

SOME LESSONS FROM OPTICAL EXAMINATION OF THE PFC Phase-II CALORIMETRIC CURVES

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ABSTRACT

Much current skepticism of the cold fusion phenomenon was created by a paper by the MIT Plasma Fusion Center (PFC) reporting a "failure-to-reproduce" the experiments of Fleischmann and Pons, as opposed to its later claimed "too-insensitive-to-confirm" experiments. Because it may be the single most widely quoted work used by critics of cold fusion to dismiss the phenomena, the paper should have clarified all data points and the methodology used.

The present study used optical scanning of the PFC Phase-II data curves from the paper and later curves purported to be the same experiment. Quantitative analysis of the curves reveal that a bias was introduced into the D₂O curve relative to the light water curve tending to obscure the generation of heat. The Phase-II algorithm was also insensitive to steady state excess heats.

keywords: calorimetry, PFC Phase-II experiment.

INTRODUCTION

Electrochemically-induced excess enthalpy reactions using palladium filled with deuterons^{1,2,3} have been difficult to reproduce, and incorrectly connote a "failed" technology in the minds of many scientists – even as the positive literature grows. Many skeptics cite the published Phase-II data⁴ from the Massachusetts Institute of Technology Plasma Fusion Center (PFC). However, by 1991 scientific criticisms of the PFC data and techniques pointed out faults with its thermal calculations and conclusions⁵ and differences between several curves purported to be the result of a single Phase-II heavy water experiment in 1989. More criticism has accrued over differences between one in-house report (July 10, 1989) and a later July 13, 1989 prepublication report⁶. The most serious complaint has involved alleged "shifting" of the heavy water excess power curves⁷.

The PFC Phase-II authors discussed the paradigm used⁴.

"This equation ($P_c + P_h = \text{constant}$) allows the unknown power, P_c , to be determined. If P_h increases, then the feedback control system of the calorimeter reduces P_h to maintain T_c constant".

Therefore it is important to note that any potential curve shift would hide part, or all, of any measured excess heat. Furthermore, it was presumed that baseline shifts were the same for the H_2O and D_2O , and based upon careful calibration experiments⁶.

"(T)he data for the H_2O curve ... was taken at the time of the 1989 experiments, and in the exact same way that the data was obtained for the D_2O curve".

The curves reported by the PFC (for both heavy and light water) were examined using computed optical techniques⁹ which facilitated precise superposition of the curves. As a result, some of the figures thus demonstrate two sets of numbers along one axis consistent with the technique. These curves included the raw heater power data, the preliminary derived curves (July 10, 1989), the prepublication curves⁶ (July 13, 1989), the J. Fusion Energy published curves⁷, and the March 10, 1992 Memo curves [later compiled in an in-house PFC May 1992 Appendix¹⁰].

Table 1 lists the different curves of the Phase-II heavy water experiment in 1989. Type 1 curves are the continuous raw heater power D_2O data. A baseline shift of the heater power curves of circa 900 nanowatts/second was applied to the Type 1 curve to get the Type 2 curve. A second circa 94 nanowatts/second shift was applied to generate protoType 3. The superposition of additional points (e.g. point "A"), not present in either the Type 1 or Type 2 curves, completes the transformation to the Type 3 curve. The Type 3 curve [composed of dots in the July 13, 1989 manuscript¹⁶] was reported to be a time average of the original data. The published curve [Type 3_a⁴] is nearly identical to the (dotted) Type 3 curve⁶ and differs only in that the heavy water curve widens focally between some groups of data points. The Type 4 curve, which appeared March 1992^{9,11}, has one of the published "data" points moved 24 milliwatts; the other questioned "data" points are missing. In the "newest" curve [Type 5] all of the "data" points have vanished.

RESULTS: EXAMINATION OF THE CURVES

Figure 2 shows the matched superimposed excess heat curves taken from the July 10, and 13, 1989 data sets. The upper set is for the light water. The lower pair is for heavy water (cell B). For each paired set both the July 10, 1989 data (continuous curve in black) and the July 13th prepublication "averaged" data (blue dots) are shown.

TABLE 1 - THE PFC PHASE-II D₂O CURVES

This table lists several curves of that single experiment.

