



Research Article  
**Cold Fusion**

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**Abstract**

This paper is a review of the work which I have performed on the subject of *Cold Fusion* alone or in collaboration with other scientists. It covers a number of techniques such as solid-state electrolytes, electrolysis and gas diffusion. The experiments described below produced positive results. I also tried many other techniques that failed, which are not described.

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**1. Introduction**

My interest in *Cold Fusion* started on the day the discovery was announced, March 23, 1989. However, since I am not an electrochemist, I did not begin working in this field until 1993 when I met Francis Forrat, an engineer at the French Atomic Energy Commission in Cadarache. Following this encounter, I started working with solid-state electrolytes. Later, I continued with many different techniques including electrolysis and gas diffusion. In this paper, I described my work in this field, which has continued almost 20 years.

**2. Proton Conductors**

When I met Forrat in 1993, I was at the Lawrence National Berkeley Laboratory working on two-dimensional surface structures, a subject not related to LENR. Forrat had filed a French patent on a cold fusion technique using solid-state electrolytes [1]. This non-liquid technique gave me the opportunity to engage myself in the field. On a non-official way, I began experimenting with  $\text{LaAlO}_3$  single crystals with lanthanum vacancies.  $\text{LaAlO}_3$  single crystals with lanthanum vacancies have red color, whereas the stoichiometric crystals are white. As predicted by Forrat, when the samples are loaded with hydrogen or deuterium, the red crystals with vacancies turn into white. This behavior indicates that the lanthanum vacancies are filled with hydrogen or deuterium.  $\text{LaAlO}_3$  has a perovskite structure: when stoichiometric which is an insulator, when it has vacancies it becomes a high temperature proton conductor.

The calorimeter for the first experiments in Berkeley was very simple and therefore open to criticism. The red  $\text{LaAlO}_3$  single crystal, about  $2 \text{ cm}^2$ , 1.5 mm thick, was squeezed between two tantalum foil electrodes. This ensemble

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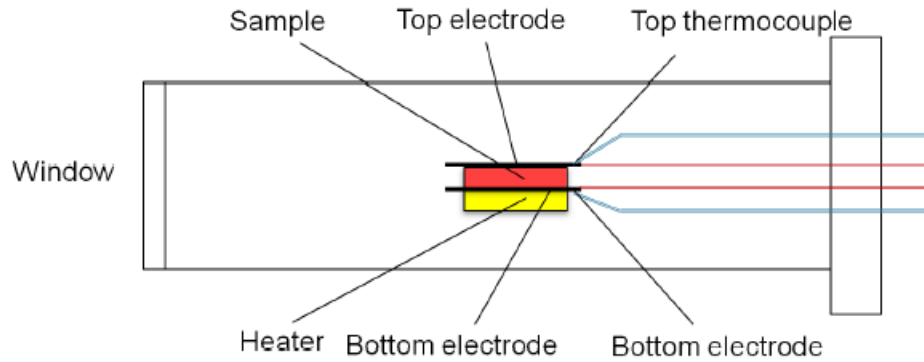


Figure 1. Chamber design].

was heated using a tungsten wire. Two thermocouples located on the bottom and the top electrodes measured the temperature of the sample. The system was positioned inside a 35 mm stainless steel chamber with electrical feed throughs on one side and a glass window on the other side. The chamber was evacuated with a mechanical pump down to  $10^{-2}$  Torr, and filled with hydrogen or deuterium gas. Figure 1 shows a schematic of the set-up.

When a DC current was passed through the crystal, a deuterium concentration profile took place with more deuterium on the cathodic side than on the anodic side. The color of the crystal changes with the deuterium concentration. On the cathodic side it becomes blue, due to the overloading of the lanthanum vacancies with deuterium that generates F centers. The middle of the crystal becomes white, since all the vacancies are now filled with deuterium, and the anodic

