

# Cold Fusion

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**Abstract**—This paper is a review of the work I have performed on the subject of Cold Fusion alone or in cooperation with other scientists. It covers a number of fields like solid-state electrolytes, electrolysis, gas diffusion. The experiments described below are the one having given positive results. However, many other attempts have failed.

**Index Terms**—Solid-State, electrochemistry, deuterium diffusion, plasma electrolysis.

## I. INTRODUCTION

My interest in Cold Fusion started day one. However, not being 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, gas diffusion and plasma electrolysis. In this paper, I report my almost 20 years of work in this field.

## II. PROTON CONDUCTORS

When I met Francis Forrat in 1993, I was at the Lawrence National Berkeley Laboratory working on two-dimensional surface structures, a subject not related to LENR. Francis Forrat had filed a 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 experiments with  $\text{LaAlO}_3$  single crystals with lanthanum vacancies at the Lawrence National Berkeley Laboratory.  $\text{LaAlO}_3$  crystals with lanthanum vacancies have a red color due to the V centers, whereas the stoichiometric crystals are white. As predicted by Forrat, when the samples are loaded with hydrogen or deuterium, the red color of the crystals with V centers turn white. This behavior indicates that the lanthanum vacancies are filled with hydrogen or deuterium.  $\text{LaAlO}_3$  has a perovskite structure: when stoichiometric it is an insulator, when it has V centers it becomes a high temperature proton conductor.

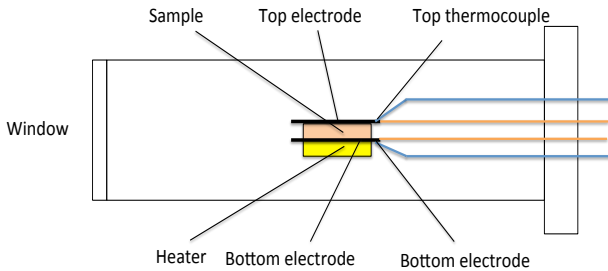


Fig. 1. Chamber design.

The calorimeter of the first experiments in Berkeley was very simple and therefore subject to criticism. The red  $\text{LaAlO}_3$  single crystal about 2 cm<sup>2</sup> by 1.5 mm was squeezed between two tantalum electrodes. The temperature of the ensemble was controlled by, a tungsten wire heater. Two thermocouples located on the bottom and top electrodes measured the temperature of the sample. The system was positioned inside a 35mm stainless-steel chamber with electrical feedthroughs on one side and a glass window on the other side. The chamber was evacuated with a mechanical pump down to 10<sup>-2</sup> Torr, and filled with hydrogen or deuterium gas. Figure 1 shows a schematic of the set-up.

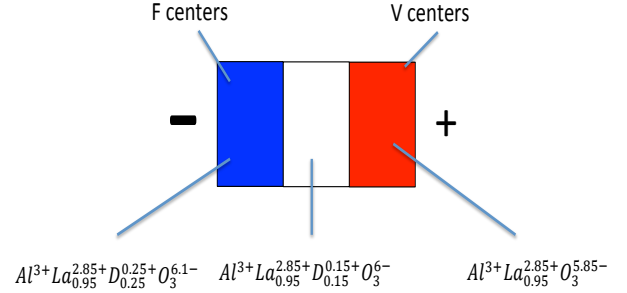


Fig. 2. Sample colors upon electrolysis.

When a DC current was passed through the crystal, a deuterium concentration profile takes 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 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 temperature difference between the bottom thermocouple and room temperature is plotted against total input power, which includes the heating power and the power passed through the crystal. In black, the curve without crystal current, and in red the curve with the added crystal current, in a deuterium atmosphere. An extra temperature rise is observed when the crystal current is added indicating an excess heat. However, the experiments were only preliminary and were not published. In particular, there was no data acquisition system, and therefore the measurements lacked precision.

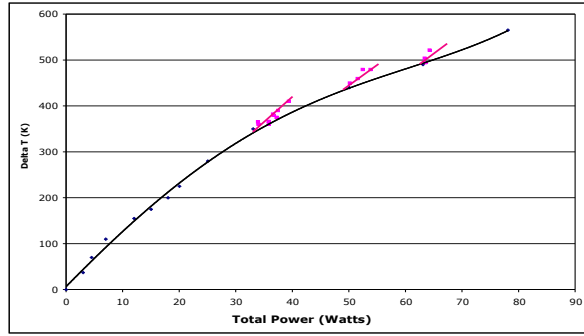


Fig. 3. Bottom thermocouple versus total power.

