

# FUSION facts

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FUSION FACTS

OCTOBER 1990

**SPECIAL ISSUE FOR ATTENDEES AT  
ANOMALOUS NUCLEAR EFFECTS IN  
DEUTERIUM/SOLID SYSTEMS CONFERENCE**

Brigham Young University - OCT 22-24, 1990

**EXCESS HEAT USING MOLTEN SALT  
ELECTROCHEMICAL CELL**

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**A. EXCESS HEAT USING MOLTEN-SALT  
ELECTROCHEMICAL CELL**

By Professors Liaw, Tao, Turner, & Liebert

THE FOLLOWING ARTICLE is published complete with TABLES AND FIGURES.

B.Y. Liaw, P.L. Tao (Hawaii Natural Energy Inst), P. Turner & B.E. Liebert (Dept. of Mech. Engr., U of Hawaii), "Elevated Temperature Excess Heat Production Using Molten-Salt Electrochemical Techniques", Being published in the *Proceedings of the Special Symposium on Cold Fusion*, World Hydrogen Energy Conference #8, Honolulu, HI, July 22-27, 1990.

**Note:** We are grateful to the authors and to the University of Hawaii for permission to print this important technical paper in full in this issue of *Fusion Facts*. Given the very large energy yields and the potential application to a much wider group of alloys, the editors believe this to be **one of the most important papers to be given at a cold fusion symposium** since the initial announcement by Fleischmann and Pons of the discovery of cold fusion (March 23, 1989).

ABSTRACT

An investigation of elevated-temperature excess heat production in the Ti-D and Pd-D systems is presented here. A eutectic LiCl-KCl molten salt saturated with LiD is used as the electrolyte in a Pd/Al or Ti/Al electrochemical cell. Typical operating temperatures are around 370°C, which results in faster kinetics compared to room temperature operation. If this system can be developed for utility applications, high-grade heat and high thermodynamic efficiencies can be expected. Since the electrolyte provides a very reducing environment, metal surface oxides are readily removed; thus, this unique system offers the possibility of using less expensive materials than Pd. A modified isoperibol calorimeter was built for the excess power measurements. Preliminary results show high levels of excess power output, especially in the Pd-D system, although the effect remains sporadic.

1. INTRODUCTION

The announcement of the achievement of excess heat production by a process attributed to "cold fusion" by Fleischmann, Pons, and Hawkins [1] introduced the potential for clean, cheap, and abundant energy from a

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virtually inexhaustible source. Even though the nature of this reaction has not been conclusively identified, detection of excess heat, tritium, and neutrons, separately or collectively, has been reported by many laboratories [2].

In the sense of practical application of this technology, the aqueous electrolytes used in most studies are limited to relatively low temperatures, typically below 100°C, unless a pressurized cell is used. In terms of thermodynamics and kinetics, however, it would be desirable to operate the system at higher temperatures where the efficiency of electricity conversion can be increased.

It has been suggested that high deuterium activity in palladium deuteride is important in order to be able to achieve excess power and heat [1]. According to the phase diagram of the Pd-H system shown in Figure 1, at the same H/Pd ratio, the equilibrium hydrogen partial pressure increases quite drastically with temperature; higher temperatures increase the deuterium activity in metal deuterides as well.

Deuteron-conducting solid electrolytes may be considered for high-temperature operation; however, of the few presently available, there are problems of long-term stability and relatively low conductivity.

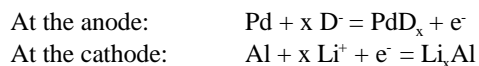
Only a limited number of metals, such as Pd and perhaps Ti, have been used in typical Fleischmann-Pons cells. On the other hand, there are many other transition metals and their alloys that can absorb substantial amounts of hydrogen and its isotopes; thus, these too should be considered potential candidates for producing excess heat. Unfortunately, these metals have hydrogen-impeding surface oxide layers; therefore, their use in aqueous systems is restricted.

The use of molten-salt electrochemical techniques to generate excess power at elevated temperatures, typically 350-500°C, is presented here. The use of molten salt techniques to study metal-hydrogen systems has been demonstrated by Luedecke *et al.* [3,4] and Liaw *et al.* [5,6]. The molten salt electrolyte in this case is a eutectic LiCl-KCl saturated with LiD, which has a melting temperature of about 350°C. LiD provides the deuteride-conducting species (D<sup>-</sup>) in the electrolyte, along with a very strong reducing environment that removes surface oxides on metals and thus facilitates deuterium reaction with the metal. Since quite a substantial amount of LiD can be incorporated into the melt, the electrolyte has a high ionic conductivity. Accordingly, we believe that this approach is superior to the aqueous system for increasing the deuterium activity in metals in many aspects, including: elevated-temperature operation to assure a higher thermodynamic efficiency, use of less expensive materials, and, possibly, a higher power gain due to better kinetics.

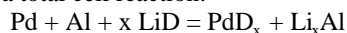
## 2. PRINCIPLES

Recently, Deublein and Huggins [7] have proposed a novel approach of using a eutectic LiCl-KCl molten salt saturated with LiH as an effective means to prepare hydrogen-transparent metal surfaces. The same technique, demonstrated by Liaw *et al.* [5,6], and Deublein *et al.* [8], showed that hydride-conducting electrolytes can be used to control metal-hydrogen reactions in electrochemical cells. The alkali hydrides used in the electrolytes dissociate in the melt and form alkali and hydride ions. The hydride ion can thus be transported in the electrolyte and, eventually, metal hydrides are produced electrochemically.

We expected the deuterium system to behave in a similar fashion. Therefore, an electrochemically-induced reaction, similar to that reported by Fleischmann and Pons, can be conducted using a cell, as shown in Figure 2. The cell reactions are:



for a total cell reaction:



The thermal behavior of the cell, which is monitored by a thermocouple in an isoperibolic calorimeter, allows a determination of the dynamic heat balance of the system. The heat that is generated during electrolysis results in a change in the thermocouple's emf and the power determined from previously obtained calibration data.

## 3. EXPERIMENTAL ASPECTS

The cell shown in Figure 2 consists of an Al container and crucible and a dewar flask with additional glass fiber (1" Kaowool, 8# density) insulation. The Pd sample (Engelhard, 99.99%) was melted with a propane/oxygen torch before use. The Ti rod (AESAR/Johnson Matthey, 99.99%), 0.635 cm in diameter, was used as received. Both Pd and Ti were used as the positive electrode materials in separate experiments. A section of Al tubing (700/SF 6061) 2.54 cm long and 0.32 cm thick was used as the negative electrode to react with Li. The Al electrode was constantly replenished after being fully loaded with Li. LiD (Aldrich, 98+ at% D) and eutectic LiCl-KCl (Lithco, 47.6 wt% KCl + 51.9 wt% LiCl) were used as received. Current collectors were steel rods, 0.3 cm in diameter. The experiments were carried out in a controlled argon environment where oxygen and moisture were continuously removed from the glove box.

The calorimetric measurements were based on a dynamic heat balance determined by a thermocouple in the electrolyte. The K-type thermocouple (Omega) was

protected with an ungrounded stainless steel sheath, 0.1 cm in diameter.

The calibration procedure was conducted by employing a resistor heating tape in contact with the reaction cell container as a joule heat source. By varying the power to the resistor heating tape,  $P_r$ , we obtained a corresponding delta T versus  $P_r$  relation as a calibration curve. Each experiment was calibrated before and after the high-current excursion to monitor the heat capacity variation of the reaction cell.

An experiment based on the Ti-D system was conducted and its temperature and power history recorded. The Ti sample was 1.3215 g and 0.99 cm long. The area of the Ti sample was estimated to be 2.49 cm<sup>2</sup>. A current density of about 40 mA/cm<sup>2</sup> for two months was used to ensure complete loading of deuterium throughout the sample before later use for high current-excursions.

Similar experiments on Pd were also performed. The Pd was 0.4874g and had an irregular shape due to melting. The surface area of the Pd was estimated to be about 0.99 cm<sup>2</sup>. It was charged for more than three weeks at 4 mA/cm<sup>2</sup> before the first high-current excursion.

#### 4. RESULTS

##### Ti-D System

Figure 3 shows the temperature and the potential of the TiD<sub>x</sub>/LiCl-KCl (eutectic) + LiD/Al cell after the initial loading at 40 mA/cm<sup>2</sup>. The temperature of the cell was measured first without an electrolysis current. A constant 600 mA current (240 mA/cm<sup>2</sup>) was then applied and the thermal response monitored. In the beginning, the temperature of the system decreased for about 10 hours. Later, the cell potential, as well as the temperature, increased after 17 hours of operation. Based on the calibration curve shown in Figure 4, which was determined before and after electrolysis, the temperature was transformed into an equivalent power output.

As shown in Figure 3, after 17 hours of operation at a constant 240 mA/cm<sup>2</sup>, the cell potential increased to between 1.0 and 1.5 V for about 30 hours. The total input power was based on that supplied from the resistor heating tape and the electrochemical power to the cell. Although this is an open system, the thermoneutral potential of the total cell reaction was not subtracted from the cell potential in the calculation of the input electrochemical ( $I \times V$ ) power.

The total output power was obtained from the thermocouple reading and the calibration curve. Figure 5 shows that the first 20 hours of high-current charging resulted in less output than total input power. After this

time, the measured output power exceeded the input power rather persistently. Figure 6 shows the excess power gain in the course of charging, indicating an increasing trend with time. The electrolysis was terminated due to the consumption of the limited amount of LiD available in the cell.

##### Pd-D System

Figure 7 is the result of two separate experiments showing two calibration curves and the corresponding temperature response of the PdD<sub>x</sub>/LiCl-KCl (eutectic) + LiD/Al cell under four different charging current densities. TABLE I gives the details of the measured cell voltage, current density, heater power, electrochemical power, and output power, as well as the calculated excess power and heat.

As an example shown in the last entry in TABLE I, the power to the heating tape was maintained at about 69.25 W, the cell potential was typically in the range of 2.45 V, and the electrochemical input power was about 1.68 W at 692 mA/cm<sup>2</sup> for a total input power of about 70.9 W. We would expect 1.68 W of joule heating to result in a 5.1 °C increase in temperature; however, the temperature increased by 82.4° C, which corresponds to a gain of about 27.1 W, according to the calibration curve. Therefore, a net gain of 25.4 W was in excess, which results in an excess power gain of 1512 percent, in the range of 627 W/cm<sup>3</sup> Pd.

Figure 8 shows the time-dependent power behavior of the second charging experiment and the difference between the measured output power and the total input power, which represents the excess power from the reaction. The area between the two curves is, therefore, the excess energy that was produced during the electrolysis of LiD. Integration of the curves yields an excess energy of 5.02 MJ for this particular experiment, which was limited, again, by the amount of LiD present in the cell. The electrochemical charge applied to the cell during the charging period was 154,600 Coulombs, which corresponds to 0.801 moles of D<sub>2</sub> gas. Thus an excess heat of 6.26 MJ/mol D<sub>2</sub>, or 1096 MJ/mol Pd, was obtained.

#### 5. DISCUSSION

##### Thermochemical Aspects

Most of the thermodynamic data, especially the enthalpies, which represent heats associated with the formation of compounds and solution of hydrogen in the above systems, can be found in the open literature. When all reactions that are known to occur in these systems are considered, no rationale can be obtained that would justify attributing a thermochemical reaction to the excess power generation. Thus, these results suggest that this effect is nonchemical.

The reported enthalpies of the compounds related to these systems are compiled in TABLE II. TABLE III lists possible chemical reactions and their corresponding reaction enthalpies, as calculated from TABLE II.

For the Pd system, all calculated enthalpies for hydride/deuteride formation, hydrogen dissolution, gas evolution, and chloride formation are positive, as shown in TABLE III, indicating that these reactions are endothermic in nature; in other words, they should not contribute to any excess power measured.

Similarly, in the Ti case, we also found that hydrogen dissolution in various phases, gas evolution, and chloride formation give positive enthalpies. However, the hydride formation reactions exhibit negative enthalpies, indicating exothermic processes. The estimated power contribution from these processes is in the range of 0.17 W (for TiH<sub>2</sub> formation) to 0.61 W (in the case of hydride formation, alpha to beta) at 600 mA and 700 K, which is comparable to the amount of excess power measured. Nevertheless, these numbers are based on the assumption that the total current was entirely supplied to hydride or deuteride formation, which is unlikely in the experiment. As a matter of fact, most of the current should be consumed in gas evolution; the actual portion being applied to the hydride/deuteride formation is expected to be very small during the high-current charging stage. This means that the actual power contribution from the hydride/deuteride formation is, in reality, very small and may, in fact, be negligible.

Furthermore, we did not take into account the heat loss by gas evolution. We can estimate the heat loss carried by the gas from the heat capacity of the hydrogen gas, which is about 6.88 cal/mole/K at 298 K and 7.09 cal/mole/K at 700 K [9]. At 600 mA, a typical current level employed during high-current charging, the heat loss rate carried by the gas was of the order of 0.037 W, a relatively small contribution.

On the other hand, we believe that the deuterides have already been formed during the initial charging periods, which was further confirmed by an open circuit potential measurement and by physical examination by removing a piece of the brittle deuterated metal. Therefore, proper consideration of the thermochemical aspects during the high-current-charging excursion should emphasize the dissolution of deuterium in the deuterides, which is endothermic, rather than the exothermic deuteride formation.

Therefore, the origin of the excess heat generation can only be attributed to a nuclear process or, maybe, several processes, which are unknown as yet. There is sufficient evidence [2] from other laboratories that tritium and neutrons have been detected in highly deuterated metals,

which directly supports the hypothesis of a nuclear phenomenon.

Experiments based on LiH have been performed as well; however, no excess heat has been found to date, which suggests that there is indeed a difference between the deuterium and hydrogen systems.

## 6. CONCLUSIONS

We have demonstrated that, employing novel molten-salt electrochemical techniques, excess power production was found in both the Ti-D and Pd-D systems. In one particular case, a large amount of excess heat of 6.26 MJ/mol D<sub>2</sub> was measured in a Pd-D charging experiment. Our current effort is focused on the comparison of the H and D systems, in order to understand the excess power generation process, and attempting to identify the parameters that control the sporadic nature of the phenomenon.

## ACKNOWLEDGEMENTS

We would like to thank the Office for Technology Transfer and Economic Development, the Office of the Vice President for Research and Graduate Education, the Hawaii Institute of Geophysics, and the Hawaii Natural Energy Institute of the University of Hawaii, as well as the Pacific International Center for High Technology Research, for financial support. Dr. S. Sharma provided the Pd and Ti sample materials and Professor C.M. Jensen the glove box facility.

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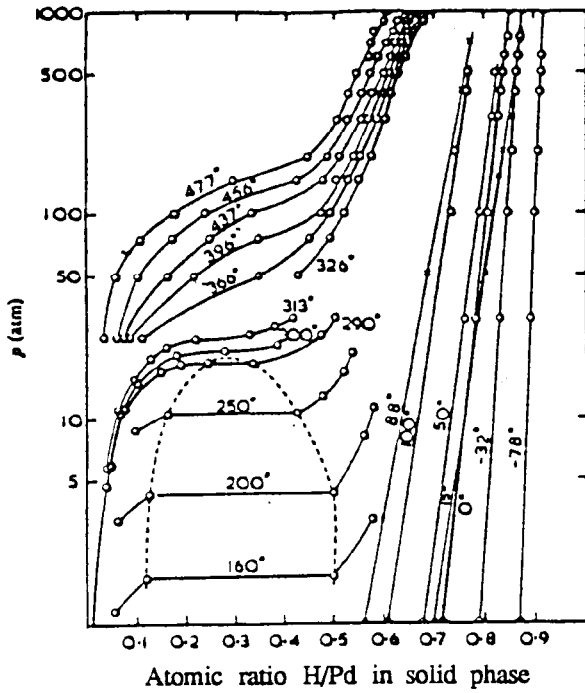


Fig 1. Binary phase diagram of the Pd-H system. After Levine and Weale [10].