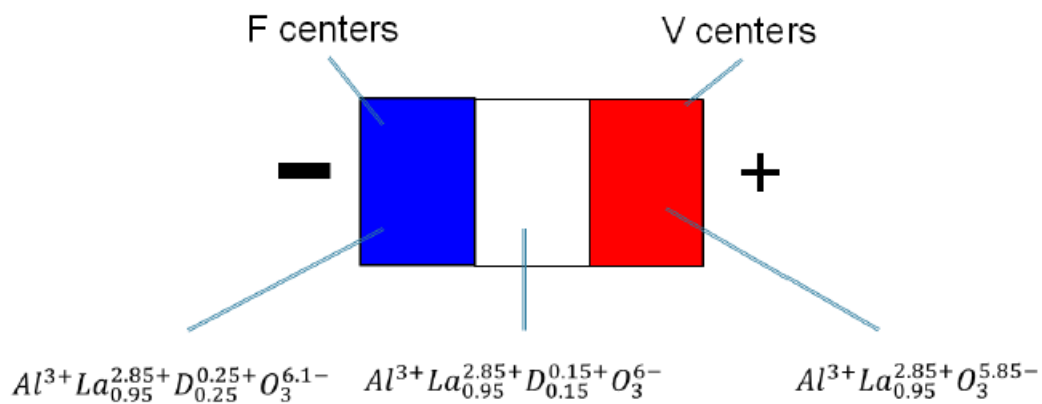
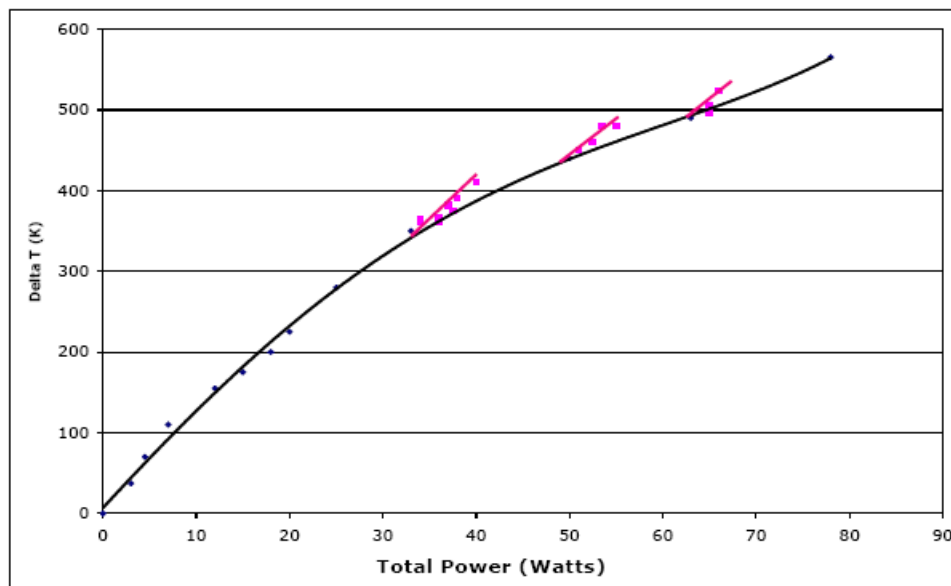


Figure 2. Sample colors during electrolysis.



**Figure 3.** Bottom thermocouple temperature versus total power input.

side remains red, because there is no deuterium diffusing on this side of the crystal. Figure 2 shows the color changes of the crystal with the corresponding crystal compositions.

Figure 3 shows a typical result where the temperature difference between the bottom thermocouple and room temperature is plotted against total input power, which includes the heating power and the power delivered directly to the crystal. The curve without crystal current is plotted in black, and the curve with the added crystal current, in a deuterium atmosphere, is plotted in red. An additional temperature rise is observed when the crystal current is added, indicating excess heat. However, the experiments were only preliminary and were not published. In particular, I did not have a data acquisition system, and the data were recorded manually. Therefore, the measurements lacked precision.

These experiments were duplicated with Georges Lonchamp in Grenoble with a better calorimeter [2]. Figure 4 shows a schematic of the new design. In order to simplify the attachment of the samples, we used two identical crystals of  $\text{LaAlO}_3$  with a common central cathode and two external anodes. The samples were placed inside a ceramic tube heated with a tungsten wire. The electrical power applied to the heater was maintained constant. When current was passed through the crystals, heat was produced and most of it passed through the ceramic tube. As the electrical power applied to the tube was constant, the extra heat changed the resistivity of the tungsten wire. By measuring the resistivity (voltage divided by current) of the tungsten wire, the heat generated by the crystals was calculated.