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, this extra heat changed the resistivity of the tungsten wire. By measuring the resistivity (voltage divided by current), the heat generated by the crystals was calculated.

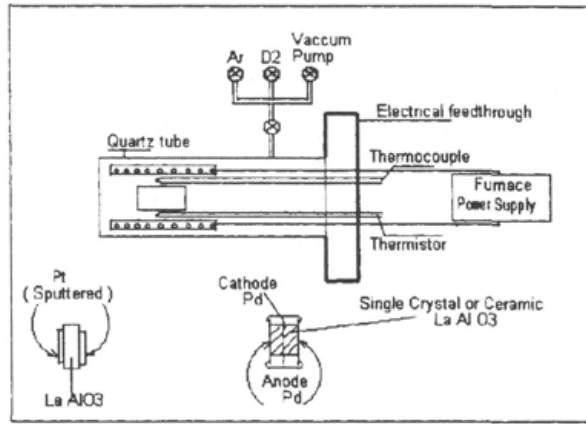


Fig. 4. Schematic of the second chamber.

Figure 5 shows the production of excess heat. We performed experiments in constant current mode, and we observed “heat after death” i.e. the heat remained for almost two hours after switching off the power supplies. Therefore, we changed to a pulsed mode which gave excellent results. We applied 120 mW pulses one second wide every minute. They produced 150 mW of excess heat. The COP was therefore 75

These experiments show the role of vacancies in LENR, and also of operations in pulsing modes instead of constant current. These results were in agreement with the observations made by Mizuno et al. [3] with a different crystal, but with similar crystallographic structures.

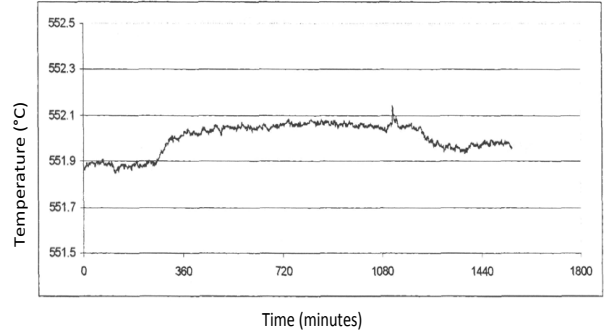


Fig. 5. Temperature rise versus time.

### III. PATTERSON TYPE EXPERIMENTS

Following James Patterson’s work [4,5] showing excess heat and nuclear transmutation, we have developed our own system [6]. The experimental set-up consisted of a cell: 30 mm ID cylinder, a nickel mesh cathode was 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 one micrometer each) were electrodeposited on the 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 by two thermistors. Figure 6 shows a schematic of the whole system.

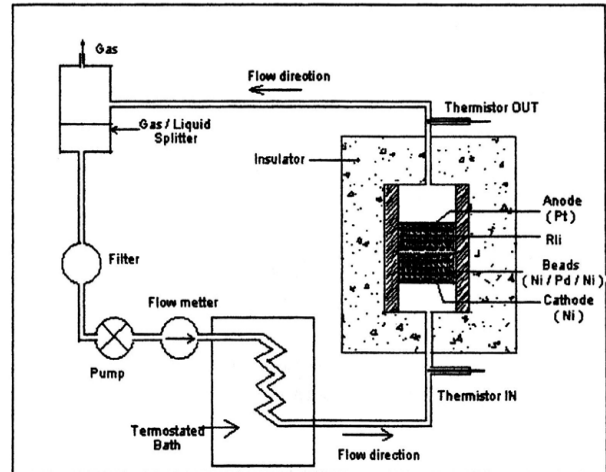


Fig. 6. Schematic of the operation of the cell.

A blank experiment without electrolysis showed no excess heat. On the contrary, when electrolysis was happening excess heat was produced. The total excess heat increasing with increasing power. However, the yield was the highest at low power. The excess heat was close to 100% at low power as shown in figure 7.

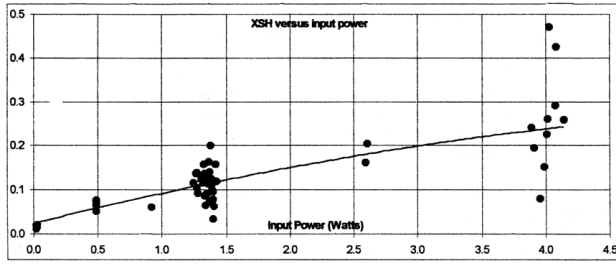


Fig. 7. Excess heat versus input power.

