From Cold Fusion to Condensed Matter Nuclear Science

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A brief history of “Cold Fusion”

- The name “cold fusion” appears to have originated with Jones and Rafelski.
- These authors invoked the phrase to describe muon catalyzed pairwise d-d fusion and later argued in 1989 that this effect was responsible for low level neutron generation in condensed matter reactions.
- The evidence for heat effects in palladium deuteride was clearly demonstrated by Fleischmann and Pons in 1989 and ultimately determined to be sound.
- Direct evidence of commensurate fusion product creation was slow in coming with Miles *et al* first claim of near quantitative ^{4}He production in 1992.
- To this date no evidence has been accumulated of reactant consumption in d -d heat production.
- The measured product distributions, $^{4}He >> {}^{3}H >> n_{\circ}$, cannot be associated plausibly with two body fusion effects
- The effect takes advantage of <u>condensed states</u> of matter

  - possibly crystalline or surface states

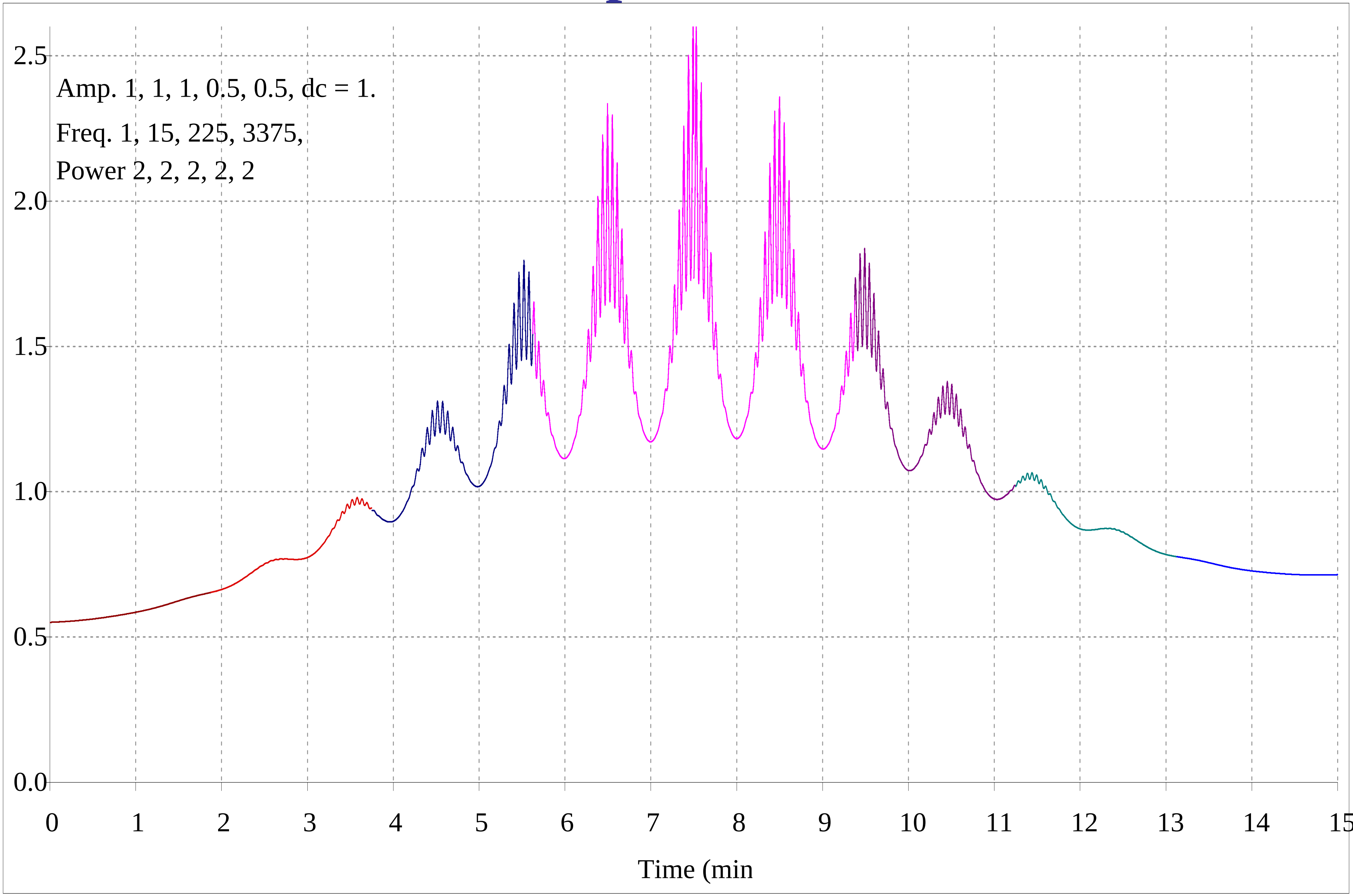
Condensed Matter Nuclear Science

- The phrase "Condensed Matter Nuclear Science" or CMNS was crafted in May 2002 at the IAC meeting of ICCF9 chaired by Prof. Li:
  - to extend the reference topic area,
  - to incorporate explicitly the connection of the phenomenon with the condensed state,
  - and accommodate increasing evidence of nuclear products not consonant with orthodox fusion or fission reactions.
- This broadening in emphasis was both rational and necessary to accommodate new information.
- This change has defocused attention from the original claim of PdD nuclear -level heat energy (and possibly helium).
- This has led to two unforeseen consequences that are largely negative, at least in the short term:
  - (i) the parameter space of excess heat production has been insufficiently well studied and understood to institute a fully replicable experiment;
  - (ii) the practical utility of metal deuteride heat production is not yet well defined in it's limits or even application.

Energetics and SuperWaves®

- A program instituted by Energetics is seeking to help redress these two deficiencies in CMNS studies:
  - by controlling the palladium metallurgy,
  - by controlling surface morphology,
  - and particularly the loading and excitation waveform(s) of electrolytic cathodes based on the theoretical concepts of Dardik.
- A program recently completed at SRI was successful in replicating experiments performed initially by Energetics scientists in Omer, Israel.
- A second, independent replication attempt was mounted and successfully completed at ENEA, Frascati.
- Results of the work at SRI and ENEA will be discussed in the context of the replicability and practically of CMNS heat effects.