Figure 5 shows the production of excess heat. We performed experiments in constant current mode, and we observed “heat after death”, i.e. heat production that continued for almost 2 h after switching off the power supply. Based on this, we knew that constant input power was not necessary, so we changed to a pulsed mode, which gave excellent results. Every minute, we applied a 120 mW pulse lasting 1 s; this produced 150 mW of excess heat. The Coefficient of Performance (COP) was therefore 75!

These results were in agreement with the observations made by Mizuno et al. [3] with a different proton conductor crystal, but with similar crystallographic structures.

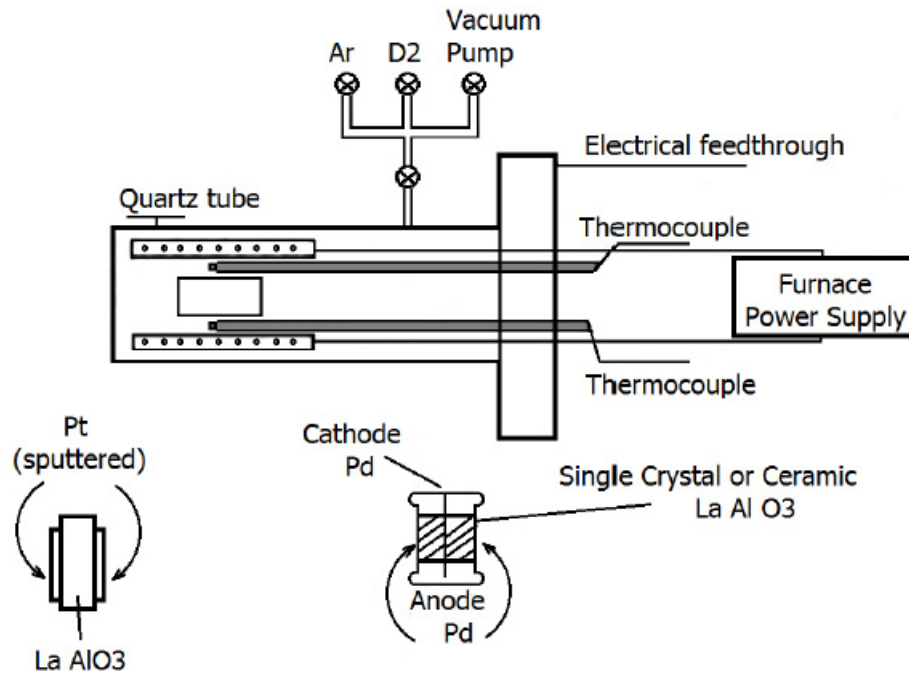


Figure 4. Schematic of the second chamber.

### 3. Patterson Type Experiments

Following James Patterson's work [4,5] showing excess heat and nuclear transmutation, we developed our own system [6]. The experimental set-up consisted of a cylindrical cell of 30 mm ID, with a nickel mesh cathode located at the bottom, and a platinum mesh anode at the top. The cathodic part of the cell was filled with 0.6 mm diameter beads; the anodic part was filled with ion exchange resins. The two compartments being separated by a nylon screen.

Three layers of nickel, palladium and nickel (about  $1 \mu\text{m}$  each) were deposited on polystyrene beads pre-covered by a thin film of copper. The electrolyte ( $\text{H}_2\text{O}$  with  $\text{Li}_2\text{SO}_4$ ) circulated through the cell, and the input and output temperatures were measured using two thermistors. Figure 6 shows a schematic of the whole system.

A blank experiment without electrolysis showed no excess heat, whereas during electrolysis excess heat was produced. The excess heat increased with increasing input power. However, the yield was the highest at low power. The excess heat was close to 100% at low power as shown in Fig. 7.

This experiment confirmed the results obtained by Patterson, but with a lower yield.

