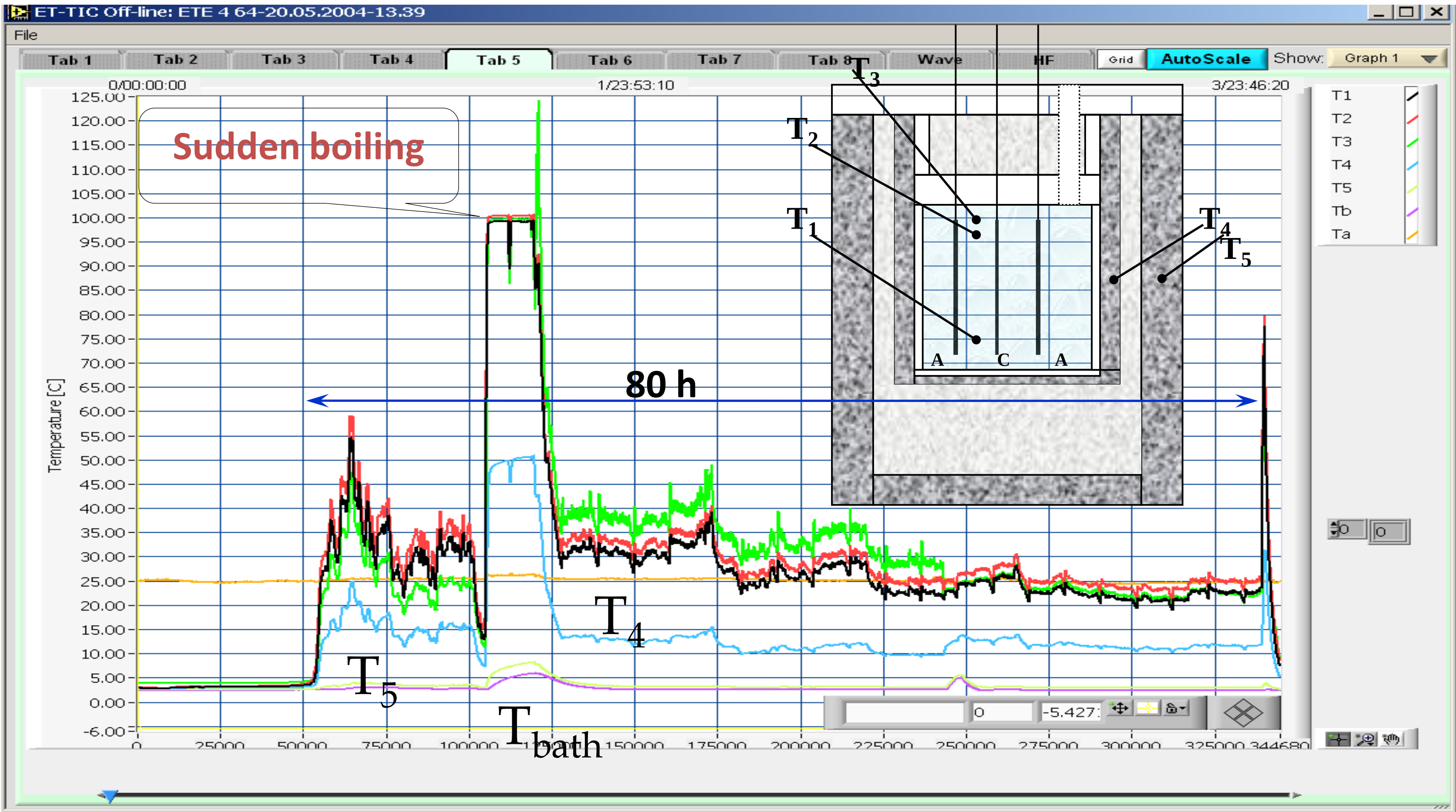
$P_{excess} = P_{out} – P_{in}$

$\text{Excess Heat} = \sum P_{excess} * \Delta t$

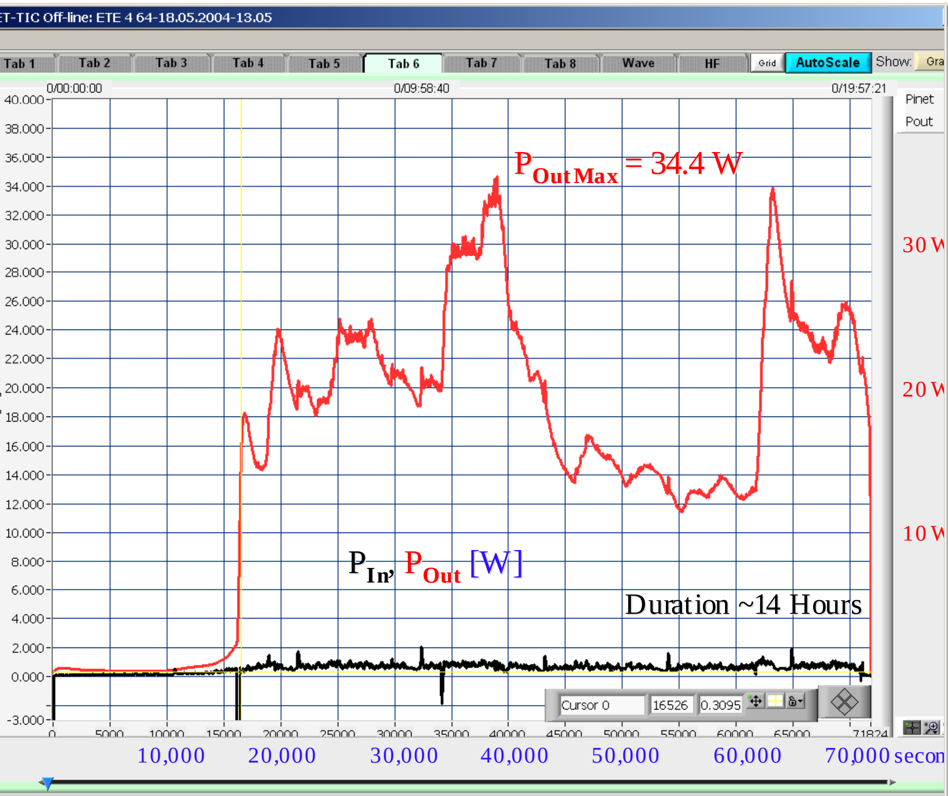


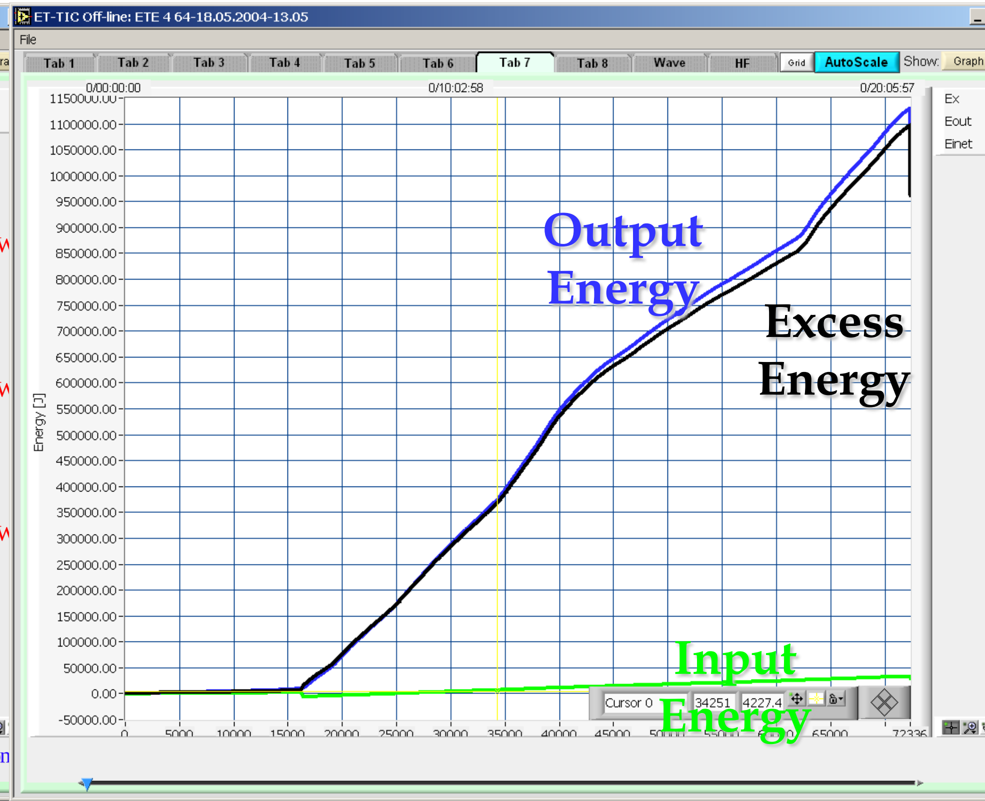
(Art from Energetic Technologies)

Excess Heat Result from Energetic Technologies in 2004, Run #64



Excess Heat Result from Energetic Technologies in 2004





E_{out} = 1.1 MJ, E_{in} = 40 kJ

Is the Excess Heat Effect Real?