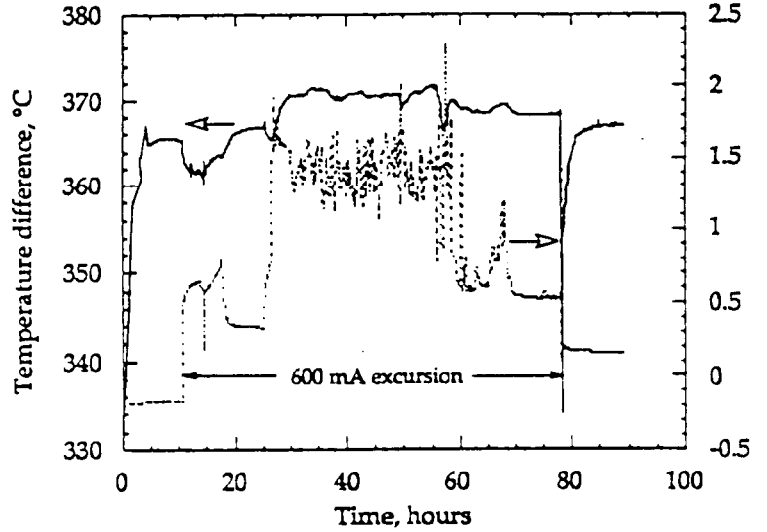


Fig 3. Time-dependent behavior of the temperature difference between the cell and ambient and cell potential in the Ti-D experiment.

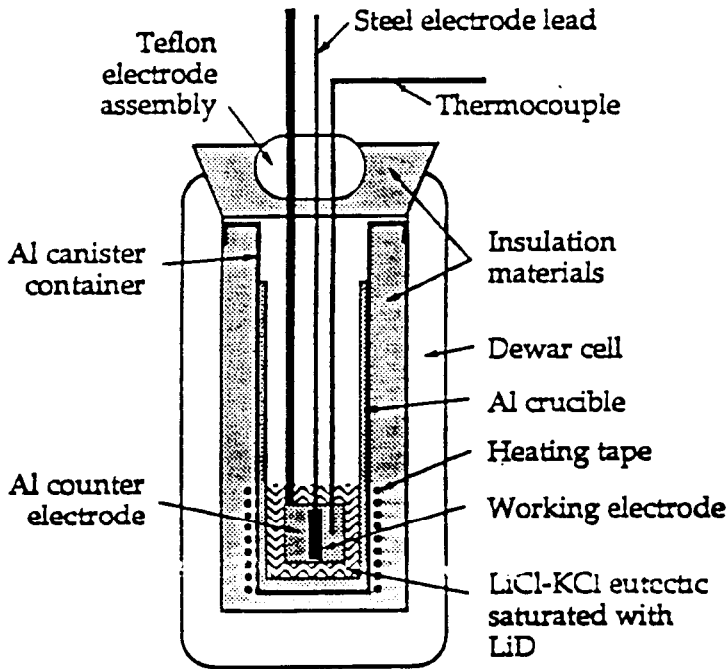


Fig 2. Schematic drawing of the elevated-temperature molten-salt cell.

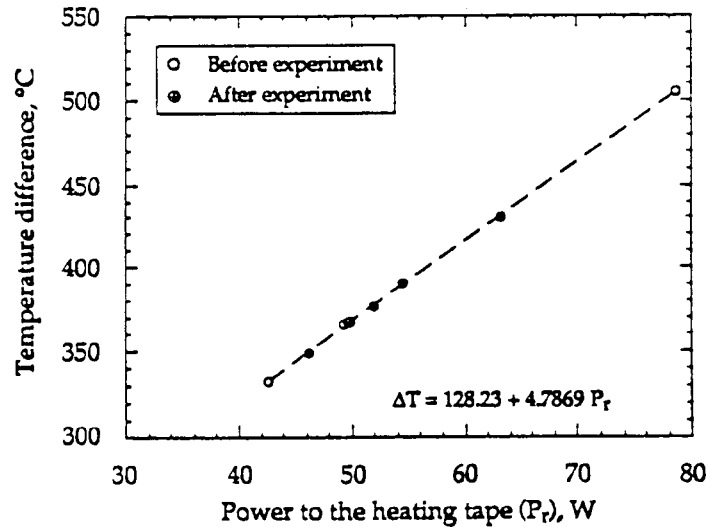


Fig 4. Calibration plot for the Ti-D system.

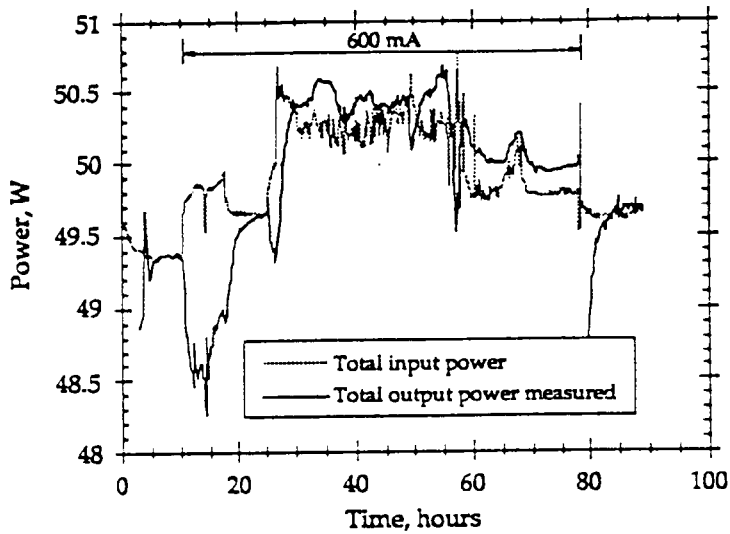


Fig 5. Time-dependent power response during high-current charging in the Ti-D system.

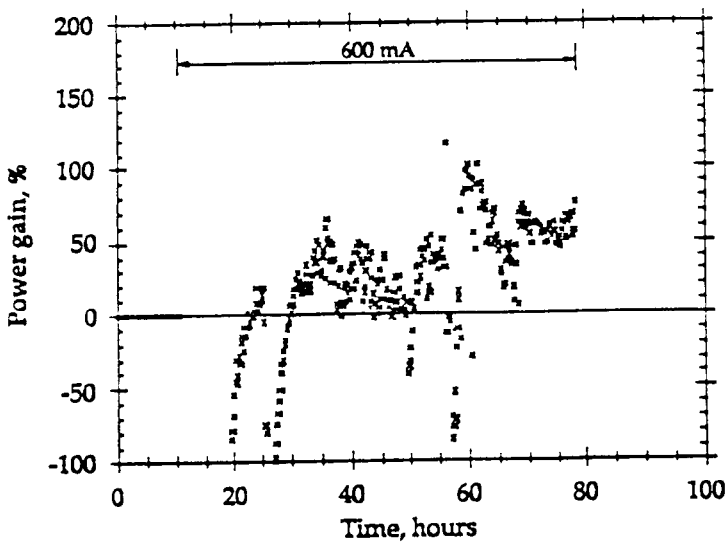


Fig 6. Excess power generation in the Ti-D system. The power gain is defined as: Percent power gain = (total output power - total input power) / (cell potential  $\times$  current)  $\times$  100.

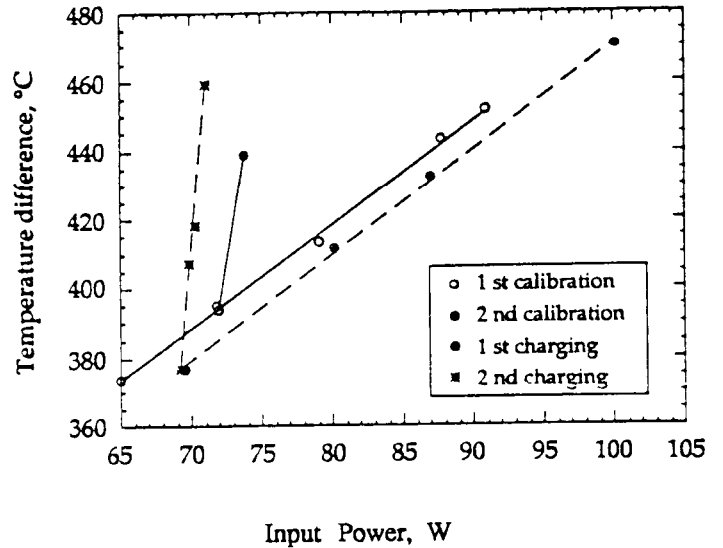


Fig 7. Thermal response and power performance from two separate charging experiments in the Pd-D system. The first charging was conducted at  $606 \text{ mA/cm}^2$ . The second charging was performed at three current densities: 290, 420, and  $692 \text{ mA/cm}^2$ , respectively.

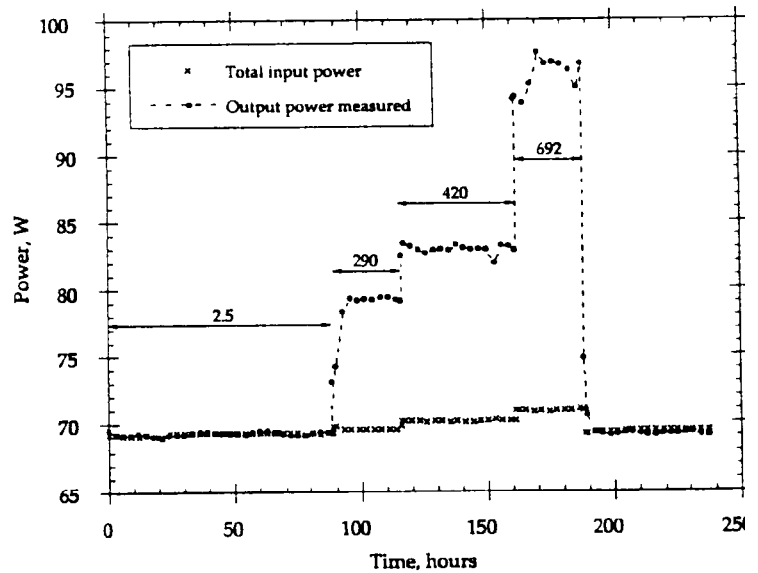


Fig 8. Time-dependent power response of the second Pd-charging experiment. Each point in Fig 8 is the result of a steady-state temperature measurement. The experiment was terminated when the LiD was exhausted. Numbers are current densities in  $\text{mA/cm}^2$ .

TABLE I: PARAMETERS AND POWER BALANCES IN THE Pd-D EXPERIMENTS

Cell Voltage, V	Current density, mA/cm <sup>2</sup>	Power to heating tape, P <sub>r</sub> , W	Electro-chemical power W	Total input power, W	Power output measured, W	Excess power, W	Excess power gain, %	Excess heat, (MJ/mol D <sub>2</sub> )
3.230	606	71.91	1.94	73.85	86.76	12.91	665	-4.15
2.188	290	69.25	0.63	69.88	79.24	9.36	1486	-6.27
2.270	420	69.30	0.94	70.24	82.81	12.57	1337	-5.83
2.453	692	69.25	1.68	70.93	96.34	25.41	1512	-7.16

TABLE II: ENTHALPIES OF COMPOUNDS INVOLVED IN THE Ti-D AND Pd-D SYSTEMS AT 298 AND 700 K<sup>(1)</sup>

Compounds	Delta H @ 298 K (kcal/mole)	Delta H @ 700 K (kcal/mole)
LiH	- 21.66	- 22.638
LiD	- 21.73 <sup>(2)</sup>	
LiCl	- 97.578	- 97.655
KCl	-104.37	-104.36
TiCl <sub>2</sub>	-123.2	-121.975
PdCl <sub>2</sub>	- 41.39	- 39.796
LiAl	- 11.7	- 12.727
PdH <sub>x</sub>		
beta hydride formation	-2.680 (x=0.56, 303 K) <sup>(3)</sup>	
beta hydride dissolution	-8.900 (in metal, 303 K) <sup>(3)</sup>	- 9.4 (x=0.35) <sup>(4)</sup> - 2.8 (x=0.65) <sup>(4)</sup>
PdD <sub>x</sub>		
beta deuteride formation	-2.350 (x=0.56, 303 K) <sup>(3)</sup>	
TiH <sub>2</sub>		
delta hydride formation	- 34.5 - 29.6 <sup>(3)</sup> - 29.472 <sup>(5)</sup>	- 35.455 - 32.708 <sup>(5)</sup>
alpha->beta hydride formation		-13.373 (688K) <sup>(6)</sup>
beta->delta hydride formation		-11.057 <sup>(7)</sup>
hydride dissolution		-10.004 (alpha, H/Ti=0.05, 737K) <sup>(5)</sup> -15.575 (beta, H/Ti=0.65, 746K) <sup>(5)</sup> -16.718 (delta, H/Ti=1.7, 737K) <sup>(5)</sup>
TiD <sub>2</sub>		
dissolution		-10.441 (alpha, H/Ti=0.05, 707K) <sup>(5)</sup> -17.774 (beta, H/Ti=0.65, 707K) <sup>(5)</sup>

(1) Data are from ref [9]

(2) From "CRC Handbook of Chemistry and Physics," 65th edition, ed. by R.C. Weast and M.J. Astle, CRC Press, Florida, 1984-85.

(3) Data are from G.G. Libowitz "The Solid State Chemistry of Binary Metal Hydrides," Benjamin, N.Y. 1965.

(4) Delta H decreases in magnitude with increasing H/Pd. Data are from P.L. Levine and K.E. Weale, J. Chem. Soc. Faraday Trans. **56**, 357 (1960).(5) Data is from A. San-Martin and F.D. Manchester, Bull. Alloy Phase Diagram **8**, 30 (1987).

(6) Data is from ref [6].

(7) Data is estimated from the reported values in R.M. Haag and F.J. Shipko, J. Am. Chem. Soc. **78**, 5155 (1956) and in P. Dantzer, J. Phys. Chem. Solids **44**, 913 (1983).

TABLE III: CALCULATED ENTHALPIES OF REACTION IN THE Ti-D AND Pd-D SYSTEMS AT 298 AND 700 K

Reaction	Delta H @ 298K (kcal/mole)	Delta H @ 700K (kcal/mole)
0.56 LiH + Pd + 0.56 Al = 0.56 LiAl + PdH <sub>0.56</sub> (hydride formation)	2.90	
0.56 LiD + Pd + 0.56 Al = 0.56 LiAl + PdD <sub>0.56</sub> (deuteride formation)	3.27	
delta LiH + PdH <sub>x</sub> + delta Al = delta LiAl + PdH <sub>x+delta</sub> (hydrogen dissolution)	5.51	0.51 (x=0.35) 7.11 (x=0.65)
y LiH + TiH <sub>x</sub> + y Al = y LiAl + TiH <sub>x+y</sub> (hydride formation from alpha to beta)		-9.41 (y=0.4)
(hydride formation from beta to delta)		-6.99 (y=0.41)
2 LiH + Ti + 2 Al = 2 LiAl + TiH <sub>2</sub>	-9.55 to -14.58	-12.88 to -15.63
LiH + TiH <sub>x</sub> + Al = LiAl + TiH <sub>x+1</sub> (hydrogen dissolution in alpha - phase)		4.91
(hydrogen dissolution in beta - phase)		2.12
(hydrogen dissolution in delta - phase)		1.55
LiH + Al = LiAl + 1/2 H <sub>2</sub>	9.96	9.91
LiD + Al = LiAl + 1/2 D <sub>2</sub>	10.03	
2 LiCl + PdH + 2 Al = 2 LiAl + PdCl <sub>2</sub> + 1/2 H <sub>2</sub>	133.05	
2 LiCl + PdD + 2 Al = 2 LiAl + PdCl <sub>2</sub> + 1/2 D <sub>2</sub>	132.72	
2 LiCl + TiH <sub>2</sub> + 2 Al = 2 LiAl + TiCl <sub>2</sub> + H <sub>2</sub>	83.06 to 78.03	83.34 to 80.59

## EDITORS' COMMENTS

### THE INVENTORS

Dr. Bruce Liebert graduated from Stanford University with a Ph.D. in Materials Science and Engineering. Dr. Borrr Yan Liaw received his Ph.D. in Materials Science and Engineering from Stanford. Both men were students of Dr. Robert A. Huggins, a senior professor in Stanford's Materials Science Department.