| # | CODE | DUR | NI | CONT | INCID | QUEST | ASYM | ? PT | BLS | DOCUMENT | ASSIGNMENT |
|----|----------------|--------|----|------|-------|-------|-------|-------|-------|----------|--------------|
| | | | | | | | | | | | |
| 1 | 1 _p | 10-98 | 1 | CONT | In.a. | In.a. | In.a. | In.a. | In.a. | 17/10/89 | Raw data |
| 2 | 1 _p | 10-98 | 1 | CONT | In.a. | In.a. | In.a. | In.a. | In.a. | JFE 90 | Published |
| 3 | 1 _p | 10-90 | 1 | CONT | In.a. | In.a. | In.a. | In.a. | In.a. | 9/1991 | Memo 1991 |
| 4 | 1 _p | 10-98 | 1 | CONT | In.a. | In.a. | In.a. | In.a. | In.a. | 13/10/92 | Best? |
| 5 | 1 _p | 11-98 | 1 | CONT | In.a. | In.a. | In.a. | In.a. | In.a. | 5/92 | PFC/RR-92-7 |
| 6 | 2 | 10-98 | 1 | CONT | In.a. | In.a. | ? | In.a. | 900 | 17/10/89 | Memo 7/10/89 |
| 7 | 3 | 118-98 | 1 | DOTS | +++ | +++ | yes | In.a. | 994 | 17/13/89 | Memo 7/13/89 |
| 8 | 1 _p | 118-98 | 1 | DOTS | +++ | ++++ | yes | In.a. | 994 | JFE 90 | Published |
| 9 | 4 | 118-98 | 1 | DOTS | - | lgone | yes | yes | 994 | 13/10/92 | 3/10/92,5/92 |
| 10 | 5 | 118-98 | 1 | DOTS | lgone | lgone | yes | gone | 994 | 13/10/92 | Memo 3/10/92 |
| 11 | 6 | 118-98 | 1 | CONT | In.a. | In.a. | In.a. | In.a. | yes | Fig.6 | Calibrated |

CODE - TYPE - Type 1 has five graphs, shown in figure 1. They are nearly identical with various portions clipped or removed. Curve 1_p may be the best raw data curve released to xx data.

DURN - Duration of Experimental Time shown in graph. Clipping often occurs at >80 hours or 0-16 hours.

CONT - Continuity. Continuous (CONT) or binned samples (DOTS).

INCID(ental) Points - Points from experimenter-created glitch.

QUEST(ionable) Points - Points beyond the raw data curve.

?ASYM(metric) SHIFT - Is there a second shift of the curve beyond the first baseline shift.

? P(point) SHIFT - Is there movement of point "A" to "A".

BLS (Baseline Shift) - Is there any baseline shift?. Quantities are nanowatts per second.

n.a. Not Applicable.

ASSIGNMENTS BY TYPE

Type 1 are the raw data curves which have been released in several forms and are virtually identical.

1_p - BEST PROBABLE RAW EXPERIMENTAL DATA - continuous.

1_c - PROBABLE RAW EXPERIMENTAL DATA - continuous.

Identical to 1_p; clipped at circa 80 hours.

Types 2 and 3 are the previously released 7/10 and 7/13/89 excess power curves. Type 3_p was published*, and is slightly different from Type 3, but not enough to warrant a new category.

2 - FIRST-SHIFTED BASELINE (July 10, 1989 curve)

Continuous (shift circa -800 nanowatts/second).

3 - SECOND-SHIFTED BASELINE (July 13, 1989 curve)

Sampled data (shift circa -990 nanowatts/second).

3_p - PUBLISHED D₂O CURVE - Figure 5b in J. Fusion Energy (9, 1989)

Types 4 and 5 (March 10, 1992 PFC memo) were derived using various regression fits (although given to five significant figures, the correlation coefficients were not presented).

4 - NEW SHIFTED BASELINE (Fig. 5 in 3/10/1992 Memo*)

Sampled data: one incidental point missing; the other shifted 24+ milliwatts; other minor differences.

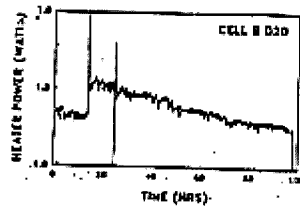
5 - NEWEST SHIFTED BASELINE (Fig. 9 in March 10, 1992 Memo*)

All incidental and questioned points missing.

6 - CALIBRATED DERIVATION OF EXCESS HEAT

Correction based upon initial slope of Phase-II data.*

**TYPE 1: RAW DATA [7/10/89]
AND CONGENERS**



TYPE 1_B [J.F.Energy '90]

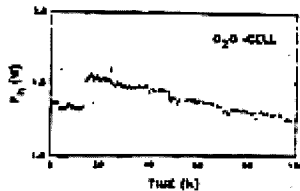
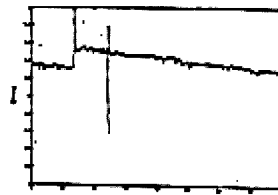
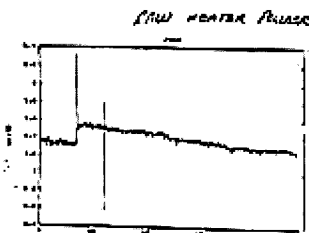


Fig. 6. Time history of the calculated heater power near $\times 10^{24}$

TYPE 1_C [circa 9/91]

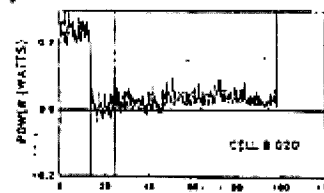


TYPE 1_D [3/10/92]

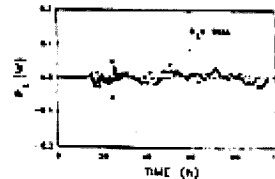


flow heater phase ϕ (11 channels)
(PER BLOCK)