SuperWaves®



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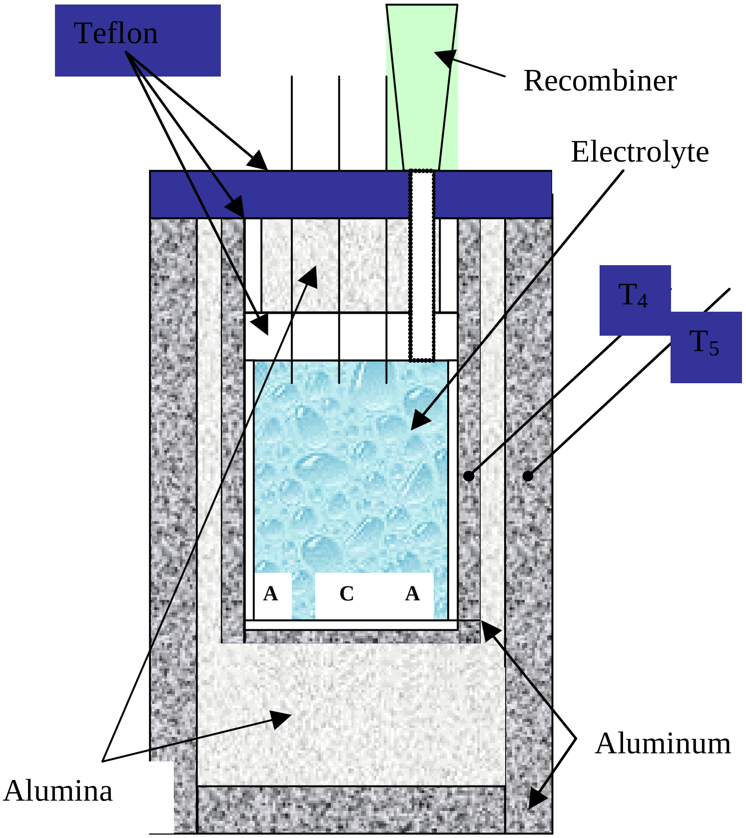
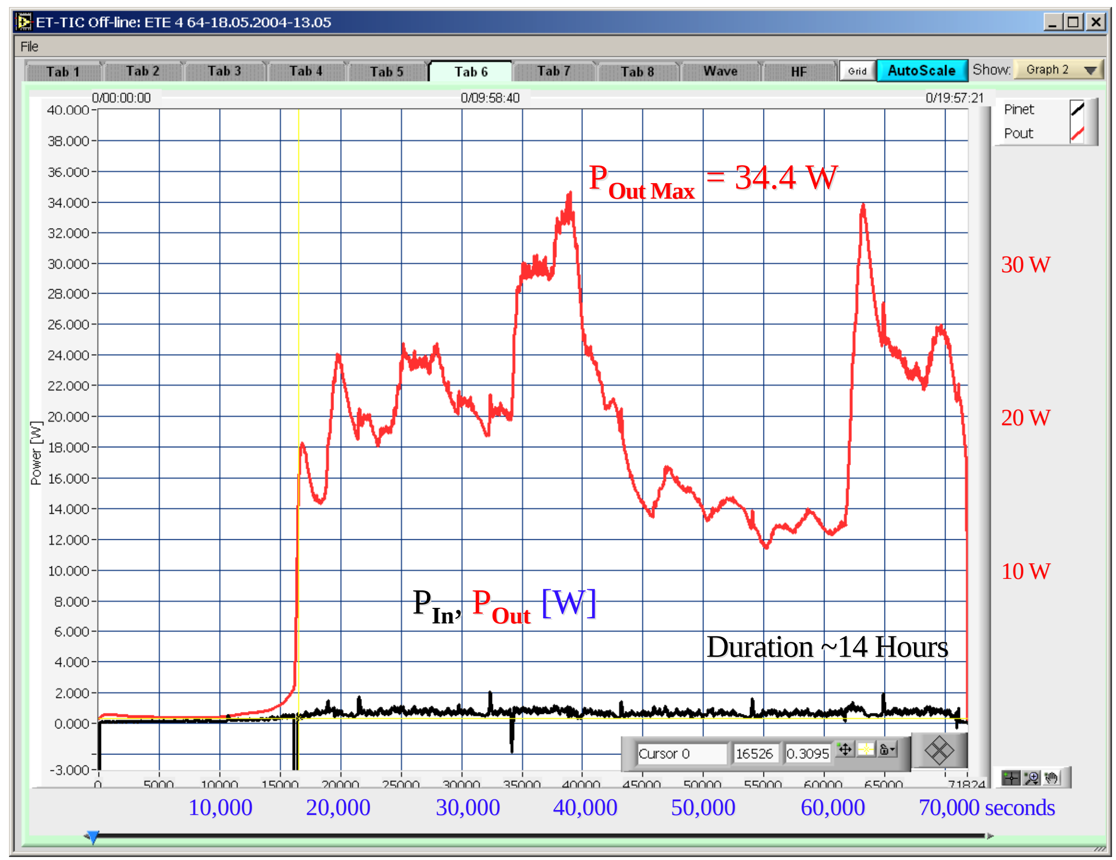
Energetics Isoperibolic Calorimeter and results





Energy Input 40 kJ, Output 1.14 MJ

> 28 x E_{Out}/E_{In}, > 70 x P_{Out}/P_{In}.