Drs. Liaw and Liebert invented the molten salt approach to cold fusion and filed patent papers in the month after the now-famous Fleischmann-Pons announcement. Their paper is the report of their first year's efforts and was presented at a cold fusion symposium at the World Hydrogen Energy Conference #8 on July 23, 1990.

### THE ELECTROCHEMICAL CELL

As noted in the paper, the use of LiD provides not only a deuterium source but also a reducing environment which will prevent the formation of hydrogen-impeding oxide surface layers on the electrode. However, the deuterium will be transported into the Pd electrode in the form of  $\underline{D}$  rather than  $D^+$  ions. As a result, the Pd (or Ti) must be the **anode** of the cell, rather than the cathode as in previous cells using  $D_2O$ . *Fusion Facts* apologizes for having initially assumed in our August issue that the Pd was used as the cathode!

The use of an inert atmosphere, as described in the paper, is also necessitated by the reducing environment. We were privileged to view the experimental arrangement used by Liaw et al. Their experiments are performed in a large glove box under an argon atmosphere. An argon-flushed airlock is provided for the introduction of tools, chemicals,



and experimental apparatus into the glove box. The isoperibolic calorimeter, together with its fifty-watt electric band heater is, of course, in the argon atmosphere.

When melted, the LiCl-KCl mixture yields  $\text{Li}^+$ ,  $\text{K}^+$ , and  $\text{Cl}^-$  ions in proportions corresponding to the eutectic composition (approximately 48% KCl, 52 % LiCl). The voltage applied to the cell is kept below the level at which the chlorine is evolved as a gas. The eutectic mixture is used because it has the lowest melting point (approximately 350°C); other compositions could be used but would initially require additional heating. (Also, note that in such cases partial melting would not yield a melt with the same composition as the bulk salt.)

Since LiD is simply the deuterium version of lithium hydride, it will dissociate to give  $\text{Li}^+$  and  $\text{D}^-$  ions. Other hydrides, which could presumably also be used, are formed with other Group I and II elements such as Na and Mg, either alone or in combination (for example, NaH and  $\text{LiAlH}_4$ ).

Dr. Liaw informs us that the solubility of LiD is such that only about 0.1g dissolves in the melt (which occupied a volume 1 3/4" in diameter and 1" high, or about 40 ml). However, a large excess (5 g) was added since the dissolved LiD is continually incorporated in the electrodes by the operation of the cell (see the reaction equation in section 2 of the paper). The additional LiD thus dissolved during the course of the experiment, and when all of this LiD was consumed the experiment terminated (after 190 hours, as shown in Fig 8).

## HEAT PRODUCTION

Four of the figures in the paper deal with the Ti-D system, showing the relatively weak effect obtained. In contrast, Figure 8 clearly shows the production of excess heat in the Pd-D system, **despite the fact that the vertical scale is only one-tenth that of the corresponding Ti figure (Fig. 5)**. Figure 7 also provides dramatic visual evidence of the excess power production in the Pd-D system. The charging uses only a small amount of additional power but produces large increases in cell temperature.

The relative heat excess, averaging as much as 1500% over tens of hours at about 700 mA/cm<sup>2</sup>, is in marked contrast to previous cold fusion experiments, which have typically provided only a few percent of average excess power, or a few tens of percent during bursts. The magnitude of the excess power is also large, up to 25.4 W, or 627 W/cm<sup>3</sup> of Pd, as is the total excess over the course of the experiment.

In Figure 8, it is also interesting to note the very linear relationship of the excess power in this system to the

current, which can now be seen quite clearly due to the larger and steadier heat output.

Current	Input Power	Output Power	Excess Power	Ratio*
2.5	69	69	0	-
290	69.7	79	9.3	0.032
420	70.2	83	12.8	0.030
692	71	96	25	0.036

\*Excess Power / Current Density (Watts / mA/cm<sup>2</sup>)

Eagleton and Bush [1] and others have also previously reported moderate increases in excess heat with increasing current density. However, this is in contrast to Fleischmann and Pons' report that excess power in their cell appeared at least proportional to the square of the current [2]. As Fleischmann and Pons have suggested the cause to be a threshold effect at low current densities in D<sub>2</sub>O, it is conceivable that a lessened threshold in a molten salt system is responsible for this difference. (This would also be consistent with the apparently less burst-like nature of the excess heat curve.)

It is also worth noting that the onset of excess heat production was rapid once the current was raised. Again, this is in contrast to a number of previous experiments. (Also, note that part of the time which was required for the power to rise after increases in the current density would be due simply to the fact that charging of the Pd will not be instantaneous.)

Furthermore, Dr. Liaw indicates that no special efforts were required to trigger the heat production. For example, while the variability of the input power shown in Figure 5 for the Ti system might suggest that continual perturbations were used as a trigger, this variability actually represents slight changes made in the heater power in order to maintain a constant cell temperature. Thus, as the temperature and cell current were kept constant, the fluctuations in the measured potential presumably simply reflect changes in the electrode and electrode surface, as have been noted in the D<sub>2</sub>O system during gas evolution.

Owing to uncertainty as to the nature of the cold fusion reaction, it has not previously been clear whether the net effect of higher temperatures should theoretically be to increase the reaction rate - for example due to kinetic effects - or decrease the rate - for example due to the lower solubility of deuterium in metals at higher temperatures. (Although the authors note that the deuterium activity increases dramatically with the increasing temperature **for a given D/Pd ratio**, such higher temperatures would lead to lower equilibrium D/Pd ratios were it not for the electrochemical loading.) As the

temperatures previously attainable have been limited by the boiling point of D<sub>2</sub>O (at 1 atmosphere pressure), it has also been difficult to test the effect of temperature experimentally. This paper now clearly suggests that the nuclear reaction rate may increase quite significantly with temperature.

However, it will still be important to test the effect of temperature changes in the molten salt system itself to determine whether the increase is indeed due to temperature. If the rate does not continue to increase markedly as the temperature of the molten salt is raised, several alternate explanations for the greater excess heat in this system are also possible:

First, screening effects for the D<sup>-</sup> ions (reduction of the effective Coulomb barrier) may be more advantageous than for D<sup>+</sup>, as suggested by the authors.

Second, the Pd surface will be altered in a completely different fashion - for example, impurities of other metals such as silver or iron in the solution would not be deposited on its surface because it is used as the anode rather than the cathode; indeed the surface will be cleaned by anodic stripping.

Third, some other feature of the cell may cause more frequent (or continuous) heat production rather than intermittent bursts. As noted previously, the excess power level (as shown in Figure 8) shows variations, especially noticeable at high current densities, but the burstlike nature seen in a number of previous experiments is not evident. (Although data points in Figure 8 were taken at 3-hour intervals, these values represented instantaneous measurements rather than averages of the data for a 3-hour period. Thus, they should still be indicative of the short-term variability of the power output.)

Repetition of the experiment in a closed cell, which will decrease uncertainties in the calorimetry results even further, is also contemplated by the authors. For example, the cell could be provided with a flow-through heat exchanger in the form of a coiled tube. It is expected that under proper operating conditions, the heater could be turned off and the cell maintained at an appropriate temperature by its own nuclear-generated heat. For operation over longer periods of time, a means of periodically introducing additional LiD may also be necessary.

Another potentially promising line of research would involve the testing of anodes of different sizes. The use of larger anodes, for example, has been stressed by Drs. Arata and Zhang [3], who state that based on their data, "using a small cathode in cold fusion research is a fatal mistake". In fact, one approach might be to use a Pd

anode large enough to bond to or be part of the heat exchange system for the needed calorimetry work.

## COMMERCIALIZATION

The commercial significance of the ability to operate at elevated temperatures and to generate more than 300% of excess heat has been discussed in the August issue of *Fusion Facts*. However, a major issue which will need to be addressed is the need for frequent regeneration of the electrodes. (See the equations in section 2 of the paper). As noted in the paper, the Al electrode was continually replenished during the experiment, and the experiment terminated after 190 hours when all of the LiD had been incorporated into the electrodes.

Nevertheless, this factor should not prevent economic development of the molten salt process, as the excess heat is far more than would be needed to provide the energy needed for the regeneration, even at quite low efficiencies. (Expressed in calories, the 6.26 MJ/mol D<sub>2</sub> excess heat produced would be 1500 kcal/mole D<sub>2</sub>, or 262,000 kcal/mole Pd, several orders of magnitude greater than the delta G values of the reactions involved.) If regeneration is to be performed, it may also be necessary to optimize the system to minimize physical degradation of the electrodes with repeated cycling.

The chemicals produced should not represent an environmental hazard. Corrosion (frequently severe in chloride solutions, especially at high temperature) should also not be a problem in the cell itself due to the reducing nature of the system; however, the salt's vapors will be corrosive.

## NUCLEAR PRODUCTS

Tritium and neutron production have not yet been accurately measured. However, the number of fusions responsible for the measured heat output can be estimated.

Assuming the reaction to be  $d + d \rightarrow t + p$  ( $Q = 4.03$  MeV,  $1$  MeV =  $1.602 \times 10^{-13}$  J), 25.4 W of excess heat would correspond to a fusion rate of  $3.93 \times 10^{13}$  /sec, or  $2.34 \times 10^{-8}$  /d-d pair if we assume a D/Pd ratio of 1. The total number of fusions corresponding to 5.02 MJ would be  $7.77 \times 10^{18}$ , or 1 in every  $2.3 \times 10^5$  deuteriums present (based on 5 g of LiD). If 1% of the fusions yield tritium, and the neutron/tritium ratio is  $10^{-8}$ ,  $8 \times 10^{16}$  tritium atoms and  $8 \times 10^8$  neutrons would have been produced. (All of the preceding values will be less if the Q of the reaction is actually higher - for example, if the reaction is  $d + d \rightarrow {}^4\text{He}$ , ( $Q=23.85$  MeV), they will be 5.9 times less.)

Liaw et al have previously indicated that more sophisticated neutron measurements are being considered. (Previous neutron measurements using a geiger counter were negative. However, as neutrons do not cause primary ionization, the neutron detection efficiency of geiger counters and similar instruments is quite low, especially for thermalized neutrons.)

Neutron measurements, besides providing an independent confirmation of the nuclear nature of the phenomenon, should provide information on short-term fluctuations in the fusion rate. (Sufficiently short-term changes would not be reflected in the temperature because of the thermal inertia of the cell.) In particular, if it is found that the neutron production still occurs in bursts, the relation between the burst duration and the time between bursts would suggest how much of an increase in the power production might be attainable by achieving continuous fusion.

#### USE OF OTHER METALS

The authors point out that "there are many other transition metals [besides Pd and Ti] and their alloys that can absorb substantial amounts of hydrogen and its isotopes." The reducing environment provided by the molten salts approach should now provide an environment in which the use of such metals as electrodes can be tried. Previous issues of *Fusion Facts* have provided many references to papers in which metal hydrides were discussed, such as ZrV<sub>2</sub>, TiCu and Mn-Er-Fe alloys. An additional reference which gives an overview of the many types of hydrides is B.L. Shaw, *Inorganic Hydrides*, Pergamon Press, Oxford, 1967.

In particular, it should be possible not only to retest Ti but also to test other less expensive metals, and to see whether other metals give significantly better results than even Pd. Such work should also make it possible to establish whether or not certain characteristics of Pd, such as its tendencies to explosively exhaust deuterium and thus rapidly contract when slightly supersaturated, play an important role in the cold fusion process, as has been suggested by some researchers. [for example 4]

#### REFERENCES CITED

It is worth noting that this paper is based on work in electrochemical hydrogen storage in metals originally done at Stanford in the 1980s under the direction of Dr. Huggins. Thus, references 3, 4, 6 and 7 cited in the paper may also be of particular interest.

Reference 3 (Luedecke et al) describes the earlier use of a lower-melting-point organometallic salt, NaAlEt<sub>4</sub> (Et =ethyl), and NaH in hydrogen-storage experiments. (The

metals investigated were alloys of Mg with Cu, Ni and Al; all formed MgH<sub>2</sub>, and the Ni alloy also formed Mg<sub>2</sub>NiH<sub>4</sub>.)

Reference 4 (Luedecke et al) reports on the same work, but discusses in more detail how this process prevents oxide and hydroxide layers from forming on the anode, and will eventually remove any already present.

Reference 6 (Liaw) is reviewed below. See page 13.

Reference 7 (Deublein and Huggins) investigates Ti, V and Pd. The rationale for the use of hydrides to introduce hydrogen into the anode of an electrochemical cell is explained in the greatest detail, and sample calculations of the voltages required to render various metals immune to oxidation in a cell are shown. Excerpts from this paper can be found immediately following on page 12.

Reference 10 (Levine and Weale) also provides historical data, including an early note pointing out that H/Pd ratios significantly greater than the expected 0.6 (or measured 0.69) for Pd in equilibrium with hydrogen gas at STP can be achieved by electrolysis. (Figure 1 in the Liaw et al paper, which is taken from Levine and Weale, also shows the range in which the alpha and beta phases of PdH<sub>x</sub> coexist, beneath the dotted line in the lower left. These phases, with different H/Pd ratios, can coexist with each other at lower bulk loadings, i.e. H/Pd<sub>av</sub> < 0.5).

[1] Robert T. Bush (Cal Poly), "Isotopic Mass Shifts in Cathodically-Driven Palladium Via Neutron Transfer Suggested by a Transmission Resonance Model to Explicate Fusion Phenomena (Hot and Cold) Within a Deuterated Matrix," *Proceedings of the First Annual Conference on Cold Fusion*, March 28-31, 1990, Salt Lake City, UT, pp 213-228.

[2] Martin Fleischmann et al (U of Utah), "Calorimetry of the Palladium-Deuterium-Heavy Water System," *J. Electroanal. Chem.*, Vol 287, 1990, pp 293-348.

[3] Yoshiaka Arata (Kinki U) and Yue-Chang Zhang (Osaka U), "Achievement of an Intense Cold Fusion Reaction," *Fusion Technology*, Vol 18, No 1, August 1990, pp 95-102.

[4] E. Tabet and A. Tenenbaum (Lab. Fis. Inst. Rome), "Nuclear Reactions from Lattice Collapse in a Cold Fusion Model", *Physics Letters A*, Vol 144, No 6-7, 1990, pp 301-305, 1990.

## REVIEWS OF REFERENCES CITED

Gerhard Deublein and Robert A. Huggins (Stanford), "Hydrogen-Transparent Metal Surfaces Produced By Use of Molten Salts With Very Low Oxygen And Water Activities", *J. of Electrochem. Soc.*, Vol 136, p 2234 (1989).

### ABSTRACT

One can employ simple thermodynamic principles to predict conditions under which metals will not form hydrogen-blocking surface oxide layers in electrolyte environments. These principles are used to show that very low oxygen and water activities can be produced in some halide-based molten salt systems by the incorporation of alkali hydrides. Under these conditions, some normally very reactive metals will not form oxide surface layers. As a result, rapid interfacial and surface/bulk equilibria with hydrogen can be attained. Experiments are presented that verify these principles in the titanium-hydrogen and vanadium-hydrogen systems by using electrochemical methods to measure the thermodynamic and kinetic aspects of the solution of hydrogen and the formation of metal hydrides. In addition, it is shown that interfacial equilibrium is obtained very rapidly upon iron and aluminum in such metals.