### 4. Pons and Fleischmann Boiling Experiments

In their original work, Fleischman and Pons [7] operated their cells below boiling temperature. Later, they let the cell go up to boiling, and by measuring the amount of water evaporated and the input electrical energy, they calculated the amount of excess heat produced [8,9]. In Grenoble we reproduced this type of experiment with success [10]. Figure 8

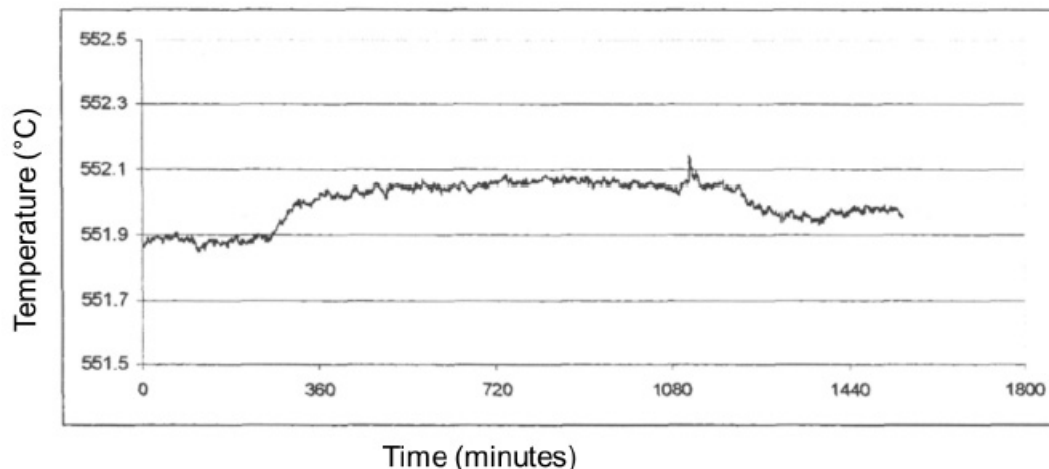


Figure 5. Temperature rise versus time. Input power: 2 mW (120 mW 1 s pulse every 60 s). Output power: 150 mW.

shows a schematic of the cell, which is identical to the one used by Fleischmann and Pons.

We measured excess heat up to 29% at boiling temperatures (see Table 1). This is in qualitative agreement with Fleischmann and Pons. However, the magnitude of the excess heat measured was less important than what they observed. Their analysis of the boiling off in two periods, assuming that the vast majority of the excess heat was produced at the end of the experiment, was difficult to evaluate.

As shown in Table 1, the experiments with  $\text{Li}_2\text{SO}_4$  are surprising since they show that the palladium is more active, and that even platinum is active.

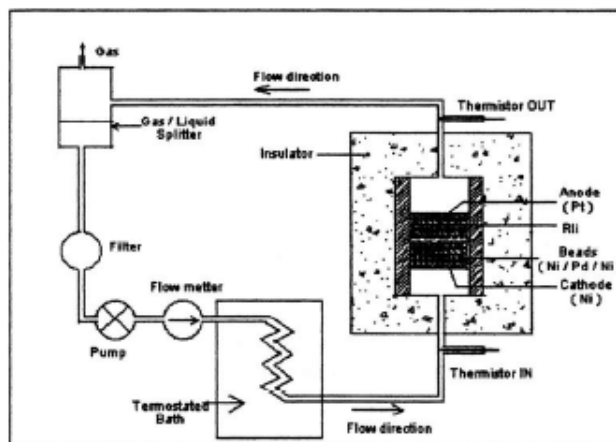


Figure 6. Schematic of the operation of the cell.