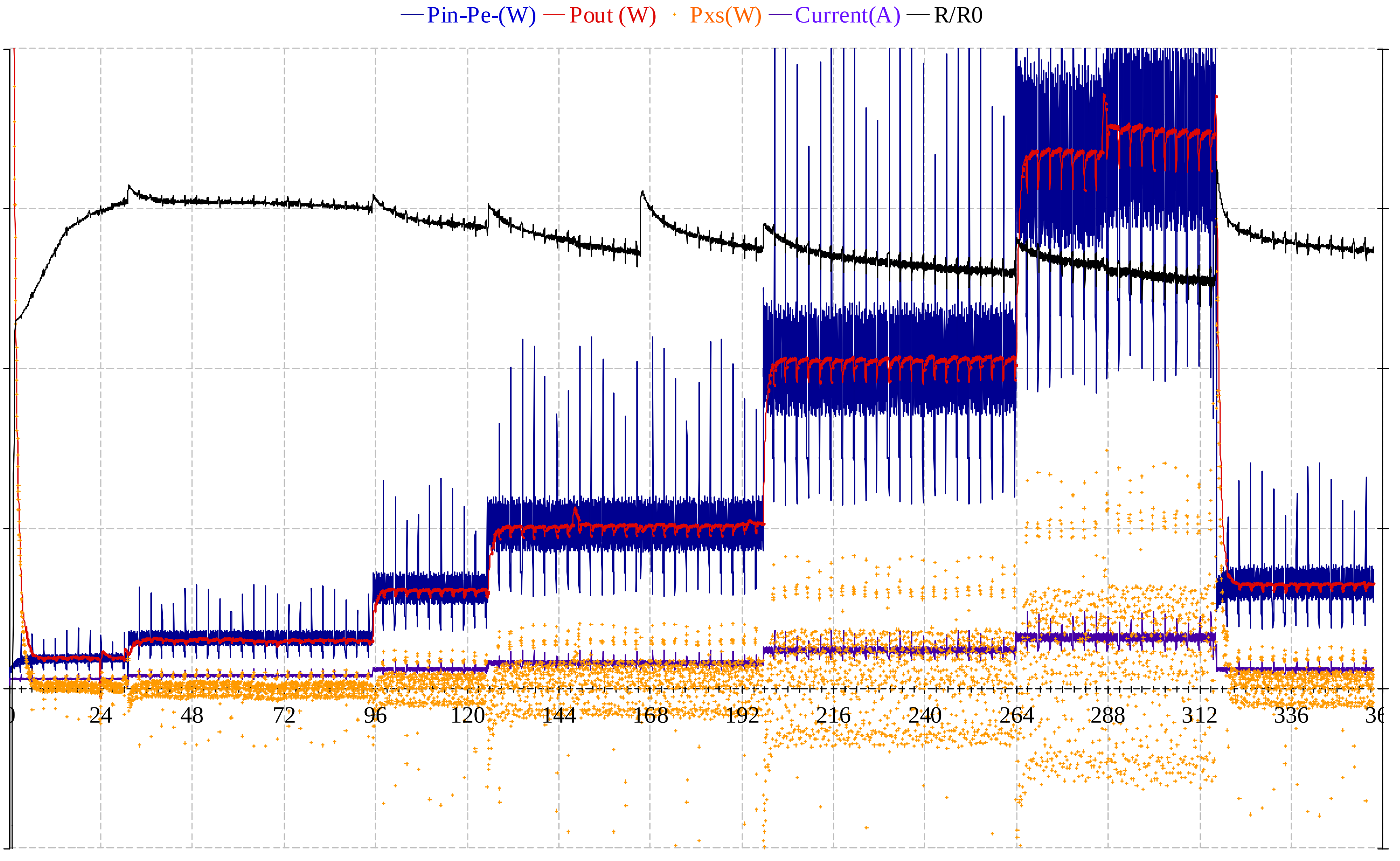
Calibration

Summary of results

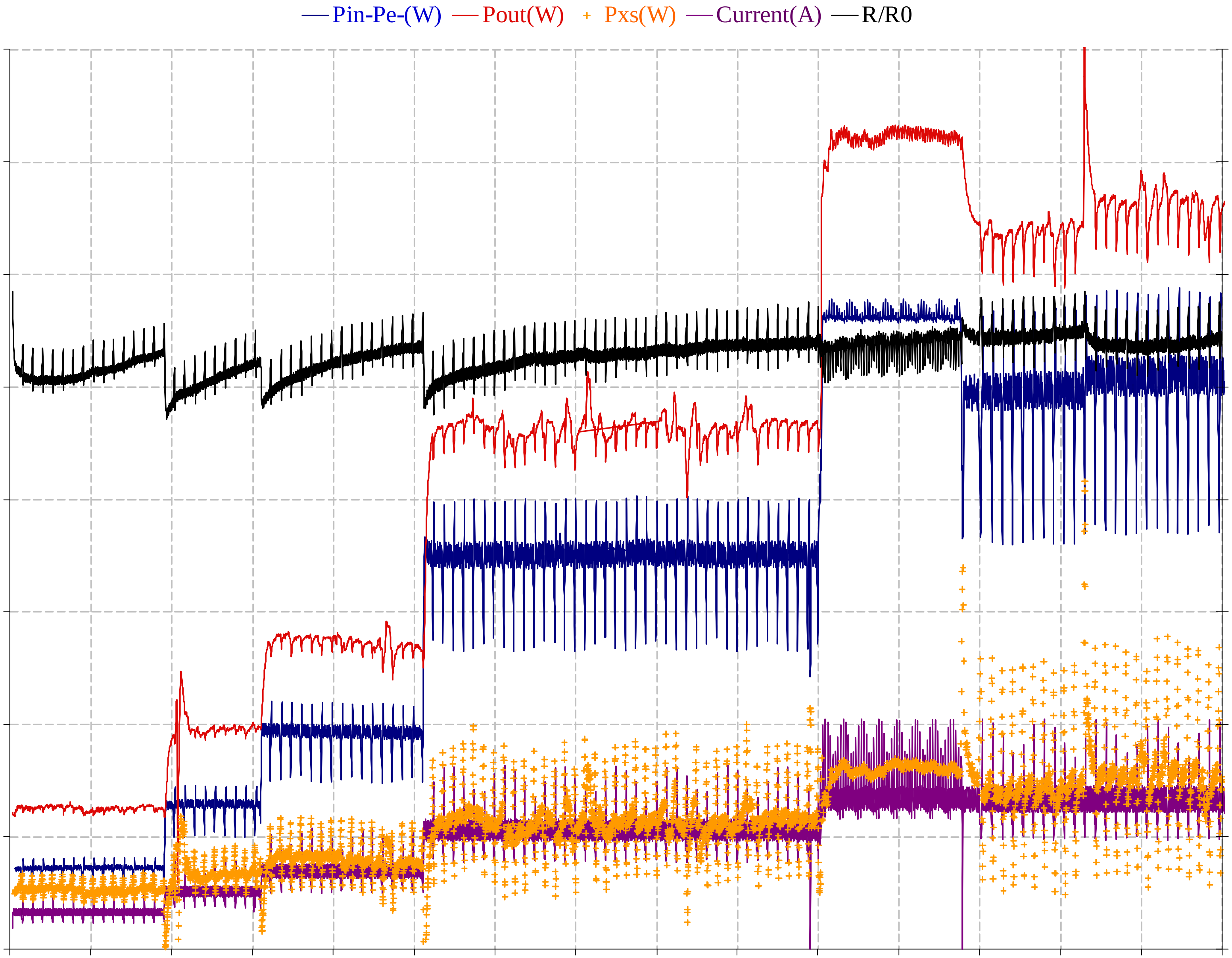
	Cell - Calorimeter		Cathode	Min. R/R°	Max. D/Pd	Excess % of P_{In}	Power (mW)	Energy (kJ)
1	9-7	E	Lot A	1.77	0.895	<5%		
2	11-8	E	L5(2)	1.67	**0.915**	**60%**	**340**	**514**
3	12-9	E	Lot A	1.84	0.877	<5%		
4	15-7	E	L5(1)	1.77	0.895	<5%		
5	16-8	E	L5(4)	1.86	0.871	<5%		
6	17-9	E	L1(1)	1.55	**0.939**	**20%**	**460**	**407**
7	21-7	E	# 830	1.92	0.836	<5%		
8	22-8	E	L5(3)	1.8	**0.888**	**30%**	**200**	**188**
9	35-7	S	L17(1)	1.32	**0.985**	**12%**	**1800**	**553**
10	35-8	S	L17(2)	0.95	**1.059**	**13%**	**2066**	**313**
11	35-9	S	L17	1.39	0.971	1%		
12	43-7	S	L14-2	1.73	**0.903**	**80%**	**1250**	**245**
13	43-8	S	ETI	1.63	0.923	**5%**	**525**	**65**
14	43-9	S	L14-3	1.61	0.927	1%		
15	51-7	S	L25B-1	1.55	**0.939**	**12%**	**266**	**176**
16	51-8	S	L25A-2	1.52	**0.945**	**5%**	**133**	**14**
17	51-9	S	L19	1.54	**0.941**	**43%**	**79**	**28**
18	56-7	S	L24F	1.55	**0.939**	**15%**	**2095**	**536**
19	56-8	S	L24D	1.84	0.877	4%		
20	56-9	S	L25B-2	1.56	0.937	3%		
21	57-8	S	Pd-C	N.A.	N.A.	**300%**	**93**	**115**
22	58-9	S	L25A	1.69	**0.911**	**200%**	**540**	**485**
23	61-7	S	L25B-1	1.63	**0.923**	**50%**	**105**	**146**

E = Energetics and S = SRI Data Acquisition.