### DISCUSSION

The authors state, "It is known that the rates of reaction of hydrogen with metals or alloys depend strongly on their surface condition. Effectively clean surfaces, i.e., free of electronically insulating oxide or other contamination products, are required in order for H<sub>2</sub> to react rapidly with, or diffuse into, metals and alloys. **In aqueous solutions essentially only noble metals, or metals protected with hydrogen-transparent layers of other metals such as palladium or certain intermetallic compounds that are immune to reaction with this environment and thus do not form blocking interfacial oxide layers, can be used.** Examples of the latter are the phases LaNi<sub>5</sub> and NiTi, in which the major component, i.e., Ni, is thermodynamically stable against reaction with water and against oxidation in the presence of high hydrogen activities."

In addition, Deublein and Huggins note that "Immunity or mobility is not an absolute property of metals or alloys, but depends on their environment. Thus any metal can be made immune or noble when in contact with a liquid essentially devoid of its ions and at potentials more negative (more reducing) than that at which its oxidation occurs."

In sample calculations they "consider vanadium and titanium, which are not stable against oxidation in water at ambient temperature. They can, on the other hand,

have clean reaction-product free surfaces in chloride melts, provided that the oxygen and water activities are sufficiently low."

"Thus a sample of vanadium will be immune in the chloride salt at any potential lower than 1.383 V with respect to lithium, or lower than -2.254 V with respect to unit activity chlorine at that temperature."

Similarly, the authors consider the case of hydrogen, existing in the form of hydrides in molten salts. "Hydrogen, with an intermediate electronegativity of 2.1 eV, is amphoteric. When LiH is dissolved in a LiCl, KCl melt it ionizes to form Li<sup>+</sup> and H<sup>-</sup> species. Therefore, this salt can act as a hydrogen-transporting electrolyte, with the hydrogen moving as H<sup>-</sup> ions. An analogous NaAlEt<sub>4</sub> molten salt containing hydride ions resulting from the solution of NaH has been successfully employed in prior studies of the reaction of hydrogen with magnesium alloy hydride systems. The range of stability of unit activity LiH can be calculated from its Gibbs free energy of formation. It is found to be 0.370V at 700K. Thus unit activity (saturated) LiH is stable within a LiCl, KCl molten salt electrolyte over the range from 0 to 370 mV positive of unit activity Li at that temperature. Thus, when LiH is dissolved in the chloride melt, it forms an electrolyte in which metals like vanadium and titanium are forced to be immune."

Deublein and Huggins also note that "experimentally it may be advantageous to enhance the removal of surface oxide layers by electrodepositing pure lithium on the metal surface to drive the oxygen and water activities to their lower limits, rapidly forming soluble lithium oxide."

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## LIAW DISSERTATION

Bor Yann Liaw (U. Hawaii), Several Materials Aspects of Advanced Lithium- and Hydrogen-based Electrochemical Systems. A Dissertation Submitted to the Department of Materials Science and Engineering of Stanford University for the Degree of Doctor of Philosophy, February 1988. [Available from U.M.I. Dissertation Services, 300 N. Zeeb Road, Ann Arbor, Michigan 48106, Phone (800) 521-0600. Order Number 8815019.]

### ABSTRACT

Energy storage and conversion technology has been drawing scientists' attention for decades; especially important are rechargeable batteries and fuel cells. Some recent developments have been aimed toward all-solid lithium batteries and hydrogen-based energy conversion systems. Work on rechargeable lithium batteries has included major research and development activities on all three components, positive and negative electrode

materials, and electrolytes. On the other hand, for hydrogen-based energy storage and conversion systems, the most urgent needs involve suitable electrolytes, especially for use at elevated temperatures.

In this work, a prospective positive electrode material based on lithium vanadium oxides has been explored. Also, some work has been done on a glassy lithium solid electrolyte based on the lithium sulfide and silicon disulfide system, known as one of the best room temperature lithium conductors.

Lithium reacts with lithium vanadium oxides topotactically and reversibly over a wide range of composition. Therefore, it may be interesting to employ such a material in lithium rechargeable electrochemical cells. The electrochemical behavior of the gamma-phase in this family has been studied, and is discussed in terms of thermodynamic and structural considerations. Strikingly, metastable topotactic reactions were observed at low temperatures, in contrast to the high temperature displacement reactions.

Among the best lithium conductors at room temperature found to date, are glassy materials based on the lithium sulfide and silicon disulfide system. They are being considered for use as solid electrolytes in rechargeable all-solid lithium cells. However, the compatibility of these materials with potential electrodes is important for their practical use, and should be understood. Thus, the electrochemical stability ranges of such materials have been estimated from measurements on the related crystalline phases.

In addition, a novel concept using thermodynamic considerations as general guidelines to control the electrolyte environment in electrochemical cells used to study and modify materials properties in some metal-hydrogen systems is discussed. Metal-hydrogen systems have been proposed as prospective candidates for energy storage media or as electrode materials in energy conversion devices. Stable electrochemical cells have been constructed to investigate the thermodynamic and kinetic properties of hydrogen-transporting materials, and to study their potential for future practical applications. Two examples of such potential applications, involving materials and configurations for selective hydrogen sensing, and the employment of a novel solid/liquid/solid (S/L/S) composite as a pseudo-solid electrolyte, are also presented.

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The thesis has 80 figures and 14 tables.

#### EDITORS' COMMENTS

Those who tried to replicate the original Fleischmann-Pons experiment sometimes complained about the lack of

sufficient information. We have tried to add to this first publication of the report on Liaw and Liebert's invention sufficient information from the cited references to at least outline the type of scientific experimental and theoretical work that led to the remarkable results shown by Liaw et al.

As indicated above, this dissertation discusses general thermodynamic and kinetic considerations, regarding hydrogen uptake by metals, and applications to batteries, fuel cells, and hydrogen sensors. However, the last chapters deal with the use of electrolytic cells containing molten KCl/LiCl salts with LiH; anode materials in this section include Ti, V, and to a lesser extent Pd. Liaw also mentions but does not discuss the use of other hydrides (such as organometallics) and other salts (such as KI/Li).

It is especially important to point out that working with molten salts, lithium deuteride, and palladium is not simple. Considerable care must be taken to keep oxygen and moisture out of the electrochemical cell. In addition, it is important to understand that successes are strongly dependent on the both the surface and bulk condition of the palladium anode. The concept that nuclear reactions can occur in a metal lattice is so new and so little understood that no one is fully prepared to define just what type of palladium preparation works best.

Incidentally, Liaw notes that few metal oxides are stable at the oxygen activities produced by the hydride addition (on the order of  $10^{-33}$ ). However, note that the rate of removal of previously formed oxides will vary depending on kinetic rather than thermodynamic factors. Thus, Liaw notes that in such cases electroplating of Li onto the metal surface (to form soluble  $\text{Li}_2\text{O} + \text{H}_2$ ) can be used to rapidly clean the surface.

It is fortuitous that Dr. Robert T. Bush has been able to complete his theory paper (reviewed in this issue of *Fusion Facts*) in the same time period. Even scientists should be grateful for synchronicity. It is suggested that Dr. Bush's model should be carefully reviewed and the concepts considered for guiding experimental replication of the molten salt electrochemical fusion cell.

\* \* \* \* \*

#### B. SURVEY OF NUCLEAR BYPRODUCTS

By Dennis Cravens, Michael Dehn, Samuel Faile, and Hal Fox

The following survey paper was prompted by the ever-growing number of groups (and publications) reporting nuclear effects in deuterated solids. This review does not report on experiments where excess heat only is reported. However, it does include marginal nuclear

reports. This survey is not intended to be a definitive work - i.e. it is neither complete nor error-free. However, we hope that it may provide a convenient preliminary set of references to which papers presented at the Anomalous Nuclear Effects Workshop can be related.

We invite your corrections, comments, and additions. We would also welcome any input on possible improvements to the format for future survey updates.

Finally, we would greatly welcome any future information on your progress. We especially need material from countries outside the U.S. The information which we have been getting from our correspondents and others has been greatly appreciated.

Note on conversion factors:

1) 1 Curie (Ci) =  $3.7 \times 10^{10}$  Becquerel (Bq), where 1 Bq = 1 disintegration/second. Thus, for tritium, 1 Bq =  $5.61 \times 10^8$  atoms and 1 disintegration/minute (dpm) =  $9.35 \times 10^6$  atoms.

2) In the case of neutrons, calculated production rates will be count rates/detector efficiencies.

#### ARGENTINA

U Nacional de Cuyo, Rio Negro [G-6, G-7]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (wire and plate), 0.1 M LiOD or LiD(?), Pt anode, alternating 0 and 30-90 mA/cm<sup>2</sup>

**NEUTRONS:** calculated production 0.3 n/sec; 2X (= 3 sigma above) background in multiple runs in 4 of 4 cells; 6 sigma above background for combined signal; no effect with H<sub>2</sub>O; using 18 <sup>3</sup>He counters with paraffin moderator (efficiency = 17.5%).

**TIME COURSE:** some correlation with electrolysis conditions

#### BRAZIL

U of Sao Paulo [Misc-2]

**NEUTRONS:** yes

#### CANADA

U of Ottawa [A-1]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (6 mm diam. X 2 cm), 0.2 M LiOD, Pt anode

**ISOTOPIC RATIO CHANGES?:** possible slight change in <sup>6</sup>Li/<sup>7</sup>Li ratio.

**OTHER:** Heat also.

#### CHINA, PEOPLE'S REPUBLIC OF

Beijing Normal U [Z-2]

**NEUTRONS:** in each of 5 runs, intermittent

**TRITIUM:** in each of 5 runs

Chengdu Science & Technology Inst. [G-2]

**HELIUM:** yes

**OTHER:** heat also.

China Engineering Physics Institution [G-1]

**NEUTRONS:** yes

Chinese Academy of Science [C-1]

**NEUTRONS:** yes

**OTHER:** Heat also

Nanjing U. Nanjing [W-5]

**NEUTRONS:** yes

**GAMMA RAYS:** ?

**OTHER:** heat also?

Nuclear Energy Inst., Shichuan and Beijing [D-5, W-4]

**NEUTRONS:** yes

Qinghua U. Beijing [Z-3]

**NEUTRONS:** yes

**TRITIUM:** yes

Southwest Nuclear Phys. & Chem. Inst., Shichuan [X-1]

**NEUTRONS:** yes

Xiamen U [T-5]

**NEUTRONS:** yes

#### CHINA, REPUBLIC OF TAIWAN

National Tsing Hua University, Hsinchu [Y-2]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode, 0.1 M LiOD

**TRITIUM:** approx. 10-100 X increases in 6 of 6 cells

**OTHER:** heat also

#### GERMANY

Dresden U of Technology [B-3]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (slab and 22.6 mm diam. X approx. 1.9 cm), 3 M LiOD, Pt anode

**NEUTRONS:** calculated production approx. 0.1 n/sec, max. 20 counts/hr over 12 hrs, 3/hr over 100 hrs; by scintillation (effic. approx. 3-5%)

U of Kiel [A-6]

**NEUTRONS:** yes

**TRITIUM:** yes

Affiliation unknown [F-3]

**CONDITIONS:** cluster impact- deuterated target bombarded with D<sub>2</sub>O clusters

**CHARGED PARTICLES:** 3 MeV protons

**INDIA**

Bhabha Atomic Res. Ctr. (BARC) [I-3, I-4, S-10, S-12]

**CONDITIONS #1:** electrolysis - D<sub>2</sub>O, Pd cathode (16 tubes, 3 mm diam. X 20 cm), 5 M NaOD, 200 mA/cm<sup>2</sup>

**NEUTRONS:** calculated production  $4 \times 10^7$  in 4 hrs; using 3 BF<sub>3</sub> counters with paraffin moderator (0.06% effic.) and 1 scintillator (0.4% effic.), also 3 <sup>3</sup>He counters with paraffin moderator for background measurements. Latter also showed slight increased count rate during burst consistent with their distance from the cell. Max. counts  $1.8 \times 10^4/5$  min on BF<sub>3</sub> and  $2.6 \times 10^4/5$  min on scintillator, vs approx. 65 and 650 background counts, respectively

(= 300 X and 40 X background)

**TRITIUM:**  $8 \times 10^{15}$  atoms (= 20,000 X background) in 72 hours; by scintillation

**TIME COURSE:** Multiple neutron bursts, beginning within 1 hr. Small burst also reported 2 days after cell turned off. 10-25% of neutrons in groups of 100 or more. Tritium decreasing after bursts.

**COMMENTS:** Unusually large amount of Pd used (7 cm<sup>3</sup>). n/t branching ratio  $10^{-8}$ .

**CONDITIONS #2:** electrolysis - D<sub>2</sub>O, 5 Pd-Ag cathodes (each 78 cm<sup>2</sup> X 0.1 mm sheet), 5 M NaOD, approx. 650-750 mA/cm<sup>2</sup>, Ni anode

**NEUTRONS:** max. burst of 39,000 counts/100 sec (= approx. 125-150 X background on each of 2 detectors), with estimated total production =  $4.5 \times 10^6$  neutrons (based on calibration source); using same counters as #1

**TRITIUM:**  $4 \times 10^{15}$  atoms (=> 3500 X excess after 50 hrs)

**TIME COURSE:** neutron burst after 4 hours

**COMMENTS:** Unusually large amount of Pd used (5 cm<sup>3</sup>). n/t ratio  $10^{-9}$ .

**CONDITIONS #3:** electrolysis - D<sub>2</sub>O, Ti cathode (22 mm diam. X 15 cm), stainless steel anode, 5 M NaOD, < 600 mA/cm<sup>2</sup>

**NEUTRONS:** max. 2-1/2 X background (max. 59 counts/sec vs 24/sec bkg), calculated total production =  $1.3 \times 10^7$  neutrons; using 3 BF<sub>3</sub> and scintillation counters as in #1

**TRITIUM:** approx.  $10^3$  X excess after 8 hrs ( $1.3 \times 10^{14}$  atoms), vs. 1.35 X after 12 hrs using NaOH.

**TIME COURSE:** no sharp neutron bursts. Neutron production declined immediately (but only most of the way to background) when the cell was turned off.

**COMMENTS:** Unusually large amount of Ti used (57 cm<sup>3</sup>). n/t ratio  $10^{-7}$ .

**CONDITIONS #4** (3 groups): electrolysis - D<sub>2</sub>O, Pd (various shapes), 0.1 M LiOD, 60-170 mA/cm<sup>2</sup>, Pt anode

**NEUTRONS:** calculated production up to approx.  $10^{4.5}/\text{sec}$  with total production  $1.8 \times 10^8$ ; using up to 24 <sup>3</sup>He counters with paraffin moderator (effic. 8.6%) and scintillation

**TRITIUM:** up to  $4 \times 10^{14}$  atoms ( $1.25 \times 10^4$  X increase (blank = 170 dpm)

**GAMMA RAYS:** using NaI(Tl), Ge(Li) and HPGe detectors

**TIME COURSE:** neutron bursts lasting 14-20 min over 40hrs, possible correlation with gamma bursts

**CONDITIONS #5:** gas loading of Ti

**NEUTRONS:** up to 2500 counts/sec (vs 1.5/sec background); using 24 <sup>3</sup>He counters with paraffin moderator (effic. approx. 10%)

**TIME COURSE:** neutron bursts lasting up to 45 min., within 15 min. of evacuation

**CONDITIONS #6:** gas loading of Ti (0.2-1.0 g) and Pd (0.1 g)

**TRITIUM:** up to  $6.5 \times 10^{11}$  atoms in Ti and  $1.5 \times 10^{12}$  atoms in Pd-Ag alloy; by autoradiography, scintillation, and Pd X-rays excited by tritium betas; none in undeuterated Ti

**CONDITIONS #7:** gas loading of Pd and Pd-Ag alloy (0.4-20 g)

**TRITIUM:** up to  $2.4 \times 10^{11}$  atoms; by scintillation and autoradiography

**COMMENTS:** high neutron and tritium production in a number of experiments.

Indira Gandhi Centre For Atomic Research (IGCAR), Kalpakkam [M-3]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode, Pt anode

**NEUTRONS:** yes

**TRITIUM:** yes

**OTHER:** heat also

**ITALY**

Casaccia [M-6]

**CONDITIONS:** gas-loaded Ti

**NEUTRONS:** yes

**TIME COURSE:** 1 minute after reheating from 500 to 1000 deg. C

CISE, Milano [S-11]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (50-80 X 15 X 0.4-1.0 mm), 2-3 M LiOD, 300-1000 mA/cm<sup>2</sup>, Pd and Pt anodes

**NEUTRONS:** up to a few times background (max. 16/hr vs 4/hr for a few hours); using BF<sub>3</sub> counter with polyethylene moderator (.019% effic.)