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

#### IV. PONS AND FLEISCHMANN BOILING EXPERIMENTS

In their original work, Fleischman and Pons [7] operated their cells below boiling temperature. Later, they did let the cell go up to boiling, and by measuring the amount 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, shows a schematic of the cell, identical to the one used by Fleischmann and Pons.

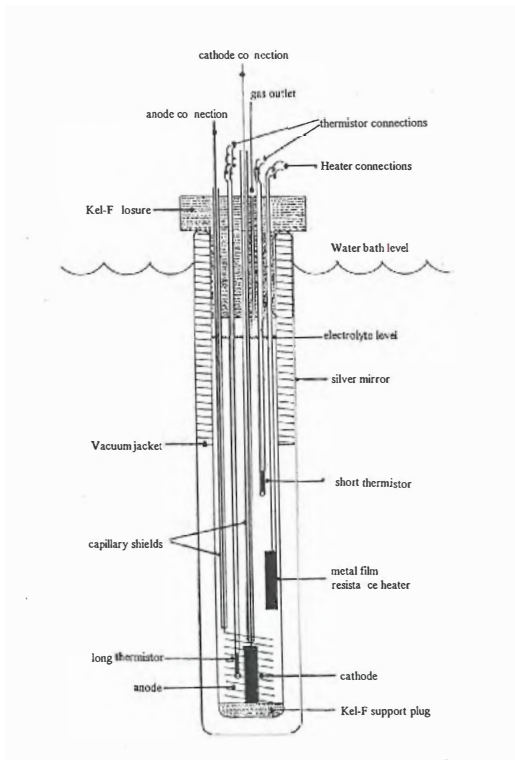


Fig. 8. ICARUS II type cell.

We measured (see table 1) at boiling temperature excess heat up to 29 %, in qualitative agreement with Fleischmann and Pons. However, the magnitude of the excess heat that we 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.

TABLE I  
EXCESS HEAT IN BOILING CELLS

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%

The experiments in Li<sub>2</sub>SO<sub>4</sub> are surprising since they seem to show that the palladium is active, and that even platinum is active.

#### V. DIFFUSION OF DEUTERIUM THROUGH PALLADIUM

In 1989, Fralick et al. [11] showed that when deuterium is pumped out of 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 on a continuous way [12]. Figure 9 shows a schematic of the mass flow calorimeter. A 2 mm diameter palladium tube 10 cm long is inserted inside the vacuum chamber. The deuterium gas is fed inside the palladium tube heated by a resistor. The deuterium diffuses out of the tube and is pumped out through the vacuum chamber.

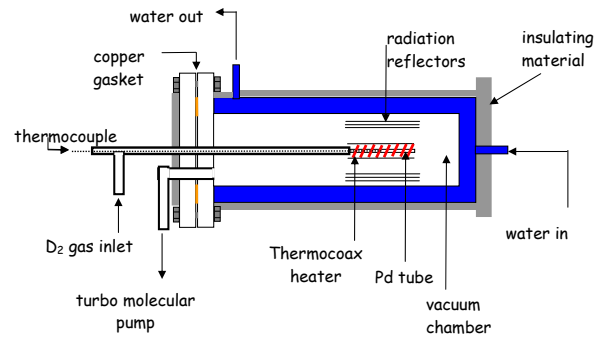


Fig. 9. Mass flow calorimeter.

Figure 10 shows the palladium tube closed at one end and the vacuum chamber with a double wall for cooling.



Fig. 10. Palladium tube and external part of the calorimeter.

Figure 11 shows a 12 days 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 Watts was detected with an input power for heating the tube of 48 Watts.

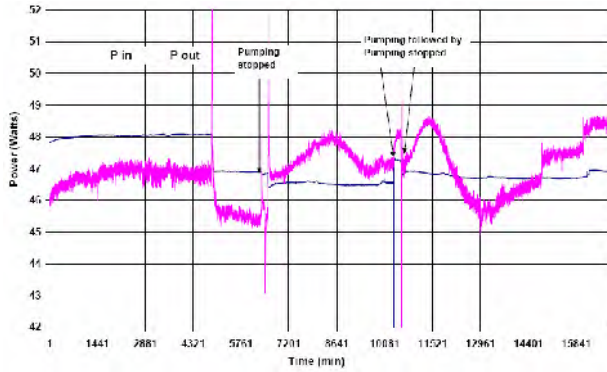


Fig. 11. Thermal heat and input power versus time.