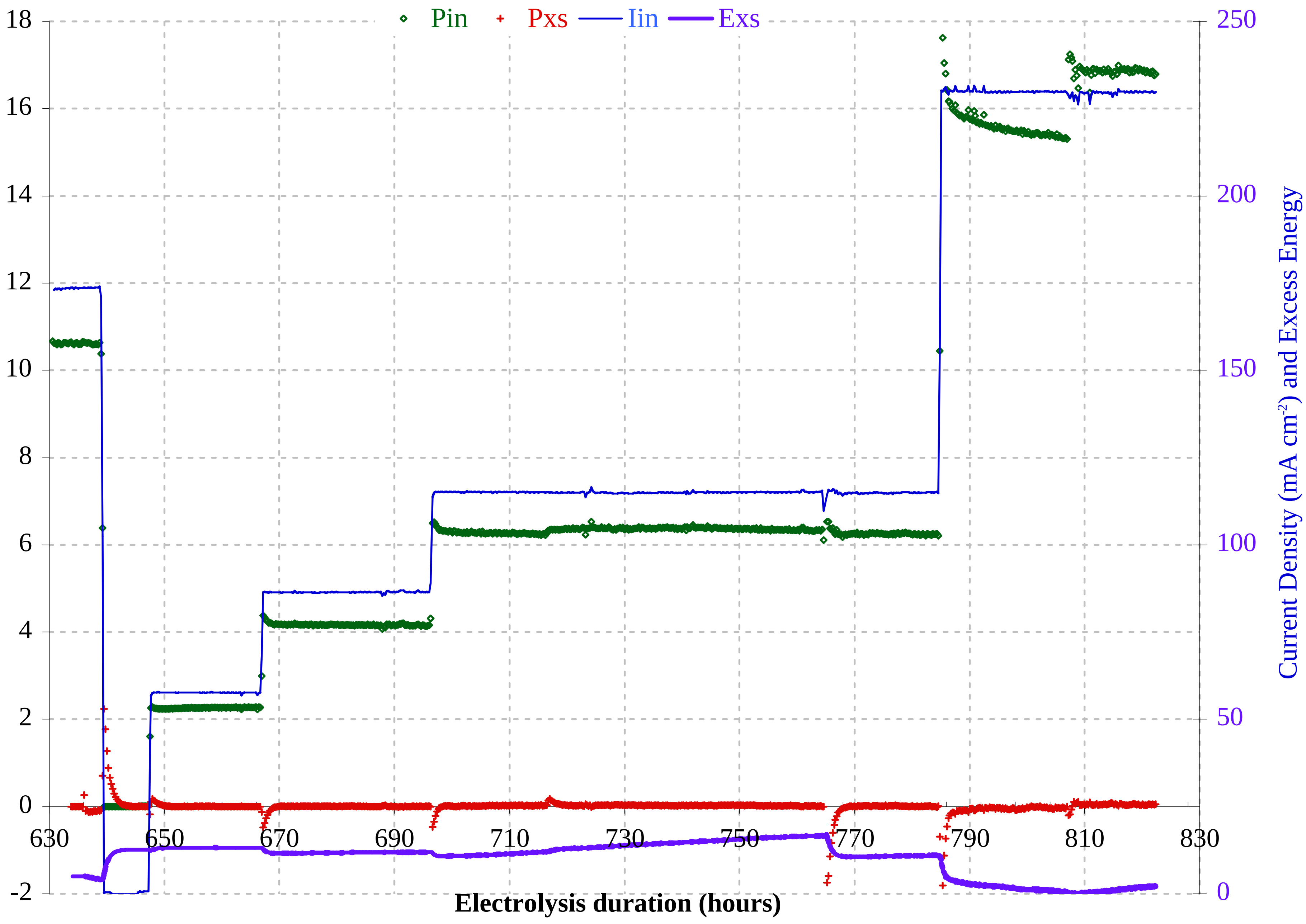
Energetics D/A - null heat result



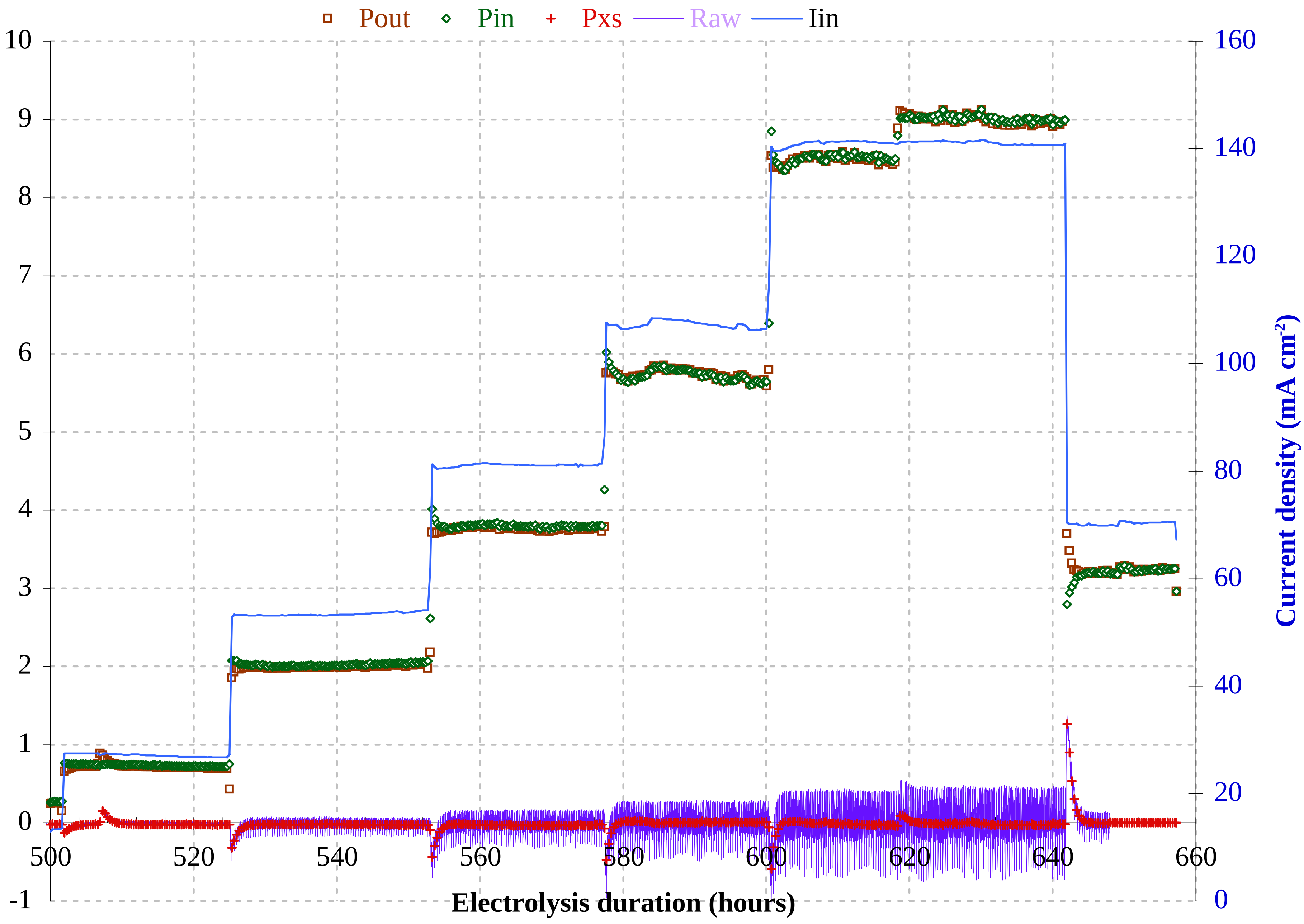
Energetics D/A - positive excess heat