**TRITIUM:** slight excess in 2 of 12 cells; by scintillation

Frascati Res. Ctr. [C-3, D-1, D-2]

**CONDITIONS #1:** electrolysis - D<sub>2</sub>O, Pd cathode (8 mm diam. X 5 cm), 0.1M LiOD, 60 mA/cm<sup>2</sup>

**NEUTRONS:** one burst only

**GAMMAS:** bursts of up to 10 X background, largest with 7250 excess counts (=  $10^{-19}$ - $10^{20}$  fusions/d-d pair/sec); using NaI(Tl) detectors (0.8 and 1.2 MeV thresholds, 140 counts/min background)

**TIME COURSE:** 7 gamma bursts of > 4 X background in a few weeks, lasting up to 15 min

**CONDITIONS #2:** gas loading, Ti and Ti alloys



**NEUTRONS:** 17 bursts in 19 runs (total 2100 hrs), up to approx. 25 counts in 100 microsec bursts; vs. 2 of 9 counts in controls; using 15  $^3\text{He}$  counters (efficiency 15%)

**TRITIUM:** in 5 of 5 tests, up to 4X background ( $= 1.3 \times 10^{10}$  T); by scintillation. Autoradiography also showed hot spots.

**TIME COURSE:** in earlier experiment, n bursts triggered by temperature changes

Istituto di Ingegneria Nucleare del Politecnico di Milano. [P-2]

**CONDITIONS:** electrolysis -  $\text{D}_2\text{O}$ , Pd (3-4 g) and Ti cathodes, 0.1M LiOD, pulsed current (max.  $< 350$  mA/cm $^2$ ), Pt anode

**NEUTRONS:** in 2 of over 100 runs, bursts  $> 4$  sigma (106 counts/2 min); using 4  $^3\text{He}$  counters with paraffin moderator (3.75% effic., background 4/min). During above burst, count rate on detector further from cell 2-1/2 sigma above background.

**OTHER:** 1 neutron burst coincided with deformation of Pd.

Catania [A-4, B-1]

**CONDITIONS # 1:** gas-loaded Pd (1 cm $^2$  X 1 mm)

**CHARGED PARTICLES:** 100 excess counts in 16 hrs with charged particle detector (Si surface barrier detector, efficiency 2.3% for  $> 1$  MeV protons). Maximum in energy spectrum at 1.8 MeV consistent with original proton energy 3.0 MeV. ( $= 10^{-23}$  fusions/d-d pair/sec)

**CONDITIONS #2:** electrolysis -  $\text{D}_2\text{O}$ , Ti cathode, impurities used by Jones, Au anode

**NEUTRONS:** 0.25 counts/sec of 2.5 MeV neutrons; by scintillation (background .08-.16/sec). Moving cell in front of background detector caused it to register.

**TIME COURSE:** max. neutrons after 1 hour, returned to background after 3 hours, in 3 runs

U of Rome [G-4, G-5]

**CONDITIONS:** electrolysis -  $\text{D}_2\text{O}$ , Pd cathode (5 X 6 X 20 mm), 0.1 M LiOD, 200 mA/cm $^2$ , Pt anode

**NEUTRONS:** calculated production  $7.2 \times 10^5$  (36 counts = 150 X background of 3.0 +/- 0.2/hr) in 4 min. burst after 150 hours; up to 7 MeV; using  $^3\text{He}$  counter with polyethylene moderator (effic. 0.005%)

**TRITIUM:** calculated production  $2.14 \times 10^{11}$  T atoms; by scintillation; versus control experiments with Pt and with Pd not generating heat

**TIME COURSE:** simultaneous heat and neutrons after 150 hrs

**OTHER:** heat also

## JAPAN

Chubu U [I-2]

**NEUTRONS:** ?

Hitachi [O-2]

**CONDITIONS:** gas-loaded Ti

**NEUTRONS:**  $> 3$  sigma above background ( $= 1-10$  n/sec calculated) in bursts at -20 deg. C; using  $^3\text{He}$  and  $\text{BF}_3$  counters

Hokkaido U - Matsumoto [M-4, M-5]

**CONDITIONS #1:** electrolysis -  $\text{H}_2\text{O}$ , Pd cathode (50 mm diam. X 5 cm), 3% NaCl, 1 A total current, Pt anode

**GAMMAS:** increase in intensity at energies  $< 130$  KeV; using Ge(Li) detector

**TIME COURSE:** effect began after 11 days, max. at 15, ceased at 17.

**COMMENTS:** Note that effect is reported in absence of deuterium.

**CONDITIONS #2:** electrolysis -  $\text{D}_2\text{O}$ , Pd cathode (5 mm diam. X 5 cm), 3% NaCl, 0.7A total current, Pt anode

**OTHER:** autoradiography showed unique ("iton") particle tracks after 21 days. None in control.

**COMMENTS:** Report of similar tracks in  $\text{H}_2\text{O}$  to be published.

Hokkaido U - Mizuno et al [M-13]

**CONDITIONS:** electrolysis -  $\text{D}_2\text{O}$ , Pd cathode (3 mm diam. X 10 cm), 0.5 M LiOD, Pt anode, 200 mA/cm $^2$

**NEUTRONS:** av. 10 X background, max 20 X background (1140 n/hr), at energy approx. 2.5 MeV, over 18 days ( $= 10^{-23}$  fusions/sec/d-d pair); by scintillation; none in control without current

JAERI [T-1]

**NEUTRONS:** ?

Kinki U and Osaka U [A-8, A-9, A-10]

**CONDITIONS:** electrolysis -  $\text{D}_2\text{O}$ , Pd cathode (20 mm diam. X 5 cm), dilute LiOD, up to 500 mA/cm $^2$ , Pt anode

**NEUTRONS:** calculated production rate up to  $10^8$ /sec, over  $10^{13}$  total neutrons in 1 of 2 cells, but only several times background in other; using 2  $\text{BF}_3$  and 1  $^3\text{He}$  counter (background 5-40 counts/hr)

**TIME COURSE:** 10 groups of n bursts in 1 month, lasting 1/2 to 40 hrs, up to  $10^{13}$  n each, after several days

**OTHER:** Heat also.

**COMMENTS:** Especially high neutron production. Rapid changes in deuterium loading.

KURRI [M-1]

**NEUTRONS:** ?

Kyushu U [F-4]

**NEUTRONS:** yes

Nagoya U [W-1]

**CONDITIONS:** gas-loaded Pd, 12 kV AC current

**NEUTRONS:** 2 bursts, 11-14 counts/sec for up to 63 sec, =  $2 \times 10^4$  X background of 2/hr; using  $\text{BF}_3$  counter

**TIME COURSE:** neutrons correlated with stimulations

**COMMENTS:** Especially high neutron production. Rapid changes in deuterium loading.

NESI [I-1]

**NEUTRONS:** yes

**TRITIUM:** ?

NTT Basic Research Labs, Tokyo [Y-1]

**CONDITIONS:** gas-loaded Pd coated with Au on 1 side, Mn and O on other

**NEUTRONS:**  $1-2 \times 10^6$ /sec

**TIME COURSE:** burst when pressure was reduced

**OTHER:** heat and bending of Pd also

**COMMENTS:** Especially high neutron production, Rapid changes in deuterium loading.

Osaka Prefecture Radiation Research Institute, [T-4]

**CONDITIONS:** electrolysis of Pd (22 mm diam. foil and coatings) in  $D_2O$ , 0.1 M LiOD or LiCl, Pt and Au anode, up to 100 mA/cm<sup>2</sup>

**CHARGED PARTICLES:** bursts significantly above background (average up to approx. 10 counts/hr with bursts to > 100/hr, vs 1/hr background > 0.67 MeV), = >  $10^{20}$  fusions/sec/d-d pair) in 6 of 30 runs, consistent with proton energies 3 MeV and less, vs none in  $H_2O$ ; using Si surface barrier detector (38% effic.)

**TIME COURSE:** bursts after several hours to several days

Osaka U [T-3]

**CONDITIONS:** electrolysis -  $D_2O$ , Pd cathode, 1 M  $Li_2SO_4$  or LiOD, alternately 400 and 800 MA total current

**NEUTRONS:** max. 15 n/sec; sharp peak at approx. 2.45 MeV, broad peak at 3-7 MeV

**TRITIUM:** 3X background

**TIME COURSE:** neutrons correlated with electrolysis conditions, also some correlation with T.

**OTHER:** n/t branching ratio  $10^{-5}$ .

PRC [W-3]

**TRITIUM:** ?

TIT [O-1, T-2]

**NEUTRONS:** yes in both cases

Tokai U [S-1]

**NEUTRONS:** yes

Tokohu U [N-1]

**NEUTRONS:** yes

## MEXICO

Mexican Institute of Petroleum [M-2]

**TRITIUM:** 25 X excess (2200 dpm/ml, vs 85 dpm/ml background) after 90 hrs in 1 of 3 cells

**TIME COURSE:** tritium did not appear until after 20 hours

U of Mexico [Misc-3]

**TRITIUM:** yes

## POLAND

Institute of Plasma Physics [Misc-1]

**NEUTRONS:** yes

## SPAIN

University of Madrid [S-2]

**CONDITIONS:** electrolysis -  $D_2O$ , Ti cathode (15 X 15 X 1 mm) in  $D_2O$ ,  $Li_2SO_4$ , Pt anode

**NEUTRONS:**  $3 \times 10^5$  in 7.59 hours (= 3000 X background of 1-2 counts/hr); using  $BF_3$  counter; count rate repeatably dropped when cell was removed and climbed when cell was returned

**TRITIUM:** increase from approx. 1050 to 1450 cpm in 700 hrs, compared with control experiment with no neutron generation; by scintillation

**GAMMA:** bursts a few times background (ex. 38.5 cpm vs. 15.5 cpm background)

**TIME COURSE:** neutrons in bursts; required 2 hours to drop to background after cell turned off. Some correlation of n, T, gamma

## SWEDEN

Royal Institute of Technology [Misc-2]

**NEUTRONS:** yes

## UNITED STATES OF AMERICA

AT&T [R-1]

**NEUTRONS:** yes

Brigham Young U - Jones et al [J-1] (see also B-1, M-10)

**CONDITIONS:** electrolysis -  $D_2O$ , Pd (foil or 5g bulk) and Ti (1-3g) cathodes, complex mixture of inorganic salts, up to 500 mA total current

**NEUTRONS:** up to 5 sigma above (3-1/2 X) background of  $10^3$ /sec at 2.5 MeV in 11 of 14 runs (total 200 excess counts in 14 runs = 2/hr or  $4.1 \pm 0.8 \times 10^{-3}$ /sec, =  $10^{23}$  fusions/d-d pair/sec); approx. 2.5 MeV; using scintillation and  $^6Li$  capture (effic. 1%). No effect with  $H_2O$  or no current

**TIME COURSE:** neutron count increasing after 1 hour, decreasing after 8.

Brookhaven National Lab. - Beuhler et al, [B-2]

**CONDITIONS:** cluster impact of  $D_2O$  on 1 cm<sup>2</sup> Ti

**CHARGED PARTICLES:** 3.0 MeV protons and apparently also 1 MeV tritons =  $10^{14}$  fusions/d (0.05-0.1 fusions/sec for  $10^{-8}$  -  $10^{-9}$  A beam) with cluster energy 300 KeV; using Si solid state detector

**COMMENTS:** max for 150 D<sub>2</sub>O/cluster; none below 20 D<sub>2</sub>O/cluster; broad shoulder to 1000 D<sub>2</sub>O/cluster

Brookhaven National Laboratory - McBreen [M-7]

**TRITIUM:** 4X10<sup>5</sup> dpm/ml

**OTHER:** heat also?

Case Western Reserve [A-2 & A-3, L-1]

**CONDITIONS #1:** electrolysis - D<sub>2</sub>O, Pd cathode (0.5-4 mm diam. X 5-10 cm), 0.1-1.0 M LiOD, up to 400 mA/cm<sup>2</sup>, Pt and Ni anodes

**NEUTRONS:** ?

**TRITIUM:** Up to 50 X background, = 1730 dpm/ml, in 6 cells; by scintillation; confirmed by 3 other labs

**TIME COURSE:** tritium occurred after several weeks, levels dropped afterwards.

**OTHER:** Heat also.

**CONDITIONS #2:** electrolysis - D<sub>2</sub>O

**NEUTRONS:** bursts

Colorado School of Mines [C-2]

**CONDITIONS:** ion implantation in Pd foil, up to 8000 mA/cm<sup>2</sup> Charged particles: 30 excess counts/day, 5 MeV and possibly 3 MeV; using surface barrier detector. Intensity proportional to current up to 2 A/cm<sup>2</sup>, less at 8 A/cm<sup>2</sup>; no excess counts with nondeuterated target or no current.

Idaho State U [F-1]

**CONDITIONS:** gas-loaded Ti

**NEUTRONS:** 0.003/sec

Los Alamos National Lab. - Claytor et al [C-4, C-5]

**CONDITIONS:** gas loading of alternating Pd and Si layers. Also Ti (300 g). Pulsed current (up to 3000 V, generally 1 W). **NEUTRONS:** max. 2.5/sec. In an earlier report, calculated production of up to 9.5X10<sup>6</sup>; using 15 <sup>3</sup>He counters with polyethylene moderator (effic. 1.3%); none with H<sub>2</sub>

**TRITIUM:** 10<sup>8</sup> - 10<sup>9</sup> dpm. In earlier report, max. 1300 X background in 96 hrs

**OTHER:** upper limit on n/t branching ratio 3X10<sup>9</sup>. Some correlation of neutrons and tritium. Addition of 5% H<sub>2</sub> was possibly helpful.

**COMMENTS:** High tritium production

Los Alamos National Lab. - Menlove et al [M-10, M-11]

**CONDITIONS:** gas-loaded Ti (chips and sponge, up to 200 g) or Ti+Pd

**NEUTRONS:** In earlier report, 0.05-0.2 counts/sec (11 sigma above background over 12 hours, plus bursts of 10-300 neutrons; detector effic. 19-34%. In later experiment, 5-10X background for many hours (calculated emission rate .001/sec); using up to 51 <sup>3</sup>He counters in polyethylene moderator (total effic. 3.6-44%, background 0.67/hr). Moving sample to different counters caused their count rate to increase.