This corresponds to an excess of 8% for 7 days. The experiment was terminated because of the cost of the deuterium gas being wasted.

#### VI. MASS FLOW ELECTROLYSIS

Isoperibolic calorimetry needs calibration; therefore it was tempting to develop a mass flow calorimeter that will give the thermal power without any calibration. This is the reason why I developed a mass flow calorimeter that can operate up to boiling temperature. Figure 12 shows a schematic of the calorimeter.

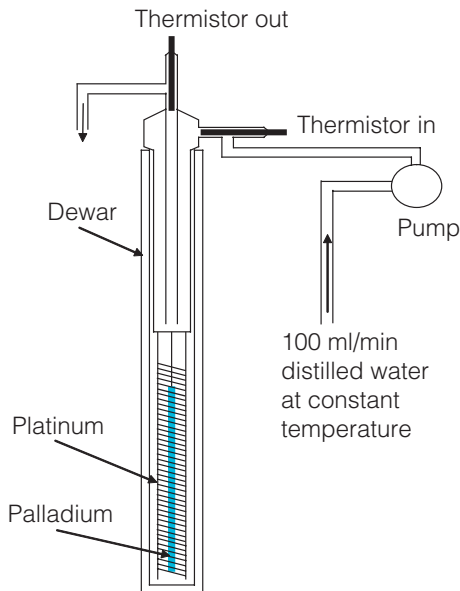


Fig. 12. Mass flow calorimeter.

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 vapors condense on a glass condenser positioned at the top of the cell.

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

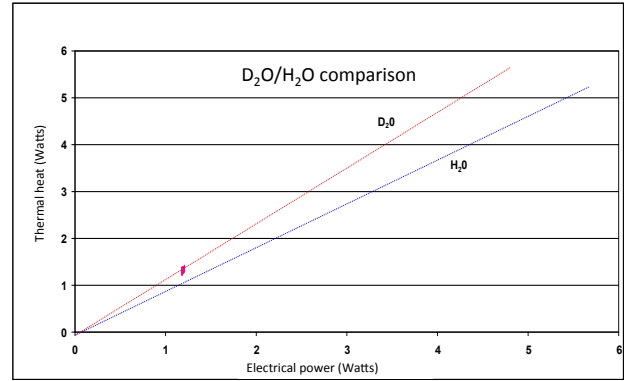


Fig. 13. Thermal heat versus input power.

#### VII. CELL EXPLOSION

In an attempt to replicate the results obtained with the palladium tube as described in section V, the 12 mm cathode was replaced by a 10 cm long, 2 mm in diameter palladium tube closed at the bottom [13]. Figure 14 shows the input and output powers versus time. Some parts of the curve show excess heat. But, at time 701, an explosion occurred.

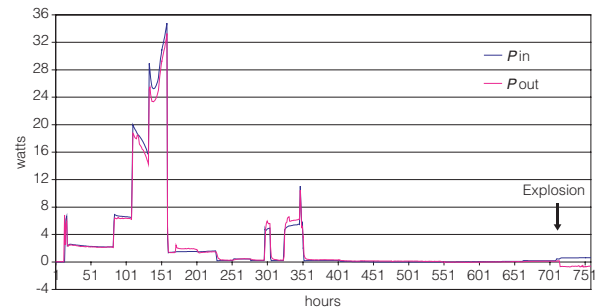


Fig. 14. Power out versus power in before the explosion.

Figure 15 shows the remains of the bottom of the cell. The glass parts were scattered meters away.



Fig. 15. Broken cell after the explosion.



Figure 16 shows both the original Dewar and The broken interior of the cell with cathode and anode.

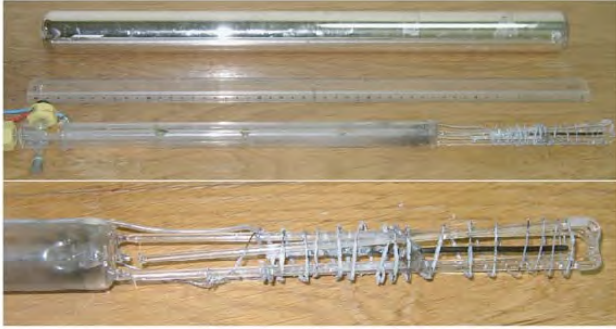


Fig. 16. Interior of the cell after the explosion.