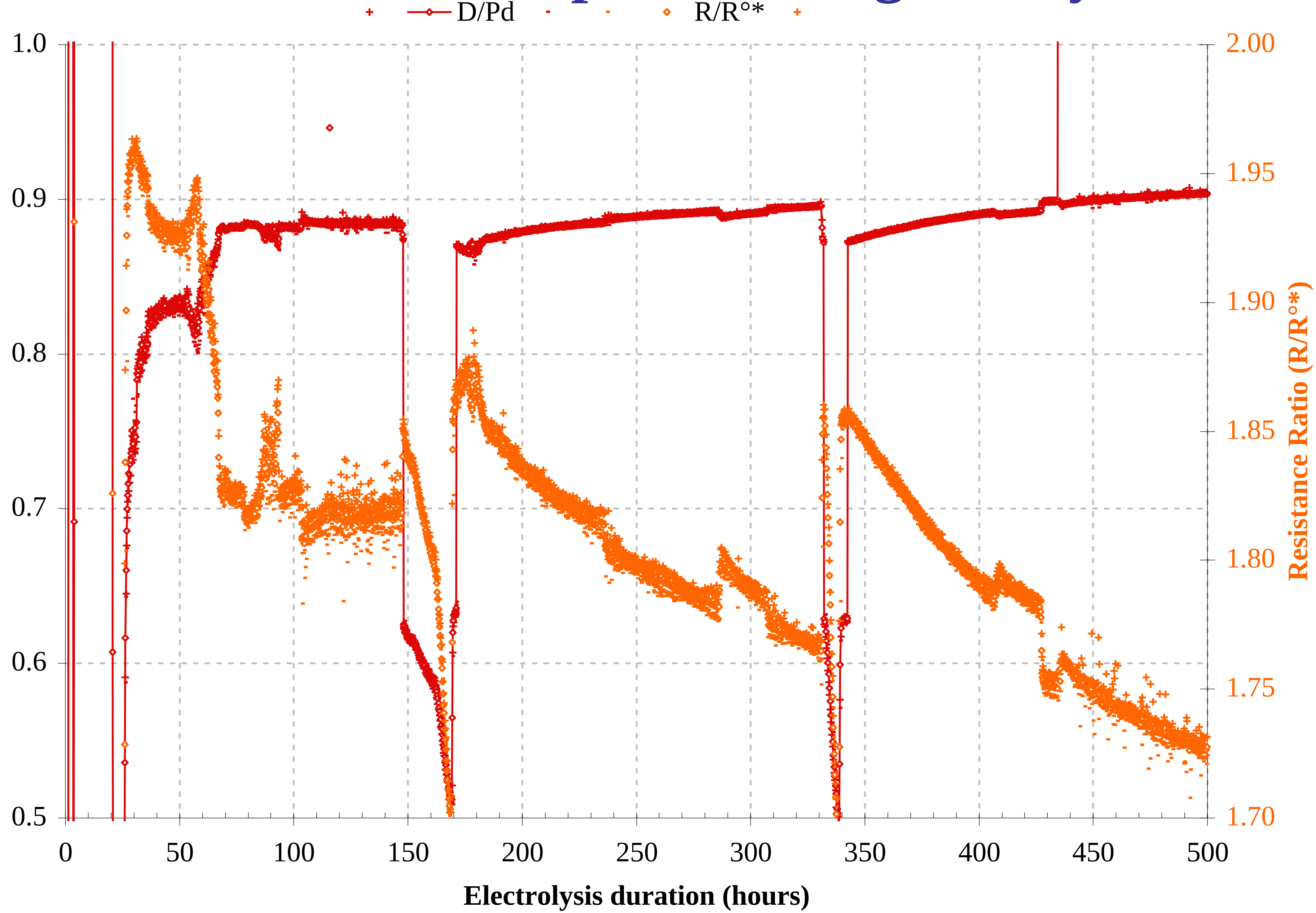
SRI D/A - null heat result (1)



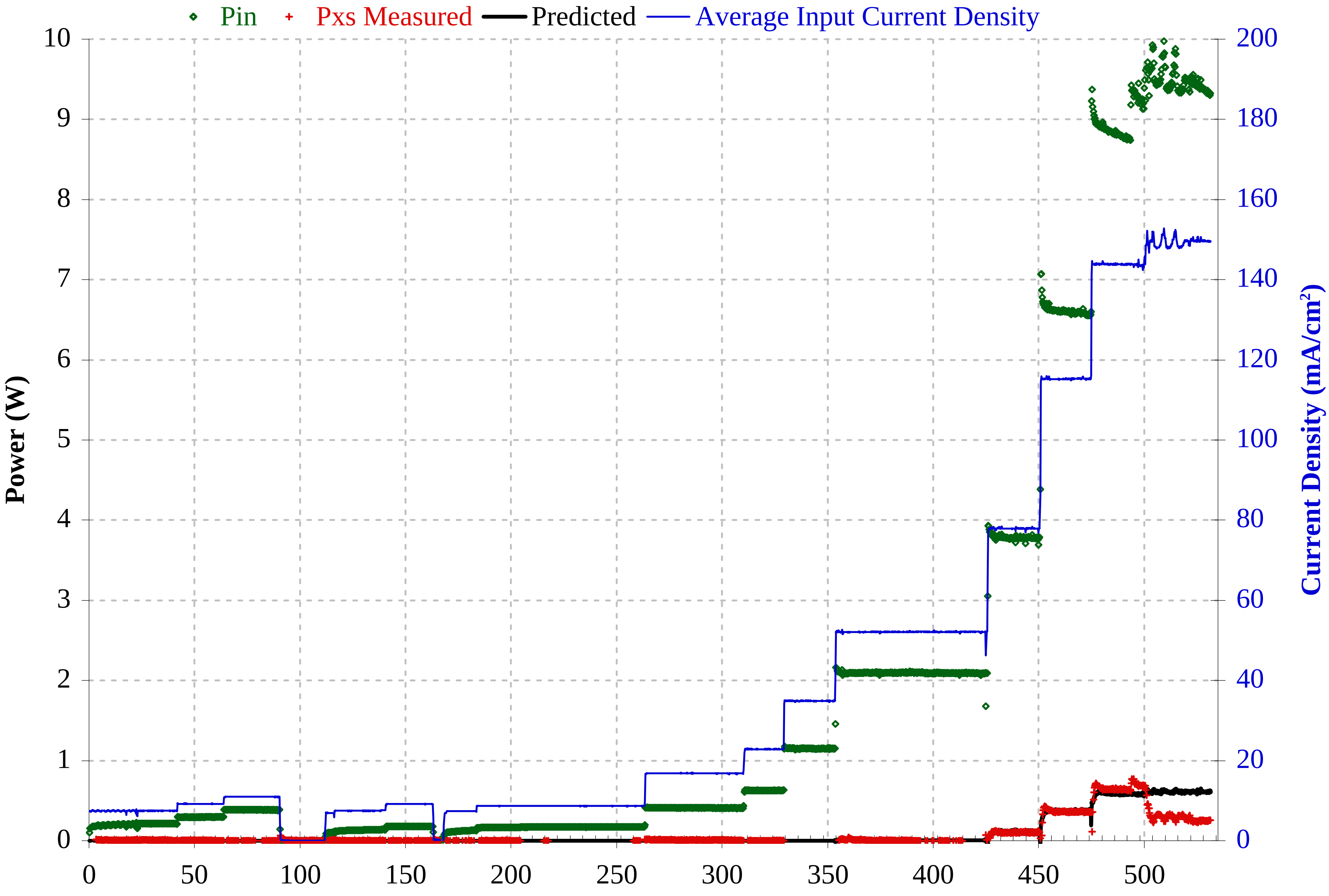
SRI D/A - null heat result (2)