**TIME COURSE:** became active after 3 weeks, remained active for several days. Usually 1-10 n per burst, occasionally 20-200, in < 200 microsec

**OTHER:** cycled to liquid nitrogen temp. and back. In an earlier test, more n per burst at -30 deg. C.

Los Alamos Nat'l Lab. - Storms & Talcott [S-13, S-14]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd alloy cathodes (coins, strips, 1-2 mm diam. rods), 0.1-0.2 M LiOD, various anodes (Pt, Ni, st. steel)

**TRITIUM:** 1.5-80X enrichment (max. 1.1-1.2X10<sup>4</sup> dpm/ml after 10 days, vs 20 dpm/ml background) in 13 of over 150 cells (> 1500 measurements); no effect in LiOH/H<sub>2</sub>O, or in Ni or Pt controls; by scintillation

**TIME COURSE:** T steady or in bursts, sometimes decreasing levels afterwards; similar cells sometimes started and stopped producing T after similar elapsed times

**OTHER:** Heat also. Tested up to 10% alloying with Li, C, S, B, Be; tested poisoning and surface treatments.

Mississippi State U [G-8]

**CONDITIONS:** ion bombardment of Pd foil and bulk, deuteron energy 1 KeV; control: nitrogen ions

**NEUTRONS:** 8 X background (36±6 counts/2 min vs 4±2 counts/2 min background and 6 counts/2 min control); using BF<sub>3</sub> detector with paraffin moderator

**TIME COURSE:** required several minutes to reach background again after beam off

National Cold Fusion Institute, U of Utah [G-9, W-2]

**TRITIUM:** 100 X background in 1 cell, low level production in others

**OTHER:** heat also

Naval Research Laboratory - Rolison et al [R-2, R-3]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (foil), 0.1M LiOD or Li<sub>2</sub>SO<sub>4</sub>, Pt anode

**OTHER:** possible 100% and 45% enrichments of <sup>106</sup>Pd on Pd surface; also depletion of <sup>105</sup>Pd and <sup>108</sup>Pd?; not seen in blank using H<sub>2</sub>O; using time-of-flight secondary-ion mass spectrometer

**COMMENTS:** Possible ZrO interference in one <sup>106</sup>Pd analysis-experiment being repeated.

Naval Systems, San Diego [S-15]

**TRITIUM:** yes

**X/GAMMA RAYS:** yes

**OTHER:** heat also.

Oak Ridge Nat'l Lab. [S-5, S-6, S-7, S-8; see also B-4]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (2.8-5.8 mm diam. X 8-8.5 cm), 0.1-1.0 M LiOD, 100-800 mA/cm<sup>2</sup>, Pt anode

**NEUTRONS:** up to 2 counts/hr (= 1.7 X background) for up to 350 hrs; by scintillation (1.2 MeV threshold, 0.15% effic.). No increase with LiOH-H<sub>2</sub>O.

**TRITIUM:** in earlier report, up to 25X increase

**GAMMAS:** max. approx. 2.5/min or 20% above background for up to 300 hrs in 2.64-3.12 MeV channel and increases in all channels below 2.12 MeV; by scintillation (effic.  $5.75 \times 10^{-3}\%$ )

**TIME COURSE:** 3 n and 3 gamma events, lasting tens to hundreds of hrs, in 2000 hrs. Some correlation of neutrons, perturbations, heat, gammas. When replaced with LiOH-H<sub>2</sub>O, took well over 100 hrs to return to background. Tritium produced in 2-3 hr burst within 2 days, level declined afterwards

**OTHER:** heat also. Tested effect of perturbations.

Sandia National Laboratory [S-3]

**CONDITIONS:** ion bombardment of Pd

**COMMENTS:** 3 X increase in fusion rate with particular crystallographic orientations. Test suggested by William E. Wells (Miami U at Oxford)

SRI (Formerly Stanford Research Institute) [M-8, M-9]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (.04 mole, 4 cm<sup>2</sup>), 0.1M LiOD, up to 600 mA/cm<sup>2</sup>, Pt anode

**RADIATION:** autoradiography showed hot spots; no controls.

**OTHER:** Heat also.

Texas A&M - Bockris et al [B-5, K-1, P-1]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (1-6 mm diam X 2.5-4 cm), 0.1M LiOD, 50-500 mA/cm<sup>2</sup>; controls: with H<sub>2</sub>O

**TRITIUM:** 10<sup>4</sup> to 10<sup>7</sup> - 10<sup>8</sup> dpm/ml (10<sup>2</sup> to 10<sup>5</sup> - 10<sup>6</sup> X bkg) in 15 of 53 cells, including 9 of 13 with 1 mm rods; by scintillation; beta spectrum also measured; levels also confirmed by Argonne, Batelle, Los Alamos, GM.

**TIME COURSE:** T in bursts after hours, days or months; bursts lasting 5-50 hours with declining levels afterwards. Possible correlation of T and heat.

**OTHER:** Heat also. > 4 mm rods continued up to 6 months; remained negative. Also tested poisoning.

**COMMENTS:** High tritium production.

Texas A&M - Wolf et al, [W-6, W-7; see also B-6]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd (0.5-6.0 mm diam. X 2-4 cm) and Ti cathodes, 0.1 M LiOD, Ni anode, up to 500 mA/cm<sup>2</sup>

**NEUTRONS:** 100/minute. In earlier report, several bursts 3-9 X background of 0.8 counts/min (= calculated emission rate 50 n/hr) in 3 of 200 experiments using same Pd wire; by scintillation (5% effic.); energy consistent with 2.5 MeV. 1/r<sup>2</sup> test showed signal was from cell. Comparison with cosmic ray activity negative. Blank with H<sub>2</sub>O negative.

**TRITIUM:** up to 10<sup>5</sup> dpm/ml; by scintillation; confirmed by energy spectrum

**TIME COURSE:** T decreases noted after bursts

**OTHER:** when neutron burst died down, wiping the wire could cause another burst. n/t branching ratio 10<sup>-8</sup>-10<sup>-10</sup>.

**COMMENTS:** High tritium production.

U of CA, Santa Barbara [M-12]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (0.1 mm diam.), LiOD, Pt anode

**NEUTRONS:** bursts; using 6 <sup>3</sup>He counters

**OTHER:** heat also

U of Florida [S-4]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (buttons), Pt anode

**TRITIUM:** up to 400% excess T in 1 cell (10<sup>5</sup> dpm/ml), 60% in another

**OTHER:** also heat.

**COMMENTS:** High tritium production.

U of Rochester [V-2, V-3]

**NEUTRONS:** yes

**TRITIUM:** yes

U of Utah - Pons and Fleischmann [F-2, see also W-8]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd cathode (sheet, rod, cube), 0.1 M LiOD, Pt anode, up to 512 mA/cm<sup>2</sup>

**TRITIUM:** calculated production =  $1-2 \times 10^4$  atoms/sec for 1 mm diam. X 10 cm rod; by scintillation, confirmed by energy spectrum.

**HELIUM:** apparent 3-10X increase in <sup>4</sup>He (10<sup>13</sup>-10<sup>14</sup> atoms) in electrolyzed Pd vs unused, by 5 labs, in ETEC/Rockwell-organized test

**OTHER:** heat also.

Vernon Regional College [C-6]

**CONDITIONS:** electrolysis - D<sub>2</sub>O, Pd-plated Ti cathode, 0.1 M LiOD

**TRITIUM:** by autoradiography

### U.S.S.R.

All-Union Institute, Monocrystals [S-9]

**TRITIUM:** yes

**HELIUM:** <sup>3</sup>He

Inst. Neftekhim. Sint. Im. Topchieva [G-3]

**CONDITIONS:** gas loading of Pd-Sm and Pd-Ru alloys (2 g powder)

**NEUTRONS:** short burst at 500 deg. C in both (1.8-1.9±0.3 X background), none when H<sub>2</sub> was used; using 12 <sup>3</sup>He counters with moderator (10.5% effic.)

Institute of Physical Chemistry, Academy of Science of the USSR, Moscow [D-3, D-4, L-2]

**CONDITIONS #1:** fracture of D<sub>2</sub>O ice

**NEUTRONS:** yes

**CONDITIONS #2:** Ti chips fractured in D<sub>2</sub>O + LiOD

**NEUTRONS:** yes

**TRITIUM:** yes

**OTHER:** also cooled with liquid nitrogen

Metal Phys. Inst., Kiev [K-2]

**CONDITIONS:** ion bombardment of Ti (500 cm<sup>2</sup>) with deuterium, 9 KeV, up to 1 A total current

**TRITIUM:** yes

**HELIUM:** <sup>3</sup>He

**COMMENTS:** possible <sup>3</sup>H and/or tritium by mass spectrometry?

Moscow State U [K-3]

**NEUTRONS:** yes

**TRITIUM:** yes; by autoradiography

**OTHER:** heat also

Odess. Gos. U [R-4]

**CONDITIONS:** electrolysis - D<sub>2</sub>O+T<sub>2</sub>O, Pd-Ag-Au cathode, 10 mA/cm<sup>2</sup>, 200 V

**NEUTRONS?:** rare events with > 10 MeV neutrons; using track detector

Perm State U [A-5]

**TRITIUM:** yes

Zelenskiy (Kharkov Inst) [Z-1]

**NEUTRONS:** yes

**TRITIUM:** yes

**X/GAMMA RADIATION:** yes

YUGOSLAVIARuder Boskovic Institute [Misc-1]

**NEUTRONS:** yes

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**NOTE:** The phrase "tabulated by Will/Bockris/Fox..." refers to the frequent exchange of lists of cold fusion successes as tracked by Dr. Fritz Will (Director, National Cold Fusion Institute), J.O'M. Bockris (Texas A&M), and Hal Fox (Editor, *Fusion Facts*).

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Michael Dehn and Hal Fox are editors of *Fusion Facts*.

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#### C. OTHER NEWS FROM U.S.

##### CAL POLYTECH- POMONA -BUSH MODEL

Courtesy of Dr. Robert T. Bush

Dr. Robert T. Bush, Professor of Physics, Cal State Polytechnic Univ. at Pomona, has completed his theory paper: The Transmission Resonance Model.

This important theoretical work is reviewed here by permission of *Fusion Technology*. The paper will be published in its March 1991 issue. This review cites theory applications to immediately help experimenters.

Robert T. Bush, "Cold 'Fusion': The Transmission Resonance Model Fits Data on Excess Heat, Predicts Optimal Trigger Points, and Suggests Nuclear-Reaction Scenarios", scheduled for publication in *Fusion Technology*, March 1991, >120 manuscript pages, 27 figs, 90 refs.

#### ABSTRACT

The transmission resonance model (TRM) previously introduced is now combined with some electrochemistry of the cathode surface and found to provide a good fit to

new data on excess heat. For the first time, a model for cold fusion not only fits calorimetric data, but also predicts optimal trigger points. This suggests that the model is meaningful and the excess heat phenomenon claimed by Pons and Fleischmann is genuine. A crucial role is suggested for the overpotential and, in particular, for the concentration overpotential; i.e., the hydrogen overvoltage. Self-similar geometry, or scale invariance, i.e., a fractal nature, is revealed by the relative excess power function. Heat bursts are predicted with a scale invariance in time, suggesting a link between the TRM and chaos theory. The model describes a near-surface phenomenon with an estimated excess power yield of  $1\text{ kW/cm}^3\text{ Pd}$ , as compared to  $50\text{ W/cm}^3$  of reactor core for a good fission reactor. Transmission resonance-induced nuclear transmutation, a new type of nuclear reaction, is strongly suggested with two types emphasized: Transmission resonance-induced neutron transfer reactions yielding essentially the same end result as Teller's hypothesized catalytic neutron transfer, and a three-body reaction promoted by standing de Broglie waves. The cross section  $\sigma$  for the nuclear reaction that is the ultimate source of the excess heat is estimated to satisfy the value range of  $10^{-29}$  approx.  $< \sigma$  approx.  $< 10^{-20}$   $\text{cm}^2$ . Suggestions for the anomalous production of heat, particles, and radiation are given. A polarization conjecture leads to a derivation of a branching ratio of  $1.64 \times 10^{-9}$  for the deuterium-deuterium reaction in electrolytic cold fusion in favor of tritium over neutrons. The model can account for the Bockris curve, in which a lower level production of tritium mirrors that of excess heat. Heat production without tritium is also accounted for, as well as the possibility of tritium production without heat. Thus, the TRM has a high probability for unifying most, in not all, of the seemingly anomalous effects associated with cold fusion.

#### EDITOR'S COMMENTS

*Fusion Facts* has been following the development of Dr. Bush's model with considerable interest since his presentation at the special Cold Fusion Session held in conjunction with the December 12, 1989, ASME meeting [1]. (See page 2, Dec 1989 *Fusion Facts*.) We also were privileged to report on Dr. Bush's presentation at the First Annual Conference on Cold Fusion. [2] (See page 17, April 1990 *Fusion Facts*.)

We wish to thank Dr. Bush for supplying us with an advance copy of his paper and to thank *Fusion Technology* for the permission to provide our readers with the abstract and a review of the paper in advance of publication.

The major sections of Bush's paper are the following:

Introduction  
 Review of the Transmission Resonance Model  
 Maxwell Velocity Distribution  
 Phonon Exchange Effects in the TRM  
 Neutron Emission in Pressurized Gas Experiments (TRM Updated)  
 Electrolytic Cold Fusion Explained by the TRM  
 Nuclear Reactions Suggested by the TRM  
 Tritium Reactions  
 The TRM's Suggestions for the Tritium Puzzle  
 Conclusion

There are several aspects of the TRM that have a direct bearing on cold fusion experiments. The data presented would lead the reader to use the model as a guide in cold fusion experiments. For example, this elaboration on the Bush model now includes the following important factors:

1. The strong role played by "overpotential" (the cathode voltage as viewed by electrochemistry).
2. The importance of the cathode surface (platinum coating and/or dendrite formation).
3. The strong variation in expected excess energy with small variations in other parameters (such as temperature) at certain levels. The model indicates that some of these curves are more fractal than monotonic.
4. The strong role that may be played by polarization of low velocity deuterons in nuclear reactions.
5. A lower voltage band where tritium is produced, a "tritium desert" at intermediate voltages, and a high voltage regime where tritium production may again be expected.
6. Similarly, regions at higher current densities at which excess heat ceases.

(This prediction of an upper limit on the current density, and the prediction of a series of possibly sharp, asymmetric drops in plots of output vs temperature or current density, are intriguing. It would be very interesting to see such behavior reproduced by other laboratories whose cells give sufficiently stable outputs.)

While awaiting publication of this important paper, Bush's previous two references can be reviewed:

[1] Dr. R.T. Bush (Cal State Polytech, Pomona), "A Transmission Resonance Model for Cold Fusion.", Presented at COLD FUSION - A STATUS REPORT session in conjunction with the ASME Winter Annual Meeting held in San Francisco, CA December 12, 1989. [This paper presents a resonance model for cold fusion

and shows how the phenomenon is temperature dependent.]

[2] Robert T. Bush (Cal State Poly Tech.), "Isotopic Mass Shifts in Cathodically-Driven Palladium via Neutron Transfer suggested by a Transmission Resonance Model to Explicate Enhanced Fusion Phenomena (Hot and Cold) within a Deuterated Matrix", Proceedings of The First Annual Conference on Cold Fusion, March 28-31, 1990, University of Utah Research Park, Salt Lake City, Utah.

#### DELAWARE - THEORY ON FUSION IN TI

Courtesy of Dr. Samuel Faile

Karl Sohlberg and Krzysztof Szalewicz (U. of Delaware), "Fusion Rates for Deuterium in Titanium Clusters", *Physics Letters A*, 1990, Vol 144, pp 6-7 & 365-370.

#### ABSTRACT

Ab initio Hartree-Fock SCF calculations for hydrogen atoms in a Ti atom matrix were performed. Computed potential energy surfaces for the D motion were used to calculate fusion rates. These calculations suggest that no stable state of  $Ti_nD_m$  exists with the small inter-deuteron distances required for measurable fusion rates.