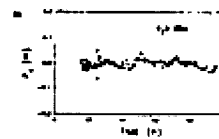
**TYPE 2: FIRST SHIFTED CURVE
[7/10/89]**



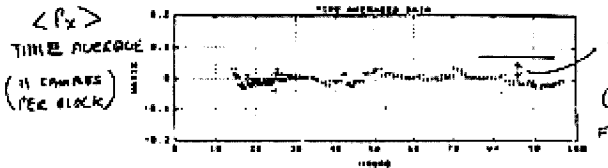
**TYPE 3: SECOND SHIFTED CURVE
[7/13/89]**



TYPE 3_B [J. Fus. Energy '90]



TYPE 4 [3/10/92; +24 milliwatt shift]



TYPE 5 [3/10/92; "cleansed"]

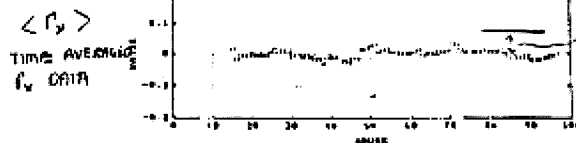


Figure 1 - FIVE TYPES OF Phase-II D₂O CURVES

These nine different graphs are of a single MIT PFC Phase-II heavy water experiment in 1989. Five types are distinguishable. The four graphs on the left (Types 1, 1_B, 1_C, and 1_D) are nearly identical with various portions clipped at 80+ hours or 0-16 hours. Types 2 and 3 are the July 10, and 13, 1989 curves, respectively. Type 3_B was published in J. Fusion Energy [9, 133 (1990)]. Types 4 and 5 appeared March 10, 1992.

The two continuous curves (Type 2 from the July 10, 1989 manuscript) demonstrate high frequency components. Examination of the light water curves (Figure 2, upper pair) reveals a very good correlation between the July 10th (Type 2) and the twice-processed (July 13th, Type 3) prepublication curves.

This implies there was a negligible (second) baseline subtraction for the light water data. In contrast, the two heavy water curves (Figure 2, lower pair) have a poorer correlation which imply a baseline subtraction. In addition, almost none of the twice-processed data points overlap the July 10th data beyond 30 hours. The Type 3 curve appears too wide on its left hand side.

Given the assymetric treatment, an attempt was made to determine what algorithm(s) were used to process the curves. A linear model was used to determine the transformations used.

$$\text{Type 2} + [A + (B \cdot t)] \longrightarrow \text{Type 3}$$

A and B define the linear terms for that second baseline shift. A has the units of watts; and B has the units of watts/second. Several curves were derived using various A and B parameters and are shown in figure 3. Figure 3 shows three sets of curves. First, a temporal averaging for the heavy water July 10, 1989 curve was derived. The upper two curves present both the low-pass ("time averaged") curve and the PFC heavy water Type 2 (July 10, 1989) curve from which it was obtained.

Various linear baseline shifts were effected upon the low-pass D_2O curve, and are shown in the mid and lower portions of figure 3. The middle set of curves in figure 3 are the superposition of the low-pass curve with four linear baseline shifts [A=0]. The published (Type 3_p) heavy water data of the PFC is also shown as the darkest dots. The darker red continuous curve (with the greatest time-varying baseline shift) shows the superposition of A=0 and B= -158 nanowatts/second upon the low-pass curve.

The lower set of curves in figure 3 show the superposition of the low-pass curve with various fixed (non time-varying) baseline shifts [B=0]. The published Type 3_p data points are again shown as the blue dots. The red continuous curve (with the greatest fixed baseline shift) shows the effect of A= -59 milliwatts and B=0 superimposed upon the low-pass curve. The published curves for heavy water [Type 3 or 3_p] are too thick for the initial data set on their left hand side. Because the possibility of superimposed points added to a linear transformation cannot be excluded, it is unclear which values of A and B produce the best fit. Notwithstanding the above, the transformation possibly used to change the Type 2 (7/10/89) to Type 3 (7/13/89) D_2O curve included approximately:

- fixed baseline shift [A=] -9.6 milliwatts, and
- time varying shift [B=] -94 nanowatts/second.

As a control, to determine the total energy subtracted from the July 10, 1989 curves, the actual integrals under the power curves were measured using the duration of the

experiment. For the heavy water this was 30 milliwatts (+/- 15%) in the time beyond 18 hours. The light water curve was characterized by an average power baseline subtraction of 0.3 milliwatts. This estimate has only qualitative agreement with the curve fitting technique (difference 12%) which may in part be due to the width of the curve as discussed above.