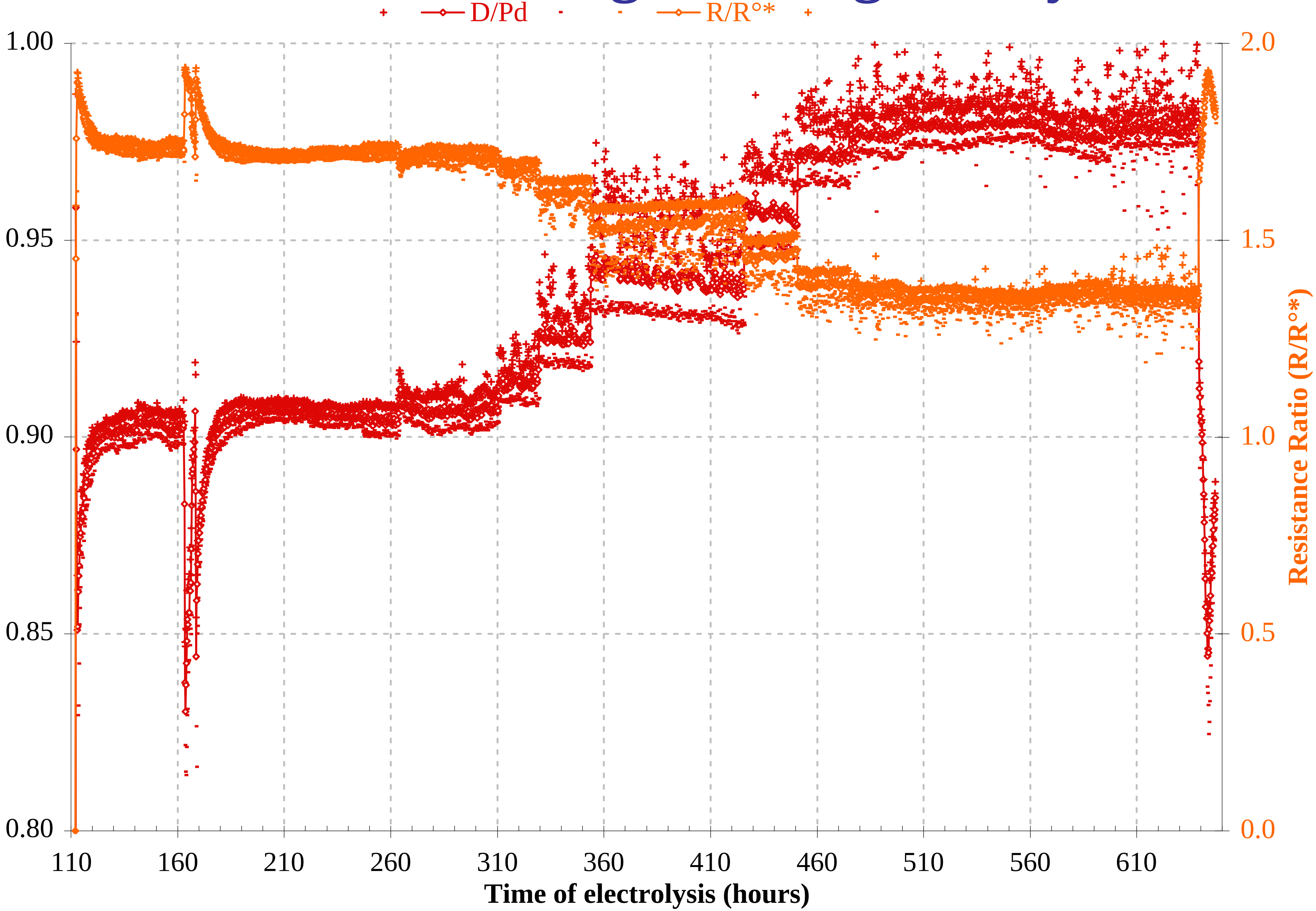
SRI D/A - associated poor loading and dynamics