- In cells loaded by electrolytic techniques that I observed at Energetic Technologies in Omer, Israel in October, 2008:
  - Recombiner concerns?
    - ET results take P_{in} = I*V, ignore recombiner heat
      - Hence excess heat reports are under-estimated
    - Volume chemical reaction?
    - Oxygen leak resulting in D-burn at cathode?
  - Ground-loops or shorts?
    - Isolation transformer coupling on cathode resistivity measurements
    - Very good laboratory technique was observed
  - Under-estimated input power?: Electrolytic Interrupter effect?
    - 50 kHz measurement system sampling, > 20 kHz BW
    - Direct measurements with a 200 MHz BW scope
    - Any such effect is < 0.01% of near DC input power
    - Proposed calibrated physical source measurement

Excess Heat Effect Is Real

- Even if input power is mis-measured due to an electrolytic interrupter effect…
  - … why didn't it appear on the 200 MHz scope?
  - … what mechanism can store 50 kJ to 4 MJ of energy near a 0.3g Pd electrode for heat release a few hours or days later?
- Even if some amazing new mechanism like this were to be discovered …
  - … it would be absent in the other methods of loading, all of which report excess heat

The Excess Heat Effect: far Greater than Chemical Heat Release

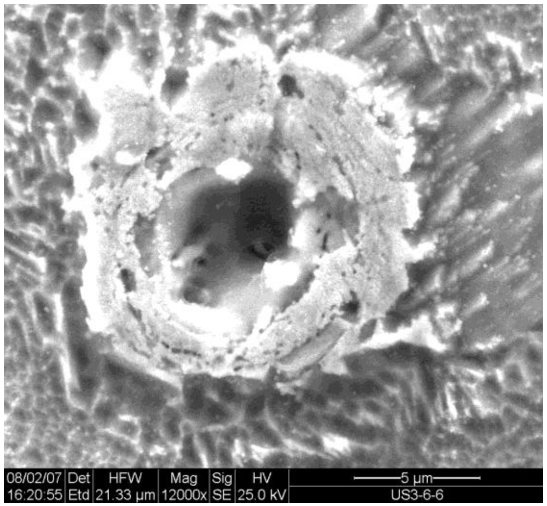
- The ET Pd cathode mass was 0.3 g ($2x10^{-3}$mole)
- Chemical release of heat:
  - ΔH for Pd +D → PdD is about 43 kJ/mole
    - So about 100 J if this heat release was somehow delayed
  - ΔH for $2D_2 + O_2 \rightarrow 2D_2O$ is about 242 kJ/mole
    - So about 500 J of delayed released heat
- Many measurements show:
  - Typical heat release per episode of 50,000 J
  - Occasional heat release of over 1,000,000 J
- Heat release is usually from ambient temperature to about 100 ^{o}C, with occasional reports of heat release up to the melting of Pd at 1,550 ^{o}C

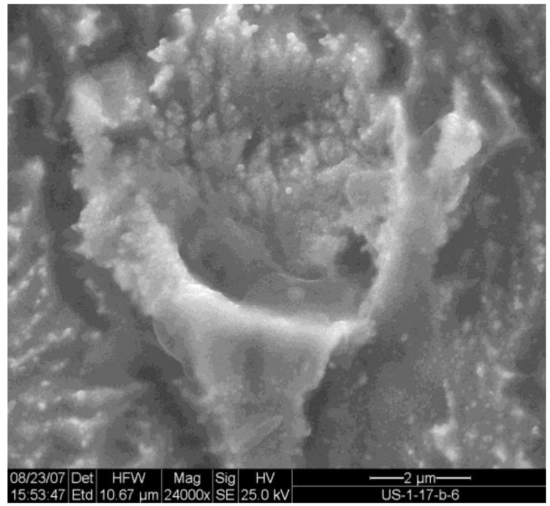
So What is Going On?

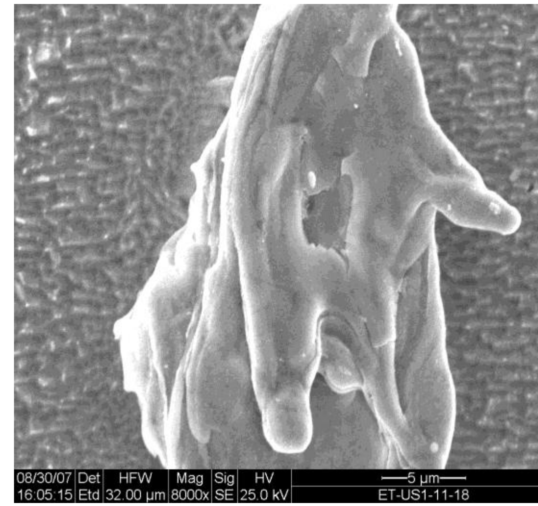
- We don’t know – it will take a lot of well controlled experiments to figure this out.
- The ‘excess heat’ appears to be real. That is enough to motivate serious study
- Evidence of a nuclear fusion process
  - A hypothesis: Ignition through muon-catalyzed D + D fusion near (but not in) the Pd.
  - Micro-craters found on the Pd surface by ET in Israel, and by Navy SPAWAR
- Very little public funding means that there is little assurance that results will come available in the public domain, at least in the USA.