In summary, this analysis demonstrated that either a relative D_2O/H_2O excess power was measured, or that an asymmetric (second) treatment of the data was used after July 10, 1989, that is, the light and heavy water data were processed differently, but that could be approximated by a linear transform. Given the asymmetric transformation, and specifically the difficulty with the fitting of a linear transform, a closer look between the curves was undertaken. This examination revealed that some of the points in the published D_2O curves appear artifactual, of two varieties⁹. Points A, A', and "iii" in figure 4, one variety, are positioned along what was purported in the published paper to have been "intentionally introduced as a time calibration mark." It is not been reported how the locations of points A and A' (in Type 3 and Type 4 curves, respectively) were chosen, or why the published temperature curve¹² changed at that time.

The artifacts were reported to the PFC in February 1992, and a March 10, 1992 PFC memo presented two "new" curves (Types 4 and 5) to "correct" this matter¹⁷. The new curve (Type 4) is examined in the mid and lower sets of curves in figure 4. At least three published data points [labelled "i", "ii", and "iii"] are missing from the Type 4 curve. Most notably absent is data point "iii", the expected opposite superior half of the "incidental" points: "A" and "A'". The magnitude of the "data" point shift [A to A'] is +24 milliwatts. This point shift is one of a number of changes used to optically identify and distinguish this Type 4 curve.

Why was a second baseline subtracted from the D_2O curve after July 10, 1989? The PFC has said that the "shift for the heavy water data came as a result of a computer subtraction designed to compensate for water evaporation (15)." However, Albagli⁴ states that the temperatures of the two solutions were similar. The temperature curve imaging indicates that the H_2O experiment was operated at a higher (1 degree Centigrade) temperature. Given that for each temperature the vapor pressure of D_2O is less than H_2O [deuterium oxide melting point (STP) is 3.82 Centigrade, its boiling point is 101.4C] more evaporation would have occurred for the light water.

In summary, putative differential excess solvent loss for heavy water is not a reasonable explanation for the asymmetric algorithm used to shift the 7/10/1989 D_2O curve. Therefore, less baseline subtraction should have been used for the D_2O data. The PFC data itself indicates that evaporation was a minor source of solvent loss, because the calculated thermoneutral potentials were quite close to their theoretical values².

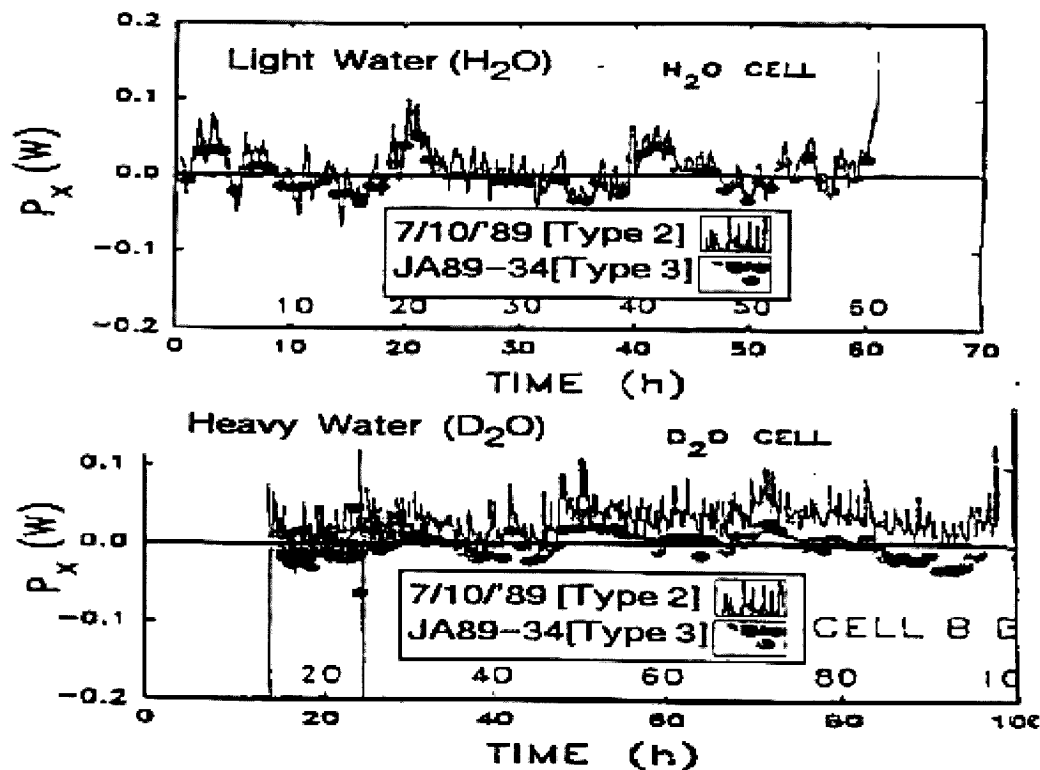


Figure 2 - Phase-II Curves from JULY 1989

These are composite curves of the MIT PFC Phase-II data [after Albagli et al. (1989, 1990)]⁴. The upper are light water (H_2O) and the lower are heavy water (D_2O). The continuous dark curves are from July 10, 1989 (Type 2). The curves composed of dots are from the July 13, 1989 PFC Report JA-89-34 (Type 3)⁶.