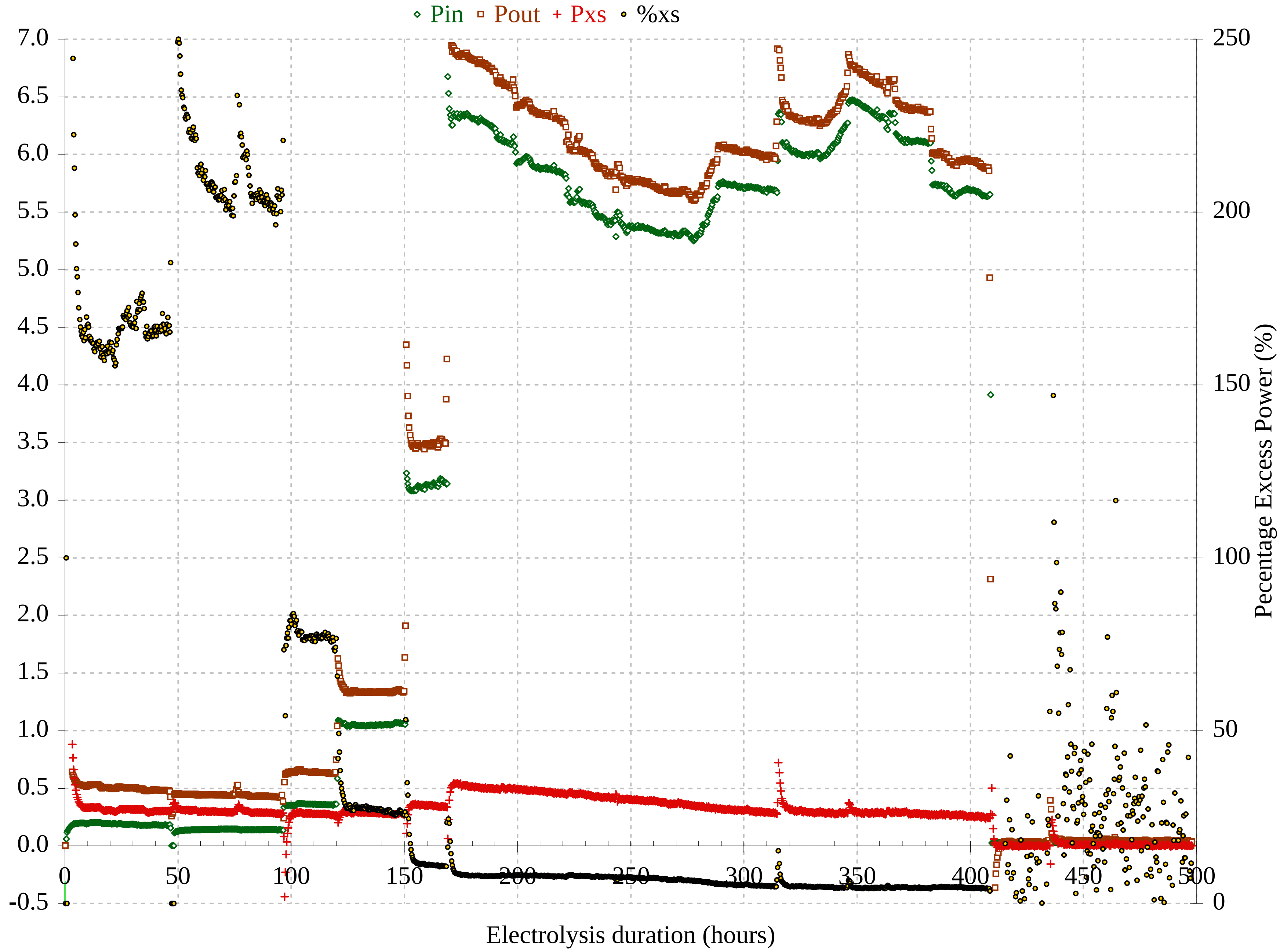
SRI D/A - mode A excess heat



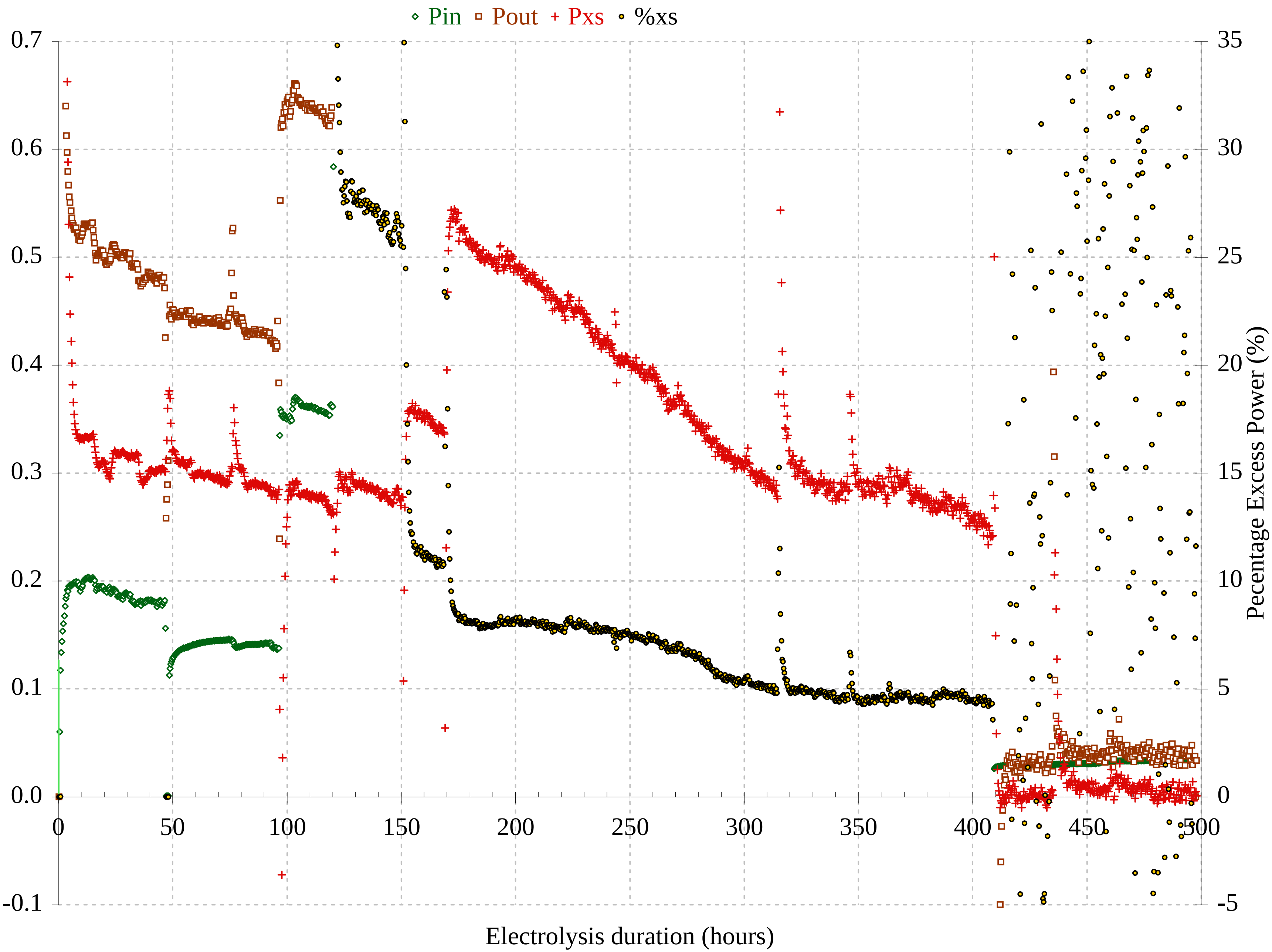
SRI D/A - associated high loading and dynamics



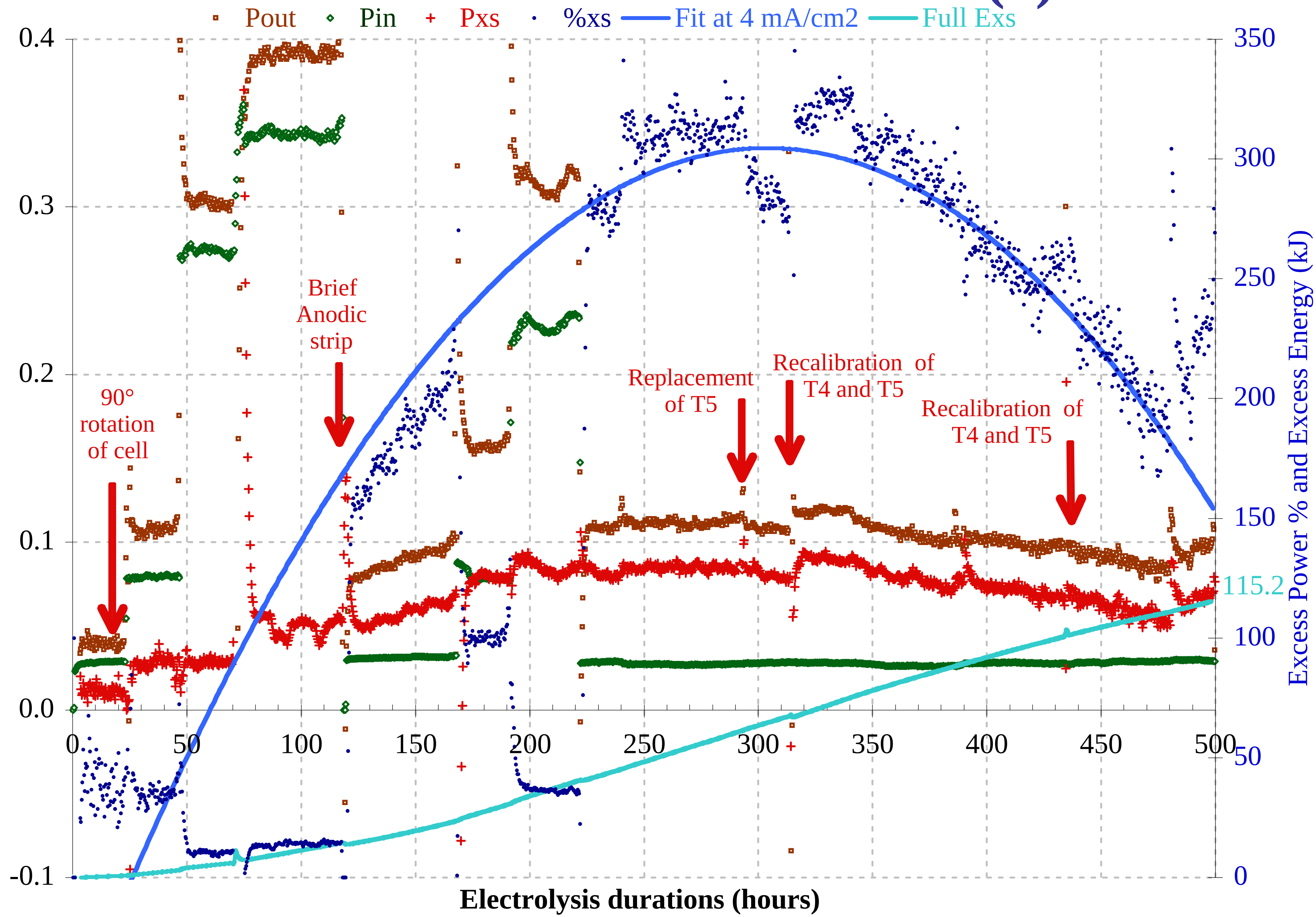
SRI D/A mode B excess heat (1)



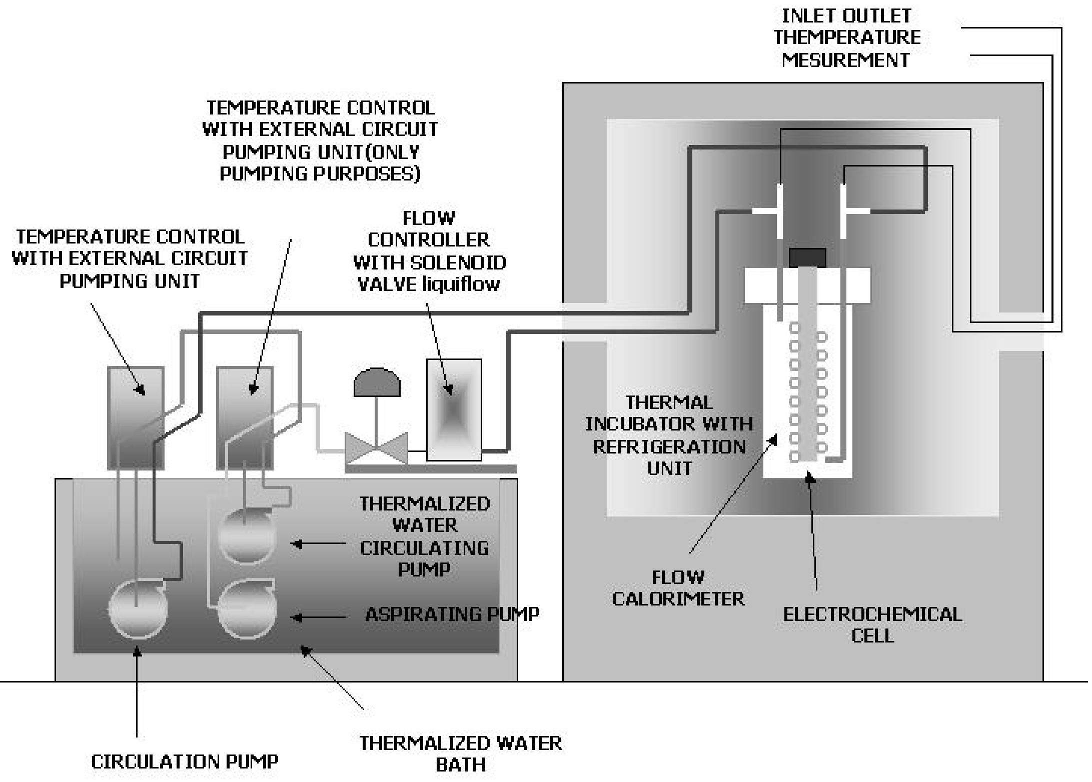
SRI D/A mode B excess heat (2)