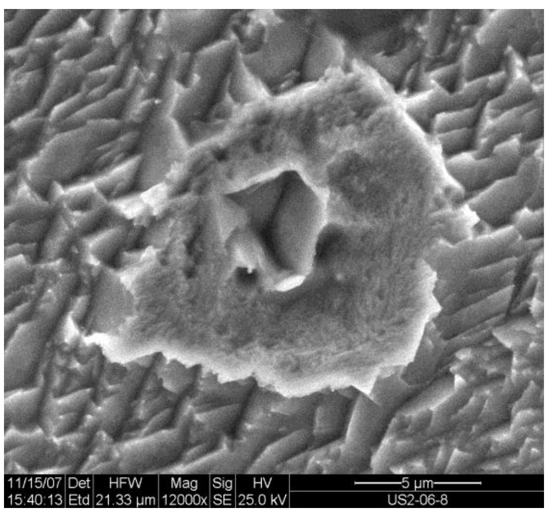
SEM images from Energetic Technologies Ltd. in Omer, Israel

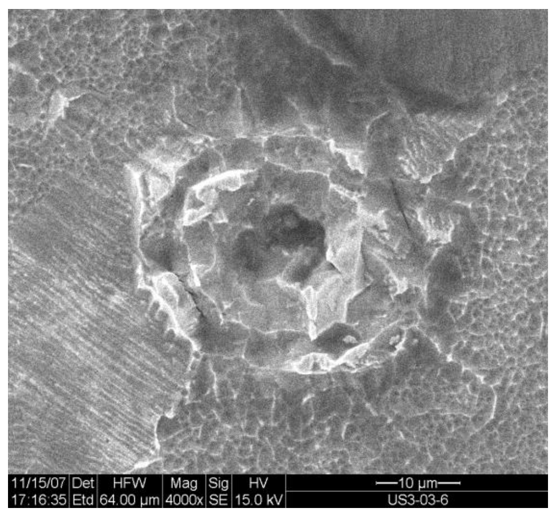
Micro-craters in palladium, possibly following extreme heat release, when loaded with heavy hydrogen . The origin of these micro-craters is still under intense debate.