RESULTS: SENSITIVITY OF THE PHASE-II METHODOLOGY

Because of the difficulties noted with the curves, a new hypothesis was explored. Was the paradigm sensitive to potential excess heat? The PFC "first subtract(ed) the baseline drift [so that] any onset of anomalous heating would appear as an excursion from zero."⁴ The attempt was to explore various linear baseline shiftst¹⁰. An independant analysis determined whether the Phase-II method was sensitive to excess enthalpy^{3,12}. The algorithm used in the Phase-II experiment is flawed because it hides any constant excess heat. The effect of removing the baseline based upon a linear regression from data taken after the experiment begins simply eliminates any steady state signal. This is shown in figure 5.

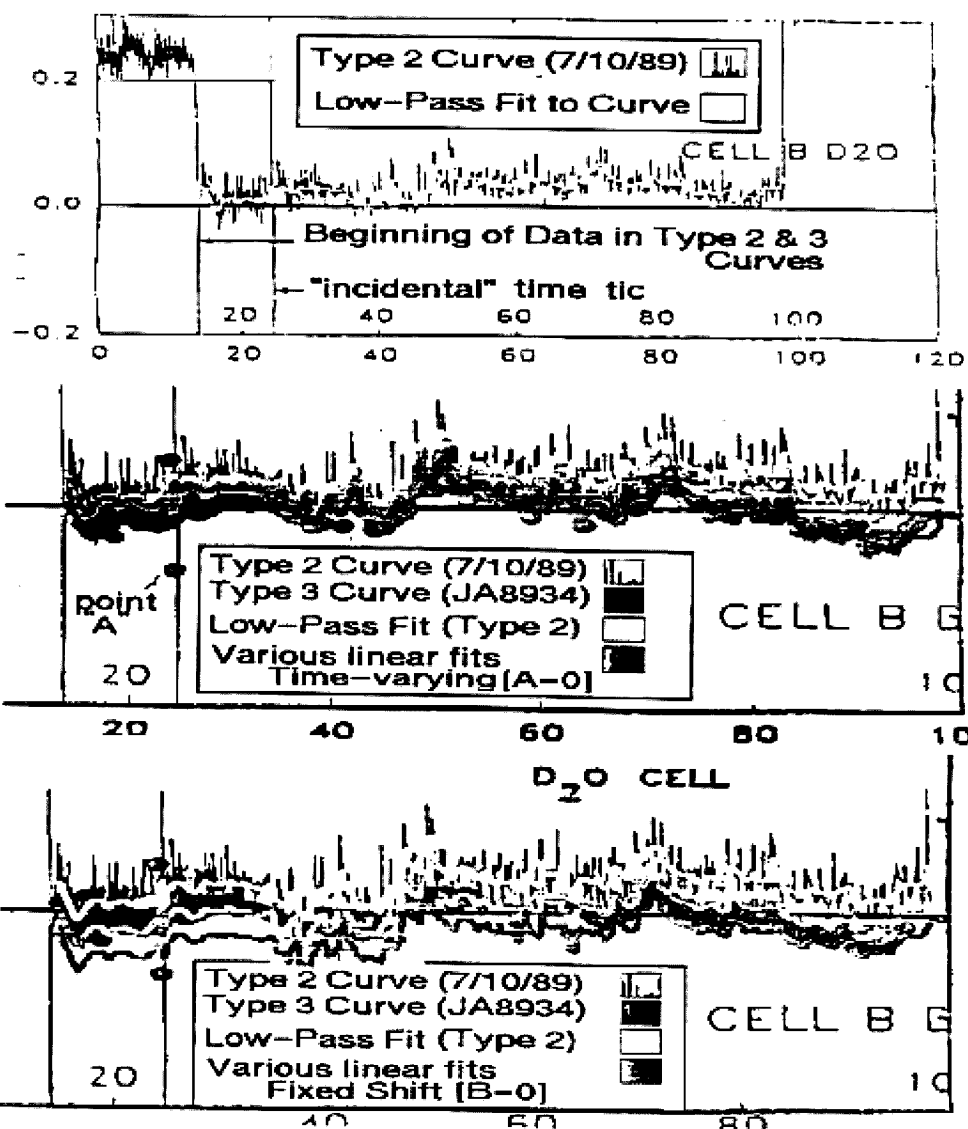


Figure 3 • LINEAR CHANGES TO THE TYPE 2 CURVE

The upper two curves are the Phase-II D_2O Type 2 curve (continuous high frequency) which is superimposed upon a low-pass [time-average] curve. The mid and lower sections show the Type 2 curve, with the low-pass curve superimposed upon it, and the published curve (J. Fusion Energy (1990), Type 3₀) in black with its characteristic thicker line and accompanying dots. Also shown are linear displacements of the low-pass curve. In the midsection, four time-varying fits [A=0] are shown; whereas in the lower section three fixed baseline shifts [B=0] can be seen.