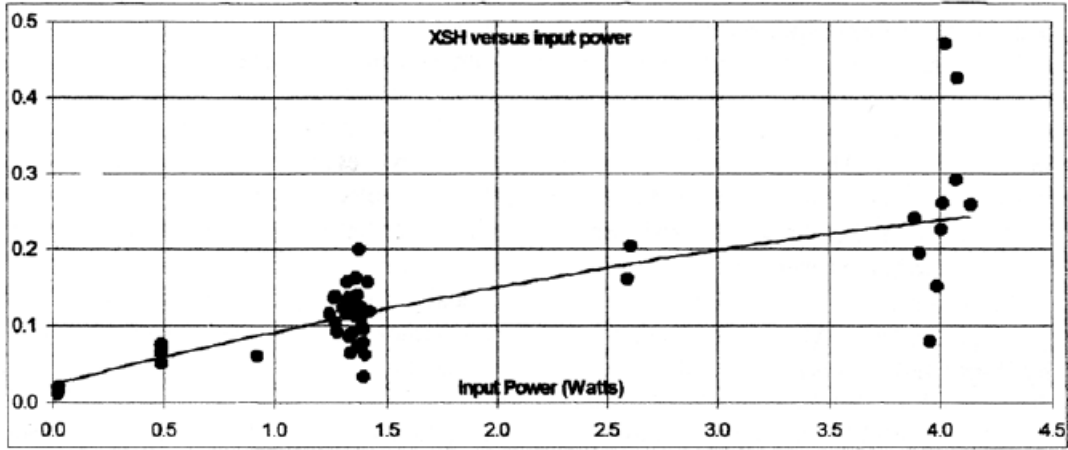


Figure 7. Excess heat versus input power (W).

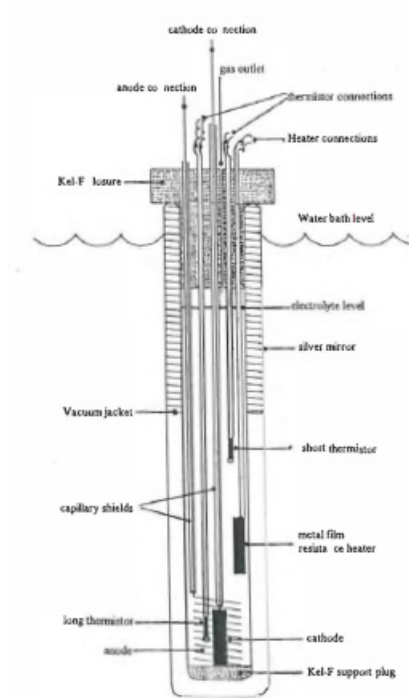


Figure 8. ICARUS II type cell.

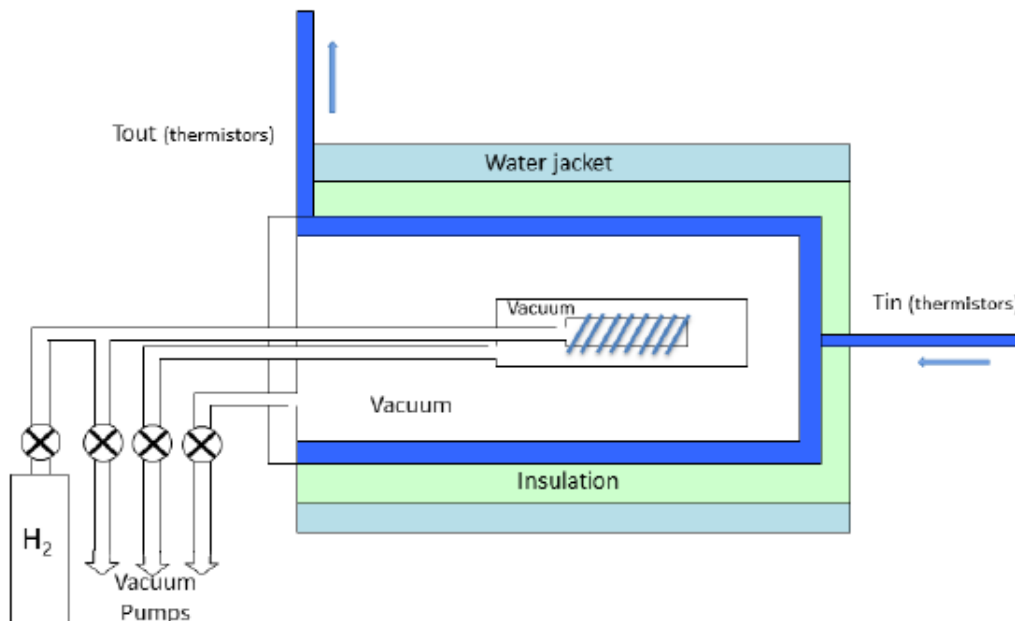


Figure 9. Mass flow calorimeter.