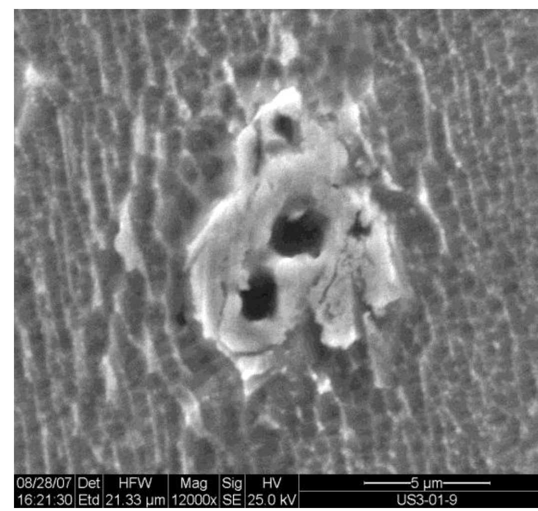




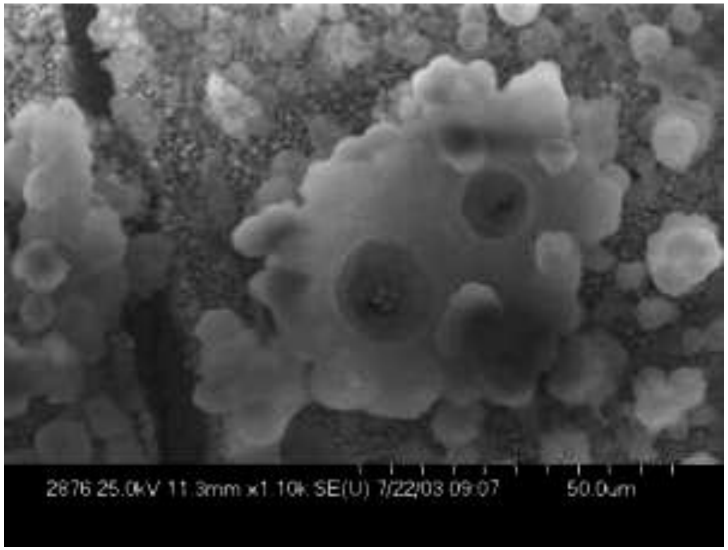


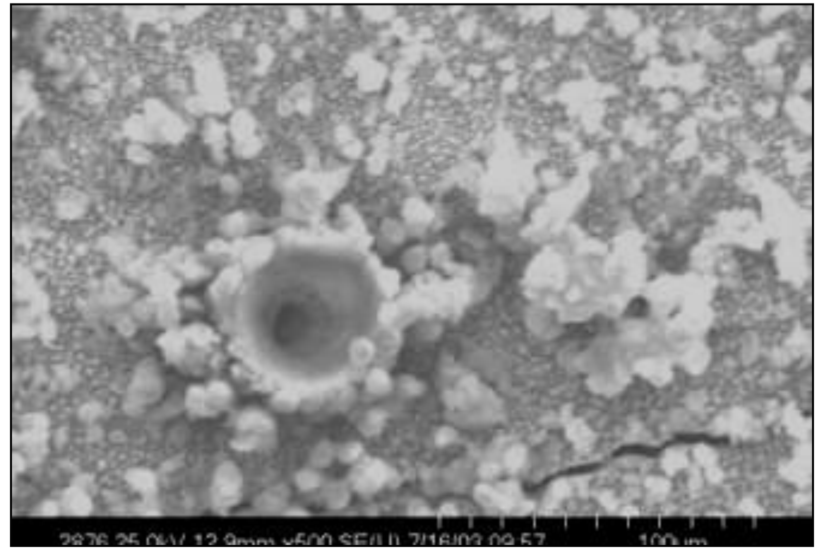


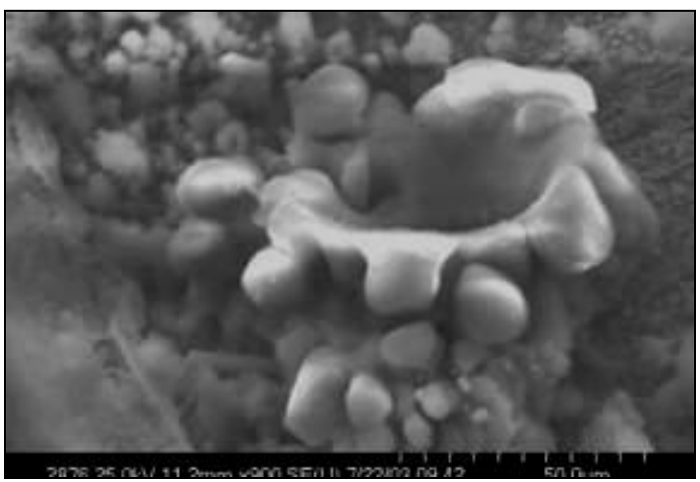




SEMs Obtained for a Cathode Subjected to an E-Field Showing Micro-Volcano-Like Features



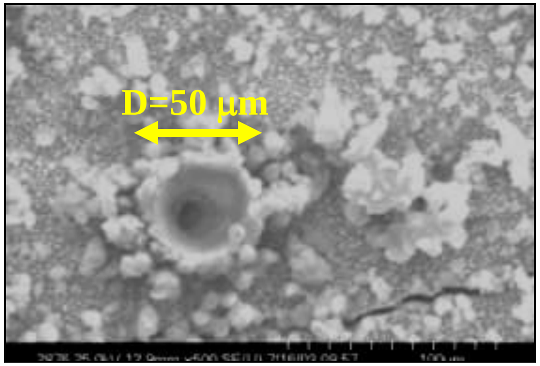


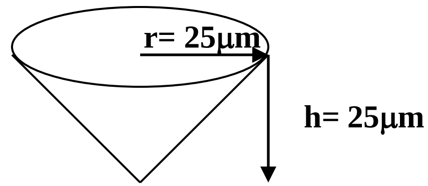


All data and images are from Navy SPAWAR's released data, presented at the American Chemical Society Meeting in March, 2009.

Total Number of Fusion Reactions Estimated From A Crater Formation

S. Szpak, P.A. Mosier-Boss, C. Young, and F.E. Gordon, J. Electroanal. Chem. **580**, 284 (2005)





Ejecta Volume

$V = \pi r^2 h/3$

$= 1.6 \times 10^4\ \mu m^3$

$V = 1.6 \times 10^{-8}\ cm^3$

Thanks to Y. Kim for Slide and corrections

D+D → ^{4}He + 23.8 MeV (to the metal, not gamma particle?)

Number of moles for deuterons in ejecta volume

$N_{moles} = 1.6 \times 10^{-8} cm^3 \times 12.02\ g/cm^3 \times (106.4\ g/mole)^{-1} = 1.8 \times 10^{-9}$ moles

Total energy required for vaporization of Pd metal in ejecta volume

$E_T = 1.8 \times 10^{-9}$ moles x $(3.62 \times 10^5$ joules/mole$) = 6.5 \times 10^{-4}$ joules

Energy released per fusion reaction

$Q = 23.8$ MeV x $(1.6 \times 10^{-13}$ joules/MeV$) = 38.1 \times 10^{-13}$ joules/reaction

Total number of deuterons present in ejecta volume

$N_D = 1.6 \times 10^{-8} cm^3 \times 6.8 \times 10^{22}/cm^3 = 1.1 \times 10^{15}$

Total number of fusion reactions

$N_R = (E_T/Q) = 6.5 \times 10^{-4}$ joules x $(38.1 \times 10^{-13}$ joules/reaction$)^{-1} = 1.7 \times 10^8$ reactions

corresponding to ~ 3.7×10^{-2} μm diameter BEC of deuterons undergoing fusion

Muon-catalyzed Ignition?

- Muons shower us at the rate of one per cm^2 per minute, with an average energy of 3 GeV and a rest-frame half-life of 2.2 μs
- Only low-energy muons can form D-μ-D
- Estimated arrival rate at thermal energies is one per cm^2 per hour (Cohen and Davies, Nature 338, 705 (1989))
- Must arrive in D-rich voids in the Pd, since muons in the Pd will be K-shell captured by the Pd and hence not available to form D-μ-D (Richard Garwin and others, discussions)
- ET experiment: $10cm^2$, estimate 1% of D in voids, hence a once in 10 hr average arrival time of an 'ignition muon'.
  - Qualitatively describes why onset time and extent of the excess heat release is highly dependent on Pd preparation
  - Does not describe how the chain reaction is sustained, or why neutrons and tritium are absent, or why the gamma is absent if the $D+D \rightarrow {}^4He + \gamma$ is favored.