The cell was not sealed, and a deuterium oxygen explosion should not have broken the Dewar. In order to check this hypothesis, several attempts have been made by triggering an explosion with a mixture of hydrogen and oxygen. Three attempts have been made without damage to the cell. It is therefore possible that in this case the explosion was of nuclear origin: some kind of chain reaction.

#### VIII. PLASMA ELECTROLYSIS

Following the work of Mizuno et al. [15,16] and Fauvarque et al. [17] of plasma electrolysis, we have started a research project in this direction. In the new approach [18], we have developed a calorimeter that can be monitored continuously. The electrolytic cell is placed on a scale having a precision of 0.2 g which data are recorded continuously by a RS232 interface directly in a computer. A LabView program measures with a 30 seconds period, both the weight loss of the calorimeter, the voltage, the current and the electrical power applied to the cathode. To ensure a good measure of the electrical power, we used a power meter Norma D600 Power Analyzer, with a sampling rate of 70 kHz.



Fig. 17. Plasma discharge.

The experiments were performed at boiling temperature, so that all the heat produced was escaping as

water vapor escaping the cell, which was continuously measured by the mass loss. The cell is a 10 cm diameter and 24 cm deep Dewar. The cathode is at the center of the cell, and the anode is a stainless-steel foil. Figure 17 shows a plasma discharge with a 3.4 mm diameter tungsten cathode and  $K_2CO_3$  electrolyte with light water.

A calibration with a resistor produced a COP (Coefficient of Performance) of 0.95, indicating that only 5% of the heat was lost by conduction. However, the major issue with this technique is the loss of water splashing out of the cell. This is happening during the plasma discharge, and not with the resistor. To resolve this problem we covered the Dewar with a plastic cap 34 cm high, with a 4 cm diameter hole at the top.

This new set-up shown in figure 18 eliminated totally the droplets leaving the cell. However, a new calibration gave a COP of 0.7 due to the large amount of heat loss through the cap.

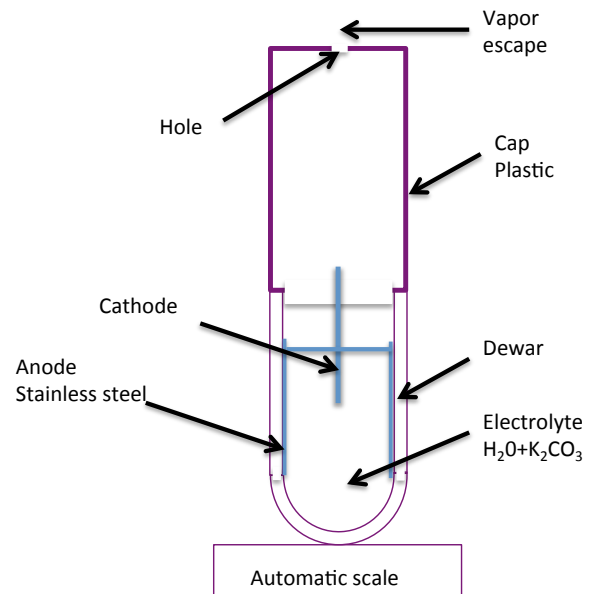


Fig. 18. Experimental set-up.

The first experiments at constant voltage produced no excess heat. We experimented with pulsed current, and the excess heat was immediate. We obtained a COP of 1.1; therefore if we compare it to the calibration, the actual COP is about 1.5. As the input power was 200 Watts, the excess heat produced was 100 Watts.

We have tried various cathode materials: tungsten, nickel and molybdenum. We did not detect major differences between these materials. We noticed that the most important factor is the diameter and the length of the electrode. Figure 19 shows a 3.4 mm tungsten cathode after use.



Fig. 19. Tungsten cathode after operation with the alumina tube limiting the active part.

The frequency of the pulses were varied, however, our best results were obtained around 1 Hz.



Fig. 20. Photograph of the experimental set-up.

Figure 20 shows a photograph of the whole system with the scale, the Dewar and the cap.

### IX. CONCLUSION

In this paper, I have reported several experiments showing excess heat with various techniques. Some had large Coefficient of Performance, like in the solid-state electrolyte experiments, but with low absolute values. On the other hand plasma electrolysis experiments showed large excess heat, but a low COP. In this paper, I did not mention the collaboration with Roger Stringham and George Russ which was very positive. We obtained interesting results in sonofusion experiments.

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

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