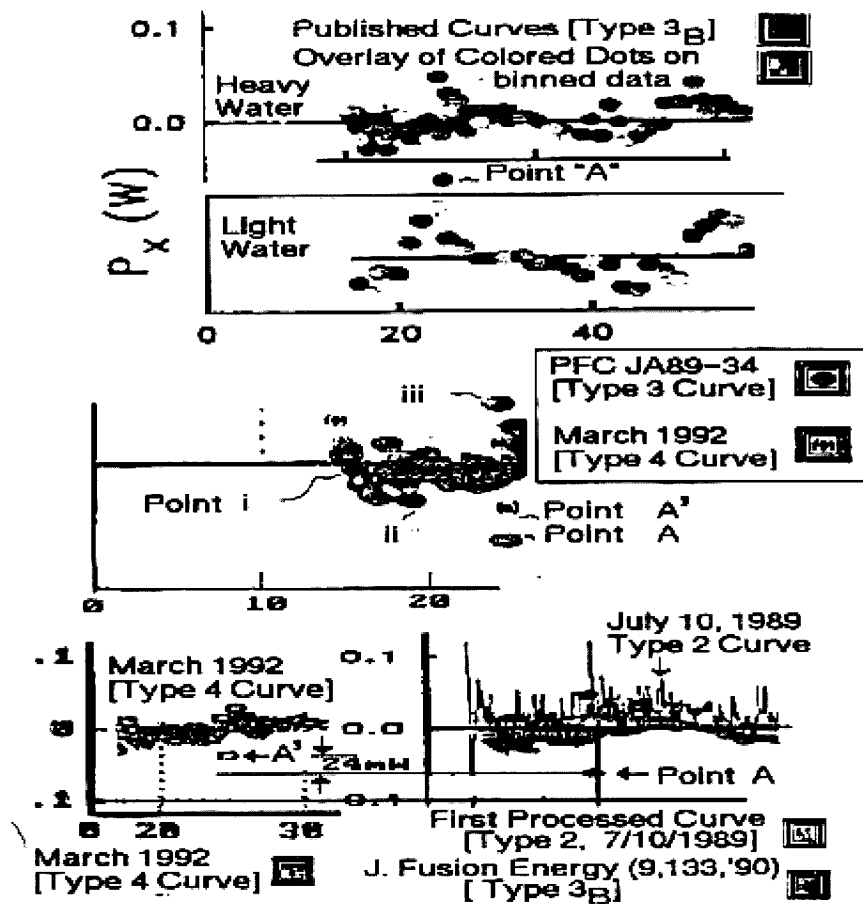


Figure 4 - EXAMINATION OF TYPES 2, 3, AND 4 CURVES

These three composites examine the PFC D₂O curves. The curves have been normalized, put in registration, and superimposed. The times are hours and the power (vertical axis) is watts.

Upper: Two juxtaposed curves (Type 2) enable a count of data points in a period of 40 hours.

Mid: These curves demonstrate the disappearance of points from the Type 3 -> Type 4 transformation. The Type 3 curve (dark dots) is compared to the post-publication-3/10/1992 (Type 4) curve. The only change is that in the 3/10/92 memo, the Type 4 curve had the symbol "[]". For easier identification and examination, one solid dot has been placed between each pair of brackets. The curves demonstrate data points A (Type 3) and A' (Type 4), and the shift of Point A' toward the baseline.

Lower: Shifted point (A) drifts by 24 milliwatts in the Type 4 curve on the left hand side. One published curve [Type 3 (PFC/JA-89-34)] is on the right hand side along with the July 10, 1989 curve [Type 2; black continuous curve].

Such flawed paradigms yield only a breakpoint at an intermediate time (the reverse-"Z" sign), and the presence of excess heat is not clearly revealed. It is interesting that reexamination of the PFC heavy water published curves (Types 3 and 3_B) reveal such a pattern which is a possible "signature" of excess heat detected by the Phase-II methodology.

RESULTS: REEXAMINATION OF THE PHASE-II D₂O CURVES

Given the asymmetry of the curve shifts for the heavy and light water experiments, and the insensitive paradigm, it is thus important to consider if there actually was excess power in the D₂O experiment. The PFC paper⁴ actually gave indications of excess power:

"(w)hen enough solvent was added to the D₂O cell to compensate for that lost to electrolysis at the end of the 100 h period shown in Figure 6, Ph (the heater power) returned to within 20% of its original value."

[Albagli et al., J. of Fusion Energy, 9, 133 (1990);
underline added for emphasis]

That 20% discrepancy in heater power, used to heat the same volume of fluid has been suggested as corroborating evidence that the heavy water cell produce excess heat. Noninski analyzed these thermal matters⁵ and calculated that as much as 2 watts per cm³ palladium of excess power was generated over 60 hours for the heavy water.

The optical analysis and integral derivations of subtracted energy from the D₂O curve⁹ indicate approximately 400 milliwatts per cm³ generated for the 9 cm by 0.1 cm diameter cathode.