#### EDITOR' COMMENTS

Nevertheless, excess heat and nuclear products have been reported in deuterated Ti by various groups. It has previously been suggested that dynamic, nonequilibrium conditions (deuteron migration or changes in net loading) and localized sites (surfaces, defects, etc) may play important roles. Thus, successful models may need to incorporate these aspects. Also it is suggested that a careful review of Bush's TRM would indicate that particle distance calculations need to be replaced by resonance (wave-based) events.

#### G. E. - NO CHEMICAL COLD FUSION?

Courtesy of Dr. Samuel Faile

L.N. Lewis, P.G. Kosky, & N. Lewis (General Electric Schenectady), "On The Search for Nonelectrochemical Cold Fusion: Production of Deuterium off of High Surface Area Palladium Colloid", *Journal Radioanalytic Nuclear Chemistry*, 1990, Vol 145 No 2 pp 81-91.

#### ABSTRACT

The reaction of  $Et_3SiD$  with  $Na_2PdCl_4$  in  $CD_3OD$  was carried out under conditions of monitoring for production of neutrons and/or gamma-rays. This reaction produces  $D_2$  off the surface of Pd colloid. The formation of high

surface area Pd metal was confirmed by TEM (transmission electron microscopy). The heat from the all protio control reaction and the all deuterio reaction was monitored and was the same within the limits of these experiments. Within the limits of neutron and gamma detection, no measurable fusion occurred during this reaction.

#### PITTSBURGH - HYDROGEN ABSORPTION

Courtesy of Dr. Samuel Faile

W.E. Wallace, R.S. Craig, & V.U.S. Rao (Dept. Chem., U of Pittsburgh), "Hydrogen Absorption by Intermetallic Compounds", Chapter 12 in Smith L. Holt, Joseph B. Milstein & Murray Robbins (Editors), Solid State Chemistry: A Contemporary Overview, published by American Chemical Society, c1980. Article submitted Sept 1978, 87 refs.

#### ABSTRACT OF CHAPTER 12

Many intermetallic compounds absorb hydrogen extensively, with volumetric capacities often exceeding that of liquid hydrogen. While the capacity of these materials is extraordinary, their most remarkable feature is the rapidity with which they dissolve and release hydrogen, the process often being 95% complete within about 200 sec at room temperature. Recent work dealing with structures, thermodynamics, kinetics, or sorption and a few aspects of the superconductivity of hydrogenated intermetallic compounds is reviewed. In hydrogenated rare earth intermetallics pressure increases, in a family of compounds, systematically with atomic number of the rare earth. In the series RETs (where RE is a rare earth and T = Fe, Co, or Ni), pressure increases in the sequence Fe to Co to Ni. Hydrogenation often significantly influences superconductivity.

#### FF EDITOR'S COMMENTS

In Table I of their article, the authors list the hydrogen capacity of several compounds relative to the amount of hydrogen contained in the same volume of liquid hydrogen ( $4.2 \times 10^{22}$  hydrogen atoms per cc at 20 K). The volumetric capacities of several intermetallic compounds to absorb hydrogen are given for 1 atm and 25 C. The RE in the compound represents the rare earths Gd, Tb, Dy, Ho, and Er.

COMPOUND	CAPACITY
REFe <sub>3</sub>	0.9 - 1.3
RECo <sub>7</sub>	0.9 - 1.4
RECo <sub>3</sub>	1.4 - 1.5
LaNi <sub>5</sub>	1.4
ErFe <sub>0.8</sub> Mn <sub>1.2</sub>	1.7
Zr as ZrH <sub>2</sub>	1.7
U as UH <sub>3</sub>	2.0

It is suggested that the study of this subject may lead to the selection of other metals and/or alloys suitable for testing as electrodes in cold fusion experiments, especially such as those of Liaw and Liebert.

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### PRINCETON - LOW THEORETICAL FUSION RATES

Courtesy of Dr. Samuel Faile

S.C. Cowley, R.M. Kulsrud (Plasma Physics Lab, Princeton U), "Some Considerations of 'Cold Fusion' Including the Calculation of Fusion Rates in Molecules of Hydrogen Isotopes", *Report 1989*, PPPL-2657; (Available from NTIS), 24 pp.

#### ABSTRACT

The fusion reaction rates were calculated in moles of H isotopes. The rates were calculated analytically as an asymptotic expansion in the ratio of the  $e^-$  mass to the reduced mass of the nuclei. The fusion rates of the H-D, D-D, and D-T reactions are given for a variable  $e^-$  mass by a simple analytic formula. A mechanism by which a sufficiently localized  $e^-$  in solid can have an effective mass large enough to explain the result of M. Fleischmann et al. (1989) is presently unknown. This calculation indicates that H-D rates should exceed D-D rates for D-D fusion rates approx.  $< 10^{-23}$  per mole per second. The D-D fusion rate is enhanced by a factor of  $10^5$  at 10,000 K if the excited vibrational excitations are suppressed. The suggestion that experimental results could be explained by bombardment of cold d by keV d is unlikely from an energetic point of view.

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### PURDUE - 2 PAPERS

Yeong E. Kim (Purdue University, Indiana) "Neutron Burst from High Voltage Discharge Between Palladium Electrodes in  $D_2$  Gas", accepted for publication in *Fusion Technology*, Fall 1990, 12 ref.

#### ABSTRACT

A recent experimental observation of neutron flux burst at a rate of  $2 \times 10^4$  times the background rate during a high AC voltage stimulation between two deuterated palladium electrodes in  $D_2$  gas is explained in terms of the experimentally measured deuterium-deuterium (D-D) fusion cross sections. Theoretical criteria and experimental conditions for improving D-D fusion rates with the use of pulsed high DC voltages are described.

#### SECOND PAPER

Yeong E. Kim, Robert A. Rice, and Gary S. Chulick (Purdue University, Indiana), "The Role of the Low-

energy Proton-Deuteron Fusion Cross-Section in Physical Processes", accepted for publication in *Fusion Technology*, Fall 1990, 27 ref.

#### ABSTRACT

We calculate the p-D fusion reaction rate at low energies ( $E \leq 2$  keV in the center of mass frame) for a Maxwell-Boltzmann velocity distribution and compare it to that for other reactions involving hydrogen isotopes. It is shown that p-D fusion dominates the other reactions for  $E \leq 8$  eV in the center of mass frame. The implications for various physical processes are discussed.

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### WRIGHT STATE & BROOKLYN POLY U. - TiCu

Courtesy of Dr. Samuel Faile

G. Bambakidis (Wright State U, Dayton) & N.G. Alexandropoulos (Brooklyn Polytechnic U.), "Plasmon spectra of crystalline TiCu and amorphous  $TiCuH_{1.41}$ ", *Journal of the Less-Common Metals*, Vol 162, 1990, pp L31-33, 9 ref.

#### INTRODUCTION

Intermetallic transition metal compounds, such as TiFe, have received considerable attention because of their actual and potential use in a variety of applications involving hydrogen, such as in hydrogen storage, heat pumps, fuel cells, and heat engines. As a prototype member of this class, TiCu forms a metastable hydride  $TiCuH_x$  over a range of hydrogen compositions, and both the crystalline (c-TiCuH<sub>x</sub>,  $0 < x < \text{about } 1$ ) and amorphous (a-TiCuH<sub>x</sub>,  $0 < x < \text{about } 1.4$ ) systems have been studied by several techniques. We report here the results of high energy electron loss spectroscopy (EELS) performed on c-TiCu and a-TiCuH<sub>1.4</sub> using a modified transmission electron microscope. Similar results for Ti and TiH<sub>2</sub> were presented previously by Alexandropoulos et al. In principle, the measurement of the plasmon spectrum, core edges, near-edge structure, extended electron loss fine structure and Compton scattering profile can give information on the state of hydrogen in the lattice and its effect on the electron structure of the host.

#### EDITOR'S COMMENTS

The hydrogen uptake ability of these materials should make them examples of other potential candidates for anodes in the Liaw-Liebert molten salt cells, provided their mechanical and thermal properties at the 350 to 400 K temperatures used are compatible.

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## D. NEWS FROM ABROAD

### BRAZIL - NEUTRON MEASUREMENTS

Courtesy of Dr. Samuel Faile

Paulo R.P. Coelho, R.N. Saxena, Spero P. Morato, I.D. Goldman, A.G. DePinho, & I.D. Nascimento (Inst. Nuc. Energy, Pinheiros, Brazil), "Search for Neutron Emission During the Electrolysis of Heavy Water", *Publ. IPEN*, 1990, vol 297, 10 pp.

#### ABSTRACT

A liquid scintillator detector, NE213, with pulse shape discrimination technique was used to observe neutrons during the electrolysis of heavy water with a Pd cathode. From the measured foreground and background counting rates, a neutron emission rate of  $(8.2 \pm 2.9) \times 10^{-3}$  n/s per gm of Pd was detected, implying  $(2.9 \pm 1.0) \times 10^{-24}$  fusion events per d pair per sec. as compared to  $\approx 10^{-23}$  fusion events per d pair per sec reported by S. E. Jones, et al., using a Ti electrode.

#### EDITOR'S COMMENTS

The low neutron emission rates noted here are in marked contrast to those achieved by groups such as Arata and Zhang - up to  $10^8$  n/s (*Fusion Technology*, Vol 18 No 1 Aug 1990 pp 95-102, as reported in the Sept 1990 issue of *Fusion Facts*). It is suggested that this Brazilian group attempt to replicate Arata and Zhang's experiment.

### ENGLAND - COLD FUSION X-RAYS?

Courtesy of Dr. Samuel Faile

P.T. Greenland (Harwell), "Issues Connected with Cold Fusion: A Room Temperature Mechanism for the Production of X-Rays", *Journal Physics B; Atomic, Molecular, and Optical Physics*, 1990, Vol 23 No 10, pp 1679-90.

#### ABSTRACT

It was previously suggested that the reaction  $d + d \rightarrow {}^3\text{He} + n$  was observed at room temperature in electrolytically deuterated Ti and Pd. The reported n production rates cannot be explained on conventional grounds, and the possibility that n are produced by fusion reactions in a small non-thermal population of fast d was raised. The K and L x-ray production which should result from these putative fast d was calculated, and n production is a more sensitive probe of fast d than x-rays. Estimates of the fusion rate/fast d, as a function of energy were made.

## EDITORS' COMMENTS

The Bush TRM has some interesting comments on the production of both tritium and neutrons. Greenland may want to read Bush's paper and determine the probability that fast d are significantly involved in cold fusion and under what conditions.

### FRANCE - OLD NEGATIVE REPORT

Courtesy of Dr. Samuel Faile

D. Aberdam, M. Avenier, G. Bagieu, J. Bouchez, J.F. Cavaignac, J. Collot, R. Durand, R. Faure, J. Favier, E. Kajfasz, D.H. Koang, B. Lefievre, E. Lesquoy, H. Pessard, A. Rouault, J.P. Senateur, A. Stutz, and F. Weiss (Various labs in France), "Limits on Neutron Emission Following Deuterium Absorption into Palladium and Titanium", *Physical Review Letters*, Vol 65, No 10, pp 1196-1196, 3 Sept 1990, 11 refs. [Paper received 12 Dec 1989.]

#### ABSTRACT

No evidence of neutron emission was observed following deuterium loading into palladium and titanium in both electrochemical and pressurization experiments. Upper limits obtained with a detector having a very clean neutron signature are at least 100 times lower than values reported in recent publications giving evidence of cold fusion. The deduced fusion rate limits were lower than  $2 \times 10^{-26}$  per second per pair of deuterons.

#### EDITOR'S COMMENTS

It is unfortunate that none of 18 authors would have learned by the time of the submission of the paper that fusing a Pd rod in a graphite crucible would lead to negative results due to C contamination (a factor reported as early as May 1989). In addition, nearly all cathodes were annealed in a hydrogen oxygen flame, which would be expected to provide an oxide layer (another method to ensure negative results). Also, the paper's first table shows that only 2 of the experiments (both fusing the Pd in a graphite or "cold" crucible) continued for more than 100 hours. The authors acknowledged the help of Dr. O. Morrison for "interesting discussions and information". Now that over 90 scientists have replicated cold fusion (and the list grows monthly), perhaps one of the group can also show the authors that neutron production is the least likely event to occur in an electrochemical cell.

### GERMANY - TESTING FOR ${}^6\text{Li}$

Courtesy of Dr. Samuel Faile

P. Frodl, O.E. Roessler, M. Hoffmann & F. Wahl (Inst. Phys., U. Mainz), "Possible Participation of Lithium in

Fleischmann-Pons Reaction is Testable", *Z. Naturforsch. A: Physical Science*, 1990, Vol 45, No 5, pp 757-8 (in English).

#### ABSTRACT

If the amount of heat reported by M. Fleischmann et al. (1989) to occur in their electrochemical fusion experiments is assumed to be produced entirely by the clear nuclear reactions  ${}^6\text{Li} + {}^2\text{D} \rightarrow 2 {}^4\text{He}$  (22.4 MeV), then the concentration of  ${}^6\text{Li}$  in the reaction fluid should during a period of 120 hours go down by a measurable amount, namely 0.25-3.4%, dependent on whether the natural isotopic mixture or (less likely) pure  ${}^6\text{Li}$  was used in the experiment.

#### EDITOR'S COMMENTS

Variations in the  ${}^6\text{Li}$  abundance in reagent Li may yield even larger changes. (See article by Dehn in section E.)

#### JAPAN - TWO TAKAHASHI PAPERS

Courtesy of Dr. Takahashi

Akito Takahashi, (Osaka University), "Opening Possibility of Deuteron-Catalyzed Cascade Fusion Channel in Pd under  $\text{D}_2\text{O}$  Electrolysis", *Journal of Nuclear Science and Technology*, Vol 26, No 5, pp. 558-560, May 1989, 5 ref.

#### ABSTRACT

In the latest paper of  $\text{D}_2\text{O}$  electrolysis fusion by Fleischmann & Pons (F-P experiment, in the following), they reported that the observed enthalpy generation showed  $10^{6-7}$  times more frequent fusion-reaction rates than those of the known fusion channels, i.e.,  $\text{D}(\text{d},\text{n}){}^3\text{He}$  and  $\text{D}(\text{d},\text{P})\text{T}$  for which they observed consistent results between the neutron and the tritium generation, and concluded surprisingly that an "unknown fusion process" took place. What did really happen in their experiment? The author has studied the problem from a theoretical point of view in the last few weeks, and has reached the conclusion that the D-cat. cascade fusion channel, i.e., the following (i)  $\rightarrow$  (ii) reaction cascade would open to be the predominant reaction channel in a highly deuterium-condensed Pd electrode. We may call this D-cat. type since deuterium exists at both the initial and the final state, (i)  $\text{D} + \text{D} \rightarrow {}^4\text{He}^*$

(ii)  ${}^4\text{He}^* + \text{D} \rightarrow {}^6\text{Li}^* \rightarrow {}^4\text{He} + \text{D} + 23.8 \text{ MeV}$ .

Calculated results of fusion rates and neutron yield are consistent with the F-P experiment, and can explain the key results of the F-P experiment. In the present note, key results of theoretical estimations are described. A detailed report will be submitted to a journal.

#### EDITOR'S COMMENTS

Takahashi notes in his paper the following, "Using the present theoretical model, the key results of the F-P experiment on  $\text{D}_2\text{O}$  electrolysis fusion could be explained. However, to confirm the present result by further more quantitative analysis, we need complicated quantum-mechanical theories and calculations supported by many data bases of experiments...". The following and later paper by Takahashi provides additional experimental evidence.

#### SECOND PAPER

Akito Takahashi, Takayuki Takeuchi, Toshiyuki Iida, (Osaka University), Masanori Watanabe, (Central Research Laboratories, Matsushita Electric Industrial Co.), "Emission of 2.45 MeV and Higher Energy Neutrons from  $\text{D}_2\text{O}$ -Pd Cell under Biased-Pulse Electrolysis", *Journal of Nuclear Science and Technology*, 27[7], pp. 663 - 666 (July 1990), 5 ref.