Evidence for Nuclear Processes

- Micro-craters observed independently by Energetic Technologies and by SPAWAR
  - Correlates roughly with excess heat production, but no attempt yet to correlate areal crater density with total excess heat release, etc.
  - Modeling by SPAWAR suggests that these craters could be of nuclear fusion origin
- The D + D → ^{4}He appears to be favored, with energy and momentum taken up by the lattice (no gamma!)
  - Mossbauer-like process, but electromagnetic, not phonon?
  - Other possible quantum coherent mechanisms: Y. Kim's BEC theory.
- Many other reports of particle emissions
  - Prelas, 1990: A 8.1 MeV γ starting 200 hrs after D-loading into Pd
  - Lipson, 2009: A 3 MeV proton emission in Pd
  - Navy SPAWAR reports of particle tracks in CR-39 integrating detectors
- Helium-4 build up in proportion to excess heat
- The levels of excess heat reports are well above chemical

Palladium Nanoparticle Excess Heat

Pd Nanoparticles have diameters less than 10 nm in Pd-Zr

- this is much less than the hydrogen passivation layer thickness in palladium

- typical [D]/[Pd] = 1.1 in gas diffusion loading experiments

Y. Arata, Y. Zhang, J. High Temp. Soc. 1 (2008): Reported excess heat for up to 50 hours following D_2 charging of Pd nanoparticles in Pd – ZrO_2 composites, while H_2 loading showed no excess heat

Akira Kitamura, Takayoshi Nohmi , Yu Sasaki , Akira Taniike , Akito Takahashi, Reiko Seto, Yushi Fujita, Physics Letters A <u>373,</u> 3109 (2009): Repeated these results

The Kitamura *et al*. Experiment

Physics Letters A 373 (2009) 3109–3112

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www.elsevier.com/locate/pla

Anomalous effects in charging of Pd powders with high density hydrogen isotopes

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ABSTRACT

A twin system for hydrogen absorption experiments has been constructed to replicate the phenomenon of heat and ^4He generation by D_2 gas absorption in nano-sized Pd powders reported by Arata and Zhang, and to investigate the underlying physics. For Pd · Zr oxide nano-powders, anomalously large energies of hydrogen isotope absorption, 2.4 ± 0.2 eV/D-atom and 1.8 ± 0.4 eV/H-atom, as well as large loading ratio of $D/Pd = 1.1 \pm 0.0$ and $H/Pd = 1.1 \pm 0.3$, respectively, were observed in the phase of deuteride/hydride formation. The sample charged with D_2 also showed significantly positive output energy in the second phase after the deuteride formation.

1. Introduction

Arata and Zhang recently reported that highly pure D_2 gas charging of Pd nano-powders in the form of Pd/ZrO_2 nano-composite induced significantly higher temperatures inside the reactor vessel than on the outside wall for more than 50 hours, while runs with H_2 gas showed almost no temperature difference [1]. To verify that the excess heat originated in a nuclear process, a QMAS was employed to show the existence of ^4He as nuclear ash in the vessel and in the powder after the charging. The charging system is a sophisticated and simplified version of the previous-generation DS reactor [2]. Replication experiments using systems similar to the DS reactor with Pd-black seem to be successful [3,4].

However, few reports on the replication experiments producing heat and ^4He with the new configuration have published yet in spite of extreme importance of the phenomenon. It is crucial to confirm the phenomenon of heat and ^4He generation with fully quantitative reliability.

In the present work we constructed an experimental system to replicate the phenomenon and to investigate the underlying physics. We report here the first results of deuterium/hydrogen absorption and accompanying heat generation, which show anomalously large isotope effect.