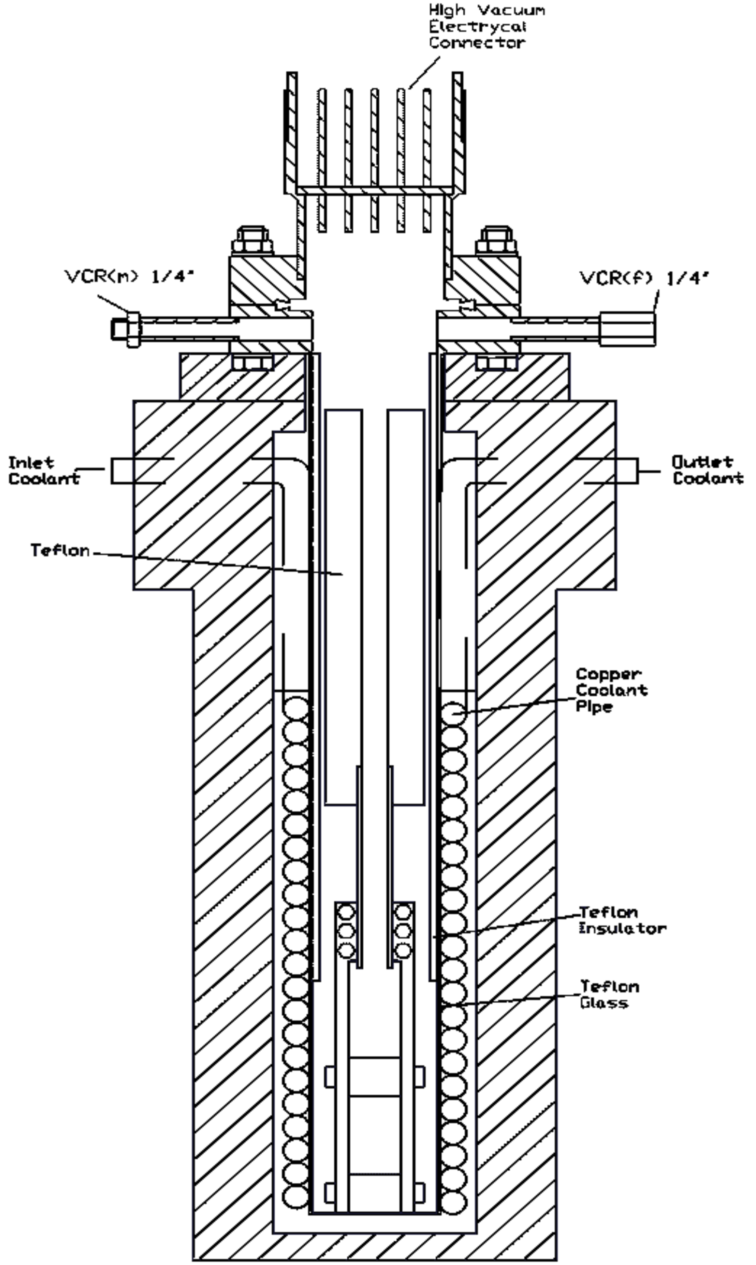


SRI D/A mode B excess heat (3)



ENEA Mass Flow Calorimeter





ENEA - Results

Data Acquisition	Cathode	Min. R/R°	Max. D/Pd	Excess % of P_{In}	Power Mode
ENEA	L14	1.54	0.941	80	B
ENEA	L17	1.4	0.969	500	B
ENEA	L19	1.7	0.909	100	A
ENEA	L23	1.69	0.911	37	B
ENEA	L25A	1.8	0.888	24	B
ENEA	L30	1.78	0.892	7000	B

Discussion (1)

- Excess power was observed to have two phenomenologically different forms that we tentatively identify as Modes A and B. The general features of these different modes are as follows.

Mode A. This behavior conforms closely to

$$\mathbf{P_{xs} = M\,(x - x^{\circ})^2\,(i - i^{\circ})\,|i_D|}$$

Where: M is a proportionality constant,

x = D/Pd is the deuterium atom loading and

x^{o} the threshold loading below which no excess heat is observed

– typically $x^{o} \approx 0.875$

i is the electrochemical current or current density and

i^{o} a critical threshold, and

$|i_D|$ is the flux of D across the interface expressed as a current density.

Discussion (2)

- The interfacial flux can be calculated directly from the minimum and maximum loading values obtained from the resistance ratio measurements in the fundamental superwave interval (15 or 20 minutes).
- Probably as a result of the superwave dynamics the interfacial flux term, $|i_D|$, was up to an order of magnitude larger in the present study compared with previous dc electrolysis of palladium wires.
- This combination of factors led to excess power effects of 5-50% of the input power, in Mode A, very consistent with previous excess heat results.
- Although the proportionality constant M is not well specified it probably reflects some properties of surface heterogeneity.
- This equation permits explanation of experiments that do not produce heat excess. The failure to meet and maintain the current, loading, and flux criteria simultaneously results in a failure to observe Mode A excess heat.

Discussion

Mode B. A second mode of behavior was seen in three experiments at SRI and five at ENEA, and in all of those exhibiting excess power greater than 100%.

- This mode is more typical of that reported previously by Energetics.

  i) Mode B excess heat initiates within 6 h of the application of cathodic current (or 4 h of maximum loading), whereas Mode A behavior requires a longer initiation time, typically several hundreds of hours.

  ii) Mode B excess heat responds sluggishly to input cathodic current density and, so far, exhibits no obvious current density threshold.

  iii) Mode B excess heat has not been observed at D/Pd loadings less than the threshold typical of Mode A behavior (D/Pd $\approx$ 0.875) but appears to respond only transiently to increased average loading.

Conclusions

- The Energetics calorimeters and cells were found to be well designed and calibrated, and capable of steady baseline operation in the absence of excess heat.
- The three sigma (3σ) calorimetric uncertainty was estimated to be approximately 5% of the input power under normal input conditions.
- Of the fifteen experiments performed using SRI data acquisition, eleven produced excess heat at or above the 3σ experimental uncertainty.
- This high level of reproducibility is attributable to two conspicuous differences between Energetics experiments and all those that preceded them:
    i. Very high deuterium atom loadings that result from SuperWave® cathodization of appropriately prepared palladium foils.
    ii. The extraordinarily high interfacial flux of deuterium in and out through the palladium cathode surface that results from superwave stimulus.
    iii. Although more reproducible the results of the Energetics/ENEA collaboration are consistent with those that preceded them:

Excess Power Production *vs*. Maximum loading of cathode