#### ABSTRACT

Since the amazing announcement by Fleischmann & Pons, many confirmation experiments on "cold fusion phenomena" have been carried out at so many laboratories in the world. In spite of major "negative" results, minor "positive" results claiming the observations of neutron, tritium and heat generations have been reported since then. The authors have reported "positive" results showing 1 or 2 n/s per cc of Pd neutron emission under the D-charging condition of  $\text{D}_2\text{O}$ -Pd electrolysis cell using a biased-pulse current operation. In this note, the authors report much clearer results of emission of "cold" D-D neutrons (2.45 MeV) and surprisingly, associating higher energy (3 to 7 MeV) neutrons, from a  $\text{D}_2\text{O}$ -Pd cell under a certain condition of biased-pulse electrolysis. The observation of the 3 to 7 MeV neutron component would show the occurrence of the  $3\text{D} \rightarrow \text{d} + \alpha + 23.8 \text{ MeV}$  reaction, since 15.9 MeV deuterons by the  $3\text{D}$  reaction slow down in  $\text{PdD}_x$  metal and produce these higher energy neutrons by the high energy D-D reaction.

#### EDITOR'S COMMENTS

This SHORT NOTE from the authors also cites a report on previous work [A. Takahashi, et. al.: "Windows of cold nuclear fusion and pulse electrolysis experiments", to be published in *Fusion Technology*.] The cited paper apparently details the method by which the authors used a strong current in region A and a weak current in region B of their cell. The experiments, running over several weeks, showed definite evidence of neutron emissions. In their discussions, the authors note, "We can say evidently that there occurs the cold D-D fusion emitting 2.45 MeV neutrons ... [dependent on several conditions] ...The

observation of the higher energy (3 to 7 MeV) component having broad peak around 6 MeV is most mysterious ... At the moment, this higher energy component of neutrons can be only explained by the **bold hypothesis of 3D fusion reaction** ... More detailed results will be reported in the near future."

#### JAPAN - REVIEW

(From Chemical Abstracts)

Oguro Keisuke (Osaka Kogyo Gijutsu Skikenjo), "Hydrogen Absorbing Alloys and Low-temperature Nuclear Fusion", *Zairyo*, 1990, Vol 39, No 437, pp 228-9, in Japanese.

#### ABSTRACT

A review with no references is given on the mechanism of absorption of H by alloys, the roles of the metal surface and bulk metal in H absorption, and Pd as an electrode for cold nuclear fusion.

#### RUSSIA - DEGENERATE PLASMA IN Pd

Courtesy of Dr. Samuel Faile

A.V. Kulakov, E.V. Orlenko, & A.A. Rumyantsev (Moscow), "Physical Mechanism of the So-called Cold Fusion", *Izv. Akad. Nauk SSSR, Energ. Transp.*, 1990, Vol 1, pp 158-160, (In Russian).

#### ABSTRACT

The mechanism of nuclear reactions occurring in D introduced into the crystal lattice of Pd was examined. Coulomb potential barrier hindering the fusion reaction of nuclei under usual conditions is lowered at the expense of shielding in the dense degenerated plasma of a crystal. The barrier is also lowered as a result of the action of quantum exchange forces connected with the indiscernibility of identical particles. These forces are connected with the properties of rearranging a symmetry of d wave function. The exchanging forces join in the distance of the order of  $10^{-9}$  cm which leads to the effective attraction of nuclei.

#### EDITOR'S COMMENTS

Are the forces suggested in the statement "These forces are connected with the properties of rearranging a symmetry of d wave function." similar to the wave-nature of matter that Bush uses in his TRM paper (reviewed in this issue)? For over a year, *Fusion Facts* has reviewed many papers in which the authors show that "particles" have a low probability to overcome the Coulomb barrier

and therefore cold fusion would not be practical. A few other authors (e.g. Bush, Preparata, Schwinger, Aspden, et. al.) deviate from the particle nature of matter and thereby come to theoretical conclusions that support cold fusion. The wave-particle duality of quantum mechanics is an accepted physical principle. Which duality is used to explain away or support experimental observations is the author's choice. We believe that cold fusion experimental data is better explained using the wave-nature of matter.

#### SWITZERLAND - CHANGES IN Pd SURFACES

Courtesy of Dr. Samuel Faile

Martine Ulmann, Jiangbo Liu and Jan Augustynski, (University of Geneva), Felix Meli and Louis Schlapbach, (University of Fribourg), "Surface and electrochemical characterization of Pd cathodes after prolonged charging in LiOD + D<sub>2</sub>O solutions", *Journal Electroanal. Chem.*, Vol 286, 1990, pp 257-264.

#### INTRODUCTION

One of the typical characteristics of the hydrogen evolution reaction is its extreme sensitivity to various impurities present in the solution. The related effects (irregular time variation of the overvoltage, anomalous Tafel slopes) are well known, not only from early fundamental work, but also from industrial practice. We showed recently that the contamination of a palladium cathode, polarized in LiOD + D<sub>2</sub>O solution, with lead and more so with zinc, leads to the build-up of very large overvoltages for D<sub>2</sub> evolution. In the present communication we describe the results of surface analyses for a series of Pd electrodes used as cathodes in the D<sub>2</sub>O electrolysis cells run for up to 34 days. These data may be relevant to the conditions of the experiments reported by Fleischmann et al.

#### EDITOR'S COMMENTS

In their discussion the authors note that they used cold-worked Pd metal foils (10 x 10 x 0.5 mm) and that the electrolytic solutions were prepared by the addition of Li metal or LiOH [sic]. They also cite a work by V.J. Cunnane, et. al., *J. Electroanal. Chem.*, 269 (1989) 163 with the following comment, "The negligible effect of mixing of the evolved D<sub>2</sub> and O<sub>2</sub> so close to the electrodes in a cylindrical electrolysis cell ... has been confirmed recently." The authors show that under the conditions of their experiment, the Pd cathode builds up a significant overvoltage. It would be of interest to determine if the recent report by Yang et. al. (National Tsing Hua U., Hsinchu, Taiwan, as reported in *Fusion Facts*, August 1990, page 3), where a daily increase in voltage resulted



in greatly improved results, is related to the overvoltage reported in this Ulmann et. al., paper.

The authors show that if overvoltage is to be avoided, then dissolved Pb and especially Zn must be carefully removed or avoided. The authors discuss other elements to avoid so that the Pd is not poisoned. In summary, the authors state, "The results reported here show clearly that the distribution of the impurities at the Pd surface, which determines its long term electrochemical behavior, may depend critically (i) on the origin of D<sub>2</sub>O and Li (LiOD) used to prepare the solutions and (ii) on the actual electrolysis conditions including the current density and the ratio of the solution volume to the electrode (Pd and Pt) surface area. Of the impurities detected, zinc appears to be the key element since it modifies the cathodic behavior of palladium strongly. The electrodeposition of Zn at the Pd cathode is influenced not only by the level of solution contamination and the current density but also by the competition between the high- and low-hydrogen-overvoltage impurities for the sites at the Pd surface. Calcium (and magnesium) seem to play a special role in forming (particularly at high current densities and in slightly more alkaline solutions) a precipitate of Ca(OH)<sub>2</sub>(Mg(OH)<sub>2</sub>). This, in turn, is expected to cause pronounced blocking of the electrode surface, resulting in a local build-up of strong electrical fields." We are indebted to the authors for their recent experimental work and report on this significant effect that may be the cause of many of the wide differences in the replication of the Pons-Fleischmann Effect.

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## E. SHORT ARTICLES FROM READERS

### ABSORPTION OF COLD-FUSION NEUTRONS IN LITHIUM-RICH ENVIRONMENTS

By Michael Dehn, Associate Editor

Neutrons produced by the reaction  $D + D \rightarrow {}^3\text{He} + n + \text{energy}$ , or by any alternate cold-fusion reaction, can be readily absorbed by lithium-based electrolytes when thermalized. The predominant secondary reaction, which generates additional T and He, is  ${}^6\text{Li} + n \rightarrow \text{T} + {}^4\text{He} + 4.8 \text{ MeV}$ .

Indeed, the cross-section for this reaction is so large -- about 942 barns for thermal neutrons at 20 deg C [1] -- that it has been used in both tritium production and neutron counters in spite of <sup>6</sup>Li's natural abundance of only 7.4%. (In contrast, the cross-section for the more common <sup>7</sup>Li isotope is only about 0.045 barns, where one barn = 10<sup>-24</sup> cm<sup>2</sup>.)

Given the low neutron production in cold fusion cells, this reaction would not lead to measurable changes in the <sup>6</sup>Li/<sup>7</sup>Li ratio. Likewise, while it is conceivable that the small amount of tritium seen in some experiments could be due to this reaction rather than the primary fusion reaction (i.e.  $d + d \rightarrow t + p$ ), this appears unlikely on the basis of other experiments in which neutron/tritium branching ratios of 10<sup>-7</sup> to 10<sup>-9</sup> are measured.

On the other hand, the existence of the <sup>6</sup>Li(n, alpha)T reaction may cause neutron production rates to be substantially underestimated under conditions in which this reaction is sufficiently favored, and thus alter the apparent branching ratio. (Unfortunately, even given the efficiency of this reaction, it does not appear that it could be used to reconcile apparent branching ratios on the order of 10<sup>-9</sup> to 1 with the high-temperature branching ratio of 1 to 1, even in experiments in which this reaction was highly favored.

For example, an electrolyte with a very high Li concentration of 10M will contain one <sup>6</sup>Li atom per 2.2 x 10<sup>-21</sup> cm<sup>3</sup>. Thus a crude calculation indicates that a typical thermal neutron would be absorbed during its passage through  $(2.2 \times 10^{-21} \text{ cm}^3) / (942 \times 10^{24} \text{ cm}^2) = 2.3 \text{ cm}$ . of the solution. Taking scattering of the neutrons by the solution into account, this distance should drop to only a fraction of a centimeter.

Note: The above estimate neglects the additional (probably somewhat larger) distance required to slow the original high-energy neutrons to an approximately thermal energy distribution. However, the low mean atomic weight of the electrolyte should render it a particularly effective moderator.

Substantially less absorption would occur before the neutrons have been slowed, as absorption is approximately inversely proportional to neutron energy except near resonances, and <sup>6</sup>Li's resonances are few and have a maximum cross-section of only a few barns [2 & 3]. Thus, in experiments in which the electrode is surrounded by very little moderator, few neutrons would react, as the cross-section at 2.45 MeV is only about 0.2 barns.

For a molten-salt cell run at 375 degrees C, the cross-section for thermalized neutrons is still approximately 2/3 that at room temperature.

This reaction is also the reason for the unusually large variations which can occur in the isotopic composition of reagent Li. (<sup>6</sup>Li percentages less than half the nominal 7.4% have been noted in commercial Li from which <sup>6</sup>Li has been extracted for use in tritium production, neutron monitors, etc.) Thus, in order for measurements of <sup>6</sup>Li depletion to be meaningful, it is imperative that the composition of the reagent Li also be checked.

This reaction need not be restricted to the Li in the cell. Minor tritium production should also take place in the reagent Li if it is stored in sufficiently close proximity to any neutron source.

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#### ALTERNATIVES TO PALLADIUM

By Dr. Samuel Faile

SOLID-STATE COLD FUSION AND DEUTERATED MOLTEN SALT COLD FUSION MAY WORK WELL WITH ALTERNATIVE METALS

Many alternative metals and alloys, as compared to palladium, hold more deuterium at higher temperatures but are more prone to corrosion and oxidation. For the solid-state devices a simple solution is to avoid oxidizing conditions. This would normally be done for the Claytor (Los Alamos) devices and those proposed by Dr. Kim in their continuing work. For the molten salt systems even though there may be increased corrosion at the higher temperatures, the [net] effects could be beneficial since oxide scale may not have a chance to form a thickness that would impede the diffusion of deuterium into the electrode. [Since this environment is a reducing environment as contrasted to the oxidizing environment of the aqueous cells. Ed.] Some of the materials I have previously suggested are cast  $ZrV_2$ ,  $DyFe_{0.8}Mn_{1.2}$ , and  $TiCu$ .

\* \* \* \* \*

#### F. UPCOMING CONFERENCES & CALL FOR PAPERS

#### ANOMALOUS NUCLEAR EFFECTS IN DEUTERIUM/SOLID SYSTEMS

Sponsored by EPRI, BYU, and U.S. DoE. Conference will be held at Brigham Young University, Provo, Utah Oct 22-24, 1990. Reporters from *Fusion Facts* will be in

attendance and will report on the conference in the November issue of *Fusion Facts*.

#### NUCLEAR PHYSICS DIVISIONAL MEETING

(AMERICAN PHYSICAL SOCIETY) to be held October 25-27, 1990 at Urbana-Champaign, Illinois. This workshop and the BYU workshop are scheduled to permit interested researchers to attend both meetings. Courtesy of Dr. Nate Hoffman.

\* \* \* \* \*

#### CALL FOR PAPERS

Courtesy of Subbiah Arunachalam

The Indian Journal of Technology (the third journal -- after *J. Electroanal. Chem.*, and *Nature*-- to publish an original research paper on cold fusion) invites papers. Both original research papers and critical review articles in all areas of cold fusion are solicited.

Manuscripts may be sent, in duplicate, to Editor, Indian Journal of Technology, PID, Hillside Road, New Delhi 7110012, India.

#### CONFERENCE PROCEEDINGS AVAILABLE

*The First Annual Conference on Cold Fusion Conference Proceedings*, is now available. The proceedings include the papers presented March 28-31, 1990 at the conference. Send check for \$55. Order from:

National Cold Fusion Institute  
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Make check payable to Research Corporation of the University of Hawaii. The price is \$15 for each copy of the Cold Fusion Proceedings. Price includes shipping and handling.

**TECHNICAL NOTES IN FUSION TECHNOLOGY**

*Fusion Technology* has initiated and is continuing a very successful section for "Technical Notes" on cold fusion. This section is intended for fast publication of important papers on new directions, innovative ideas, and new results. Over the past year over 48 papers on cold fusion have been published, making *Fusion Technology* one of the premier professional journals covering this area.

Technical Notes do not have a page limit but they typically run 2-4 journal pages (1 journal page approx. = 3 double-spaced typed pages). A brief abstract is required. ASCII format computer media can be accepted.

Technical Notes will be reviewed but the process stresses rapid response. **Reviewers are instructed to consider Technical Notes as speculative, sometimes incomplete work that should be judged on the basis of innovation, originality, and importance to fusion power development. Appropriate citations to prior work are also essential.**

Deadlines for future issues are as follows:

May 1991 issue: November 16, 1990

July 1991 issue: December 21, 1990

Send manuscripts to: George H. Miley, Editor, *Fusion Technology*, Fusion Studies Laboratory, University of Illinois, 103 S. Goodwin Avenue, Urbana, IL 61801. Fax (217) 333-2906. Phone (217) 333-3772.

**COMING IN THE NOVEMBER ISSUE**

We will publish a summary of papers presented at the B.Y.U. Anomalous Nuclear Effects conference. We will also do our best to report on the American Physical Society workshop to be held in Urbana-Champaign, Ill. This workshop should have some interesting discussions relevant to cold fusion. Some of the leaders of the American Physical Society have been vigorously opposing cold fusion. Derogatory comments were made about the March 1990 First Annual Cold Fusion Conference suggesting the dying gasps of a corpse and other unscientific observations. Perhaps the corpse could be revived by a shot of molten salt excess heat.

**NOTE OF THANKS**

Thanks to our readers who responded to our offer of a free Cold Fusion Tutorial in return for copies of letters written to their senators or congressmen. The diskettes have been mailed to all who qualified.

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