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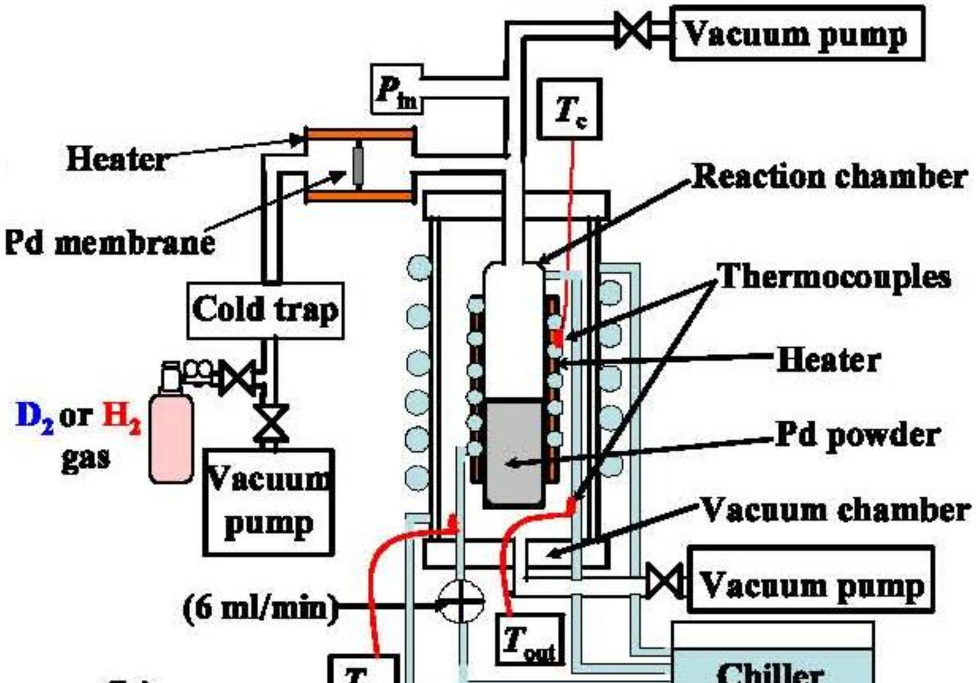
doi:10.1016/j.physleta.2009.06.061

2. Experimental procedure

An oxide sample of mixture of Pd (34.6%) and Zr (65.4%) was fabricated by Santoku Corporation, Kobe, Japan, and has an average particle size of 7.7 μm, a specific surface area of 37.1 m^2/g, and an average Pd grain size of 10.7 nm. If we assume perfect oxidation of the metal elements, 10 g of the sample contains 3.0 g of Pd.

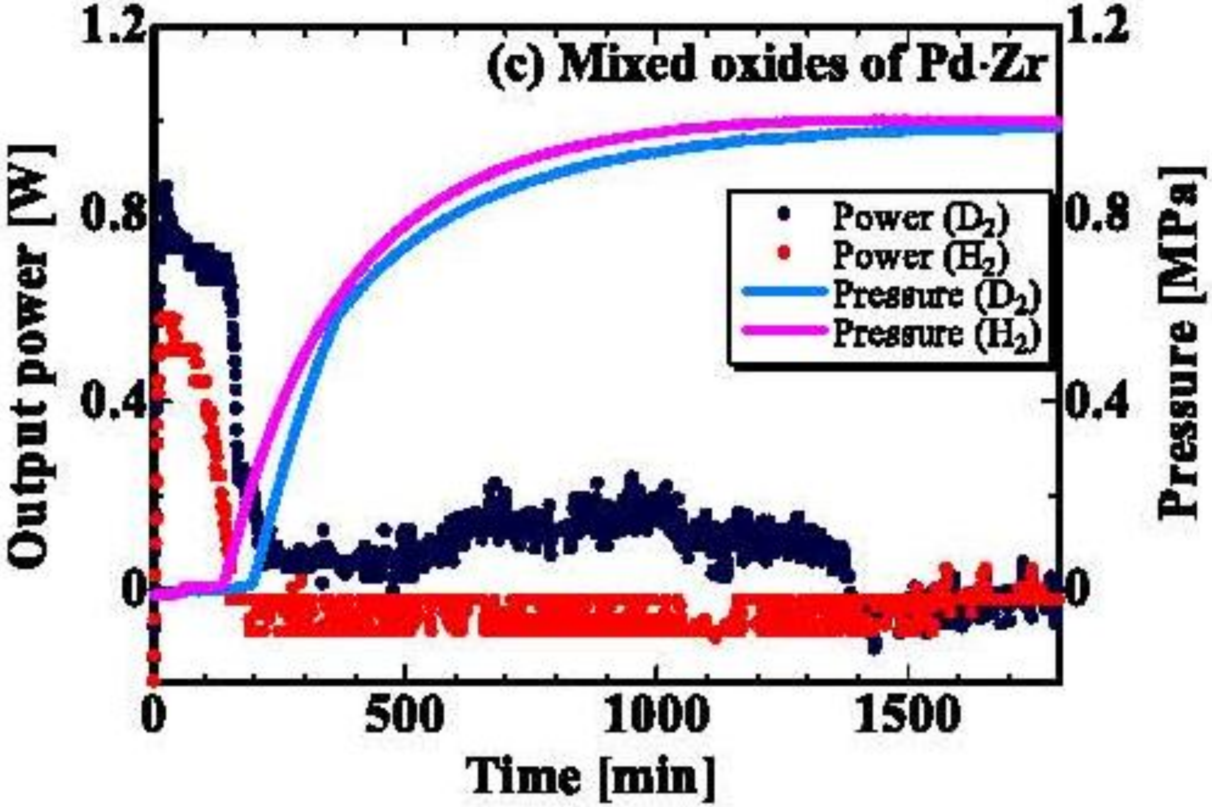
The D_2/H_2 absorption system is composed of two identical chambers (an $A_1 \cdot A_2$ twin system): one for a D_2 gas foreground run, and the other for H_2 gas background run. As shown in Fig. 1, each part has an inner reaction chamber containing Pd powder and an outer chamber that is evacuated to provide thermal insulation for calorimetry. A sheath heater and a cooling water pipe made of copper are wound on the outer surface of the reaction chamber for baking the sample powder and for flow calorimetry to estimate the heat production rate, respectively. A pair of thermocouples is provided for the flow calorimetry by measuring the temperature difference between the inlet and the outlet of the cooling water.