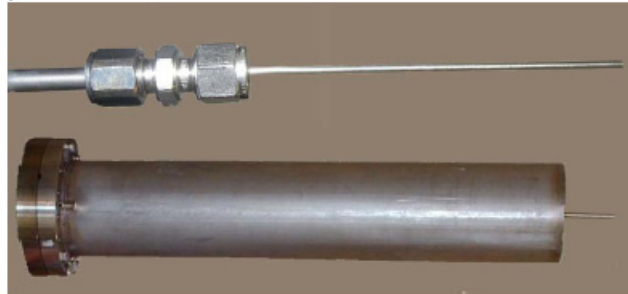
## 5. Diffusion of Deuterium through Palladium

In 1989, Fralick et al. [11] showed that when deuterium is pumped out from palladium tubes, a temperature rise is observed, whereas the same experiment with hydrogen showed no temperature change. It was therefore tempting to run a similar experiment with a method which allows continuous operation [12].

The experiment was performed in a mass flow calorimeter as shown in figure 9, where the thermal power was

Table 1. Excess heat in boiling cell

Boiling experiments in LiOD					
Cell P2			Cell P3		
Experiment	Cathode	XSH (%)	Experiment	Cathode	XSH (%)
88	Pt	0	93	Pt	0
90	Pd	12	96	Pd–Rh	8
91	Pd	20	97	Pd	7
95	Pd–Ce	5		Pd Li <sub>2</sub> SO <sub>4</sub>	9
98	Pd	14	99	Pd	14
107	Pd 1 mm	5	106	Pd–Pt–Cu	11
109	Pd	12	108	Pt	0
111	Pt	0	112	Pd	0
115	Pd	15	114	Pd	29
	Pd Li <sub>2</sub> SO <sub>4</sub>	13		Pd Li <sub>2</sub> SO <sub>4</sub>	0
			116	Pd wire	9



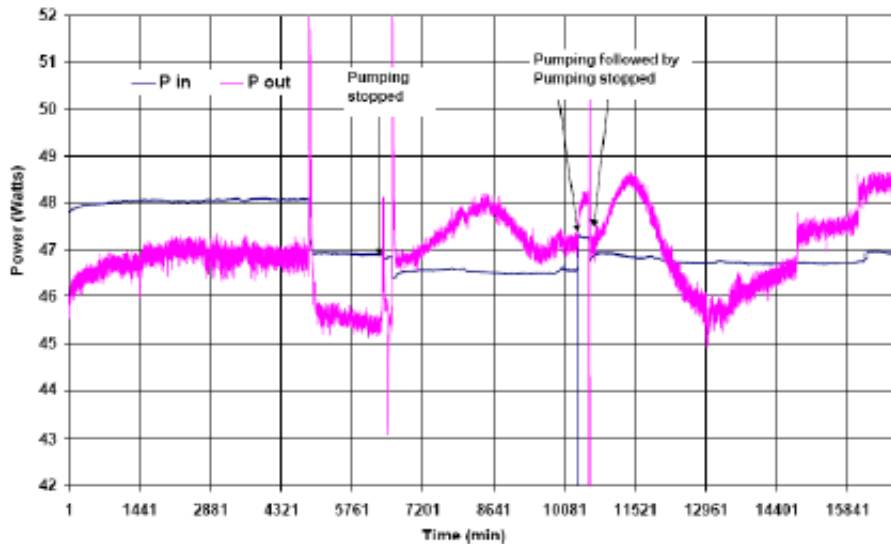
**Figure 10.** Palladium tube and external part of the calorimeter.

determined by measuring the temperature difference between output and input temperatures and the water mass flow. The palladium tube was 10 cm long and 2 mm in diameter closed at one end. See Fig. 10. The deuterium gas was introduced in the tube and diffused out through the walls of the tube in the vacuum chamber.

Figure 11 shows a 12-day experiment showing that the output power is lower than the input power when no deuterium is introduced in the tube, whereas the opposite happens when deuterium is introduced and diffuses through the palladium walls of the tube. An average of 4 W of excess power was measured with input power of 48 W for the tube heater.