This excess heat was also possibly corroborated by a calibrated excess power curve [P_{XT} , the "true" corrected excess power] for the Phase-II D₂O experiment which was derived using appropriate mathematics for the baseline correction⁹. Parametric baseline subtraction method 62 milliwatts (+/- 34 milliwatts); qualitatively similar to the value expected for a "successful" experiment^{1,4,9}. The time of apparent turn-on of excess heat is also close to the expected time cited^{1,4}.

SUMMARY & CONCLUSIONS

In the May 1992 Appendix¹⁰, the curves of the memo distributed on a limited basis by the PFC, retroactively claimed its "systematic" errors were 100 to 400 milliwatts, implying an insensitivity of >30 kilojoules.

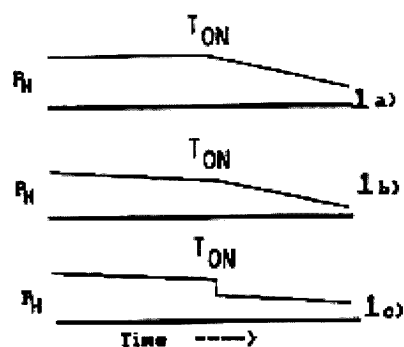
However, examination of the data indicates that the light water curve was published by the PFC essentially intact after a first baseline shift, whereas the heavy water curve was shifted a second time, even though the cells were matched, and solvent loss would be expected to be greater for H₂O. Other curve irregularities were detected enabling characterization of several different types of curves for a single D₂O experiment.

Furthermore, the Phase-II methodology appears to have been flawed because it masks any constant [steady-state] excess enthalpy. What constitutes "data reduction" is sometimes but not always open to scientific debate. The application of a low pass filter to an electrical signal or the cutting in half of a hologram properly constitute "data reduction", but the asymmetric shifting of one of two matched curves is probably not. The removal of the entire steady state signal is also not ineffective "data reduction."

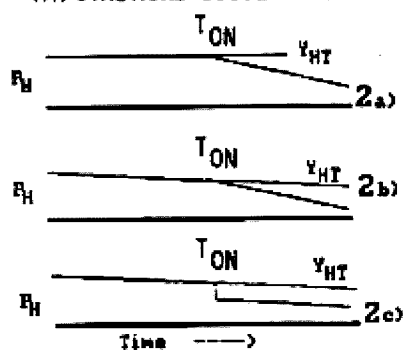
Much current skepticism of the cold fusion phenomenon was created by the PFC paper's reporting "failure-to-reproduce"¹² as opposed to its later claimed "too-insensitive-to-confirm" experiments¹⁷. Because it may be the single most widely quoted work used by critics of cold fusion to dismiss the phenomena, the paper should have clarified all "data" points and the methodology used. In addition, apparent curve proliferation, volatile points, asymmetric curve shifts, in combination with an impaired methodology have needlessly degraded the sensitivity, and believability, of the Phase-II calorimetry experiment.

ACKNOWLEDGMENTS

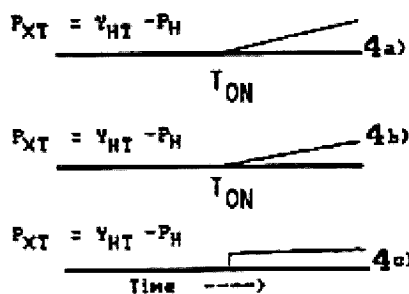
The author is grateful to many people for their support, information and/or discussions provided during the preparation of this manuscript including Dr. S. Baer, E. Mallove, I. Straus, D. Towne, G. Verner and at MIT Profs. P. Hageistein, P. Morrison, R. Parker, L. Smullin, M. Zahn, and President C. Vest.



HYPOTHETICAL SUCCESSFUL EXPTS.

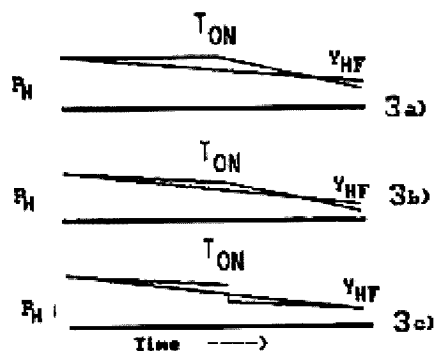


HYPOTHETICAL SUCCESSFUL EXPTS.
'TRUE' REGRESSION FIT [Y_{HT}]

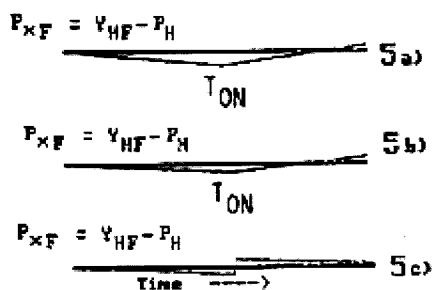


HYPOTHETICAL SUCCESSFUL EXPTS.
'TRUE' REGRESSION FIT [Y_{HT}]

THREE HYPOTHETICAL SUCCESSFUL
EXCESS ENTHALPY EXPERIMENTS
AND
THEIR EVALUATION BY
TWO METHODS



HYPOTHETICAL SUCCESSFUL EXPTS.
'FALSE' REGRESSION FIT [Y_{HF}]



HYPOTHETICAL SUCCESSFUL EXPTS.
'FALSE' REGRESSION FIT [Y_{HF}]

Figure 5 - HYPOTHETICAL EXAMINATION OF BASELINE SUBTRACTION

These three thought-experiments have "successful" experiments which produce excess heat. There are two ramp functions (1a and 1b) and a step function (1c). These three curves are treated by either of two methods to produce the respective derived excess heat curves.