The D_2 gas is nominally 99.5% pure and the H_2 is 99.998% pure. Flow rate control of D_2/H_2 gas purified through a liquid-nitrogen cold trap is made with a Pd membrane filter which also serves as an additional purifier. The Pd membrane (0.2 mm-t, 99.95%) separates the evacuated reaction chamber (50 ml) and the gas reservoir filled with D_2/H_2 at 1 MPa. The gas permeation rate is controllable between 0.1 and 25 sccm by varying the membrane temperature from the room temperature to 900 K.

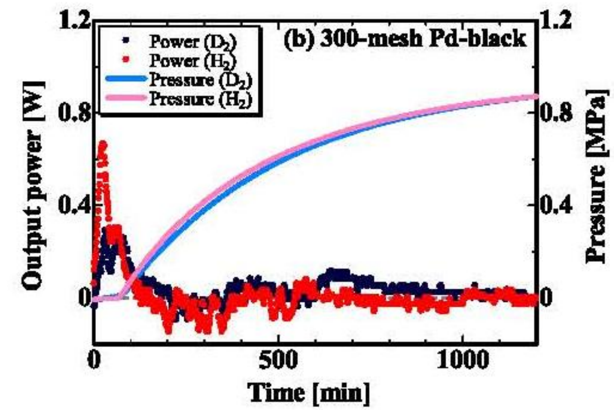


(b)

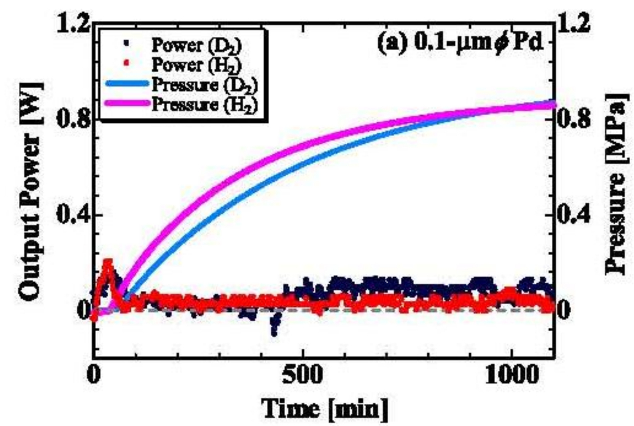
Kitamura *et al.* Results



0.001 µm: 1.8 eV /H-atom, 2.4 eV/D-atom



0.01 µm: 0.7 eV/atom



0.1 µm: 0.2 eV/atom

Theoretical Studies

- Talbot Chubb (formerly NRL)
  - Energy / momentum conservation to the lattice
- Yeong Kim (Purdue): BEC in deturium in small confines
  - Predictions for experiments, inc. D-superfluidity
  - If so, then T-dependence of condensate fraction should be readily observable
- Peter Hagelstein (MIT): Dissipation term in the many-spin spin boson hamiltonian
  - 'Toy Model' describes how D+D $\rightarrow$ ^{4}He and many photons
- Julian Schwinger (UCLA, 1990): p-D fusion, not D-D. Pd may lower the p-D coulomb barrier permitting fusion
- Many others

Junk Science or Empirical Data?

- Persistent observations, like excess heat in Pd – D and superconductivity above room temperature, should be treated as empirical evidence that our understanding of physics remains incomplete, as it probably always will be.
- It is simply too convenient and counter-productive to dismiss these observations as ‘junk science’.
- The Scientific Method is the only thing we have got, and fortunately it is the <u>only</u> thing that we need!
  - Simply apply the scientific method without prejudice, and go where the data leads you

Any ‘Lessons Learned’ Here ?

- There is a HUGE gap between new science discovery and useful engineered systems
  - Don’t speculate wildly, manage expectations!
  - Pursue basic science BECAUSE you don’t understand!
  - I really don’t know yet if this science will ever lead to energy production, but it is very important to find out systematically
- Mass media should be approached carefully with new discoveries in light of the first point above
- Research funding needs to become less dependent on the common assumptions within the culture of scientific communities, and to become much more courageous and objective

Conclusions

- The Excess Heat Effect is Real
  - This alone merits serious study
  - Years of careful work will be needed to fully understand what is going on
  - Absorption heat variation with Pd characteristic size
  - I don’t know if this will ever lead to large-scale energy production, but we must determine if so systematically

- Now for a hunch, just a guess of sorts…
  - ‘Warm’ Fusion, muon-assisted, some particles
    - Can the metal environment change muon-ash binding rate?
  - ‘Cold’ Fusion, no particles
    - How do small Pd particles / structures catalyze this?
  - Both could be going on