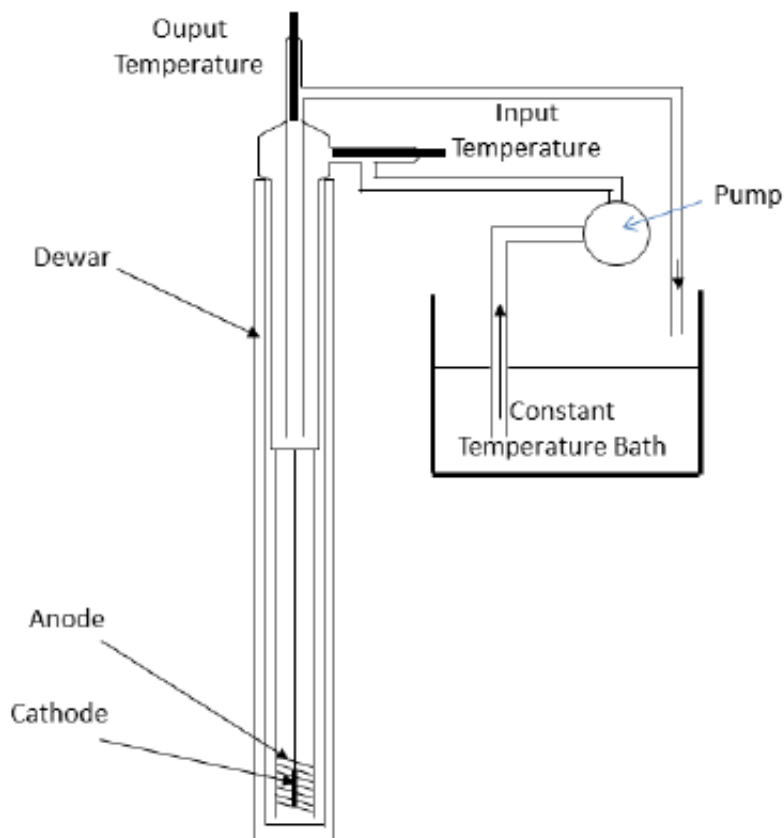
## 6. Mass Flow Electrolysis Experiments

Isoperibolic calorimetry needs calibration; therefore it was tempting to develop a mass flow calorimeter for electrolysis experiments that measures the thermal power without depending on calibration. This is the reason I developed a mass



**Figure 11.** Input and output power versus time.





**Figure 12.** Mass flow calorimeter for electrolysis.

flow calorimeter that can operate up to boiling temperatures.

Figure 12 shows a schematic of the flow calorimeter. The cell is composed of a 50 cm long, 2.5 cm inner diameter Dewar. The palladium cathode is at the center of the cell, and the platinum anode wrapped around four glass rods. The water vapor condenses in a glass condenser positioned at the top of the cell. Cooling water from a constant temperature bath flows through the top portion of the cell at 100 ml/min.

Figure 13 shows a comparison between a set of experiments in light water and heavy water, both with a palladium cathode 12 mm long and 2 mm in diameter. The difference between the two sets of curves is about 20%, indicating excess heat of 20%.

## 7. Cell Explosion

In an attempt to replicate the results obtained with the palladium tube as described in Section 5, the 12 mm cathode was replaced by a palladium tube 10 cm long, 2 mm diameter, closed at one end [13]. Figure 14 shows the input and