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7. C. ANDERSON, "Cold fusion tempest at MIT", Nature, 353, (1991).
8. Personal communication [8/30/1991] from Prof. R. Parker.
9. M. SWARTZ, "Reexamination of a key Cold Fusion Experiment: "Phase-II" Calorimetry by the MIT Plasma Fusion Center", Fusion Facts, 4, 2, 27-40, (August 1992).
10. LUCKHARDT, "PFC/RR-92-7, Technical Appendix to the Albagli paper", (May 1992).
11. It is difficult to interpret Types 4 and 5 curves because although the regression coefficients used to shift the raw experimental data curve (Type 1_D) were listed to five (5) decimal places, no mention was made of the many coefficients of fit, or why the ~18 hours of data were left off the linearization scheme.
12. M. SWARTZ, "A Method to Improve Algorithms used to Detect Steady State Excess Heat", ICCF-4 (1993).

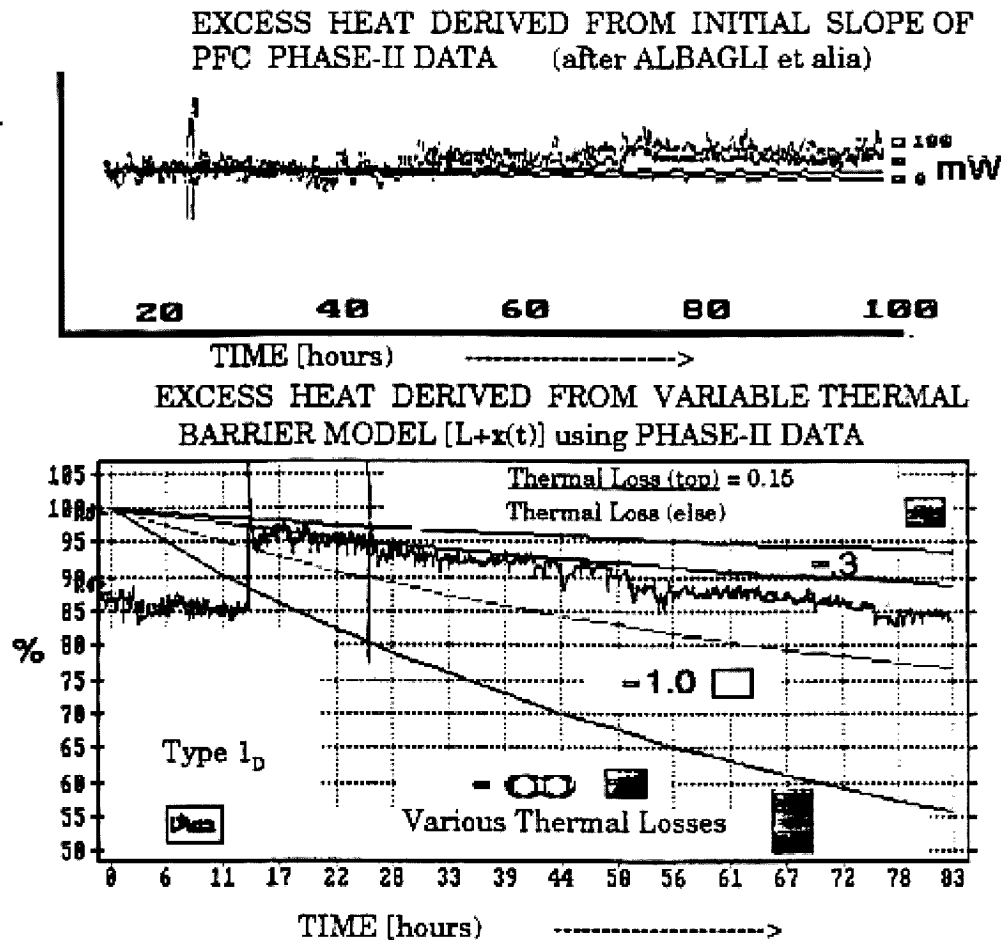


Figure 6 • CORRECTED EXCESS HEAT FOR PHASE-II D₂O EXPT.

These are the derived excess heats obtained by two alternative methodologies.

Upper: Derived using the initial baseline correction technique. The error of the method is considerable and is shown as the width of the two lines on the right side of the curve.

Lower: Derived using the varying thermal pathlength model.