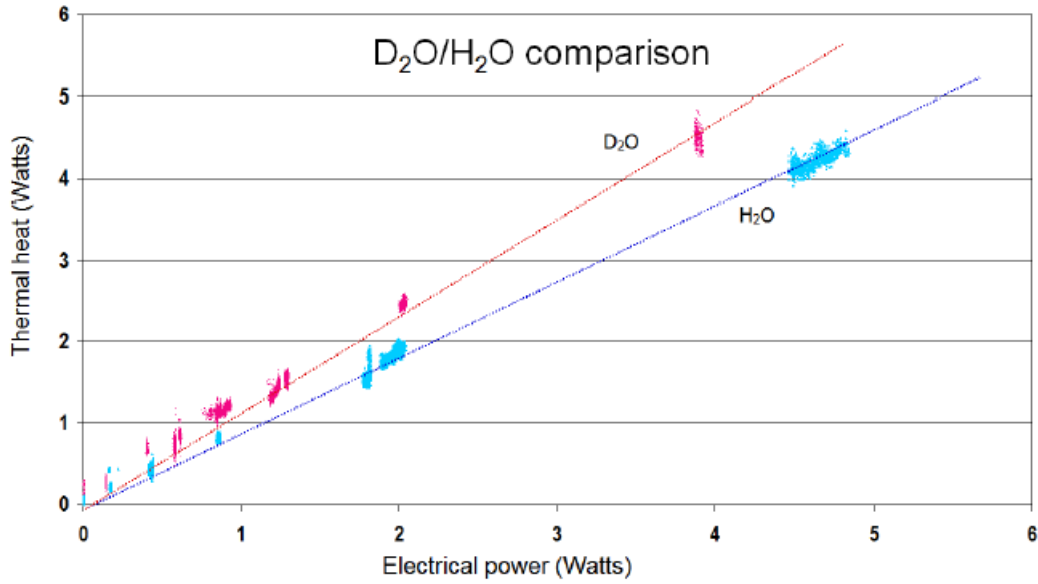


Figure 13. Comparison of experiments in light water and heavy water.

output power versus time. Up to hour 401 excess heat of a few watts appeared periodically (excess is  $P_{in} - P_{out}$ ). Soon after hour 701, an explosion occurred.

Figure 15 shows the remains of the bottom of the cell after the explosion. Glass fragments were scattered meters

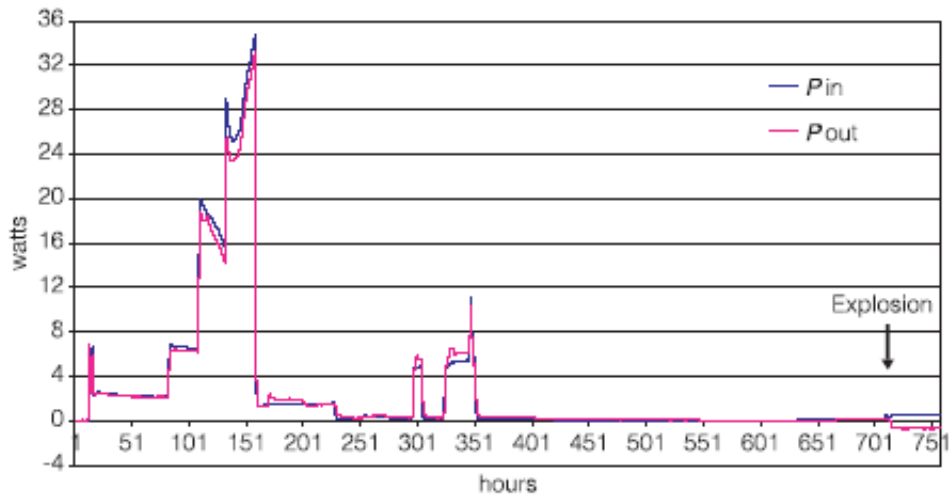


Figure 14. Power in and out versus time before the explosion.



**Figure 15.** Broken cell after the explosion.

away.

Figure 16 shows both the original Dewar and the broken interior of the cell with the cathode and anode. The cell was not sealed, so a deuterium-oxygen recombination explosion could not have broken the Dewar. To check this hypothesis, several explosions were deliberately triggered after adding a stoichiometric mixture of hydrogen and oxygen to a cell. No damage occurred to the cell as a result of these tests. It is therefore possible that in this case the explosion was of nuclear origin: some kind of chain reaction.

## 8. Conclusion

In this paper, I have reported several experiments that produced excess heat using various techniques. Some, such as the solid-state electrolyte experiments, had large COP, but low heat. On the other hand, deuterium diffusion experiments



**Figure 16.** Interior of the cell after the explosion.

showed larger excess heat, but a lower COP.

In this paper, I did not mention the collaboration with Roger Stringham and Russ George in sonofusion experiments. The results were very positive and interesting.

In addition to the positive work, I have performed many experiments which were negative with no excess heat.

### Acknowledgements

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