VALIDATION OF BRILLOUIN ENERGY CORPORATION HYDROGEN HOT TUBE EXPERIMENTS

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ICCF-20
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I. INTRODUCTION TO BRILLOUIN HHT

- HHT = Hydrogen Hot Tube
- Brillouin Energy Corporation in the Spring of 2015
- Two substantially identical LENR experiments: Berkeley and SRI
- Brillouin believes that the experiments are producing excess energy due to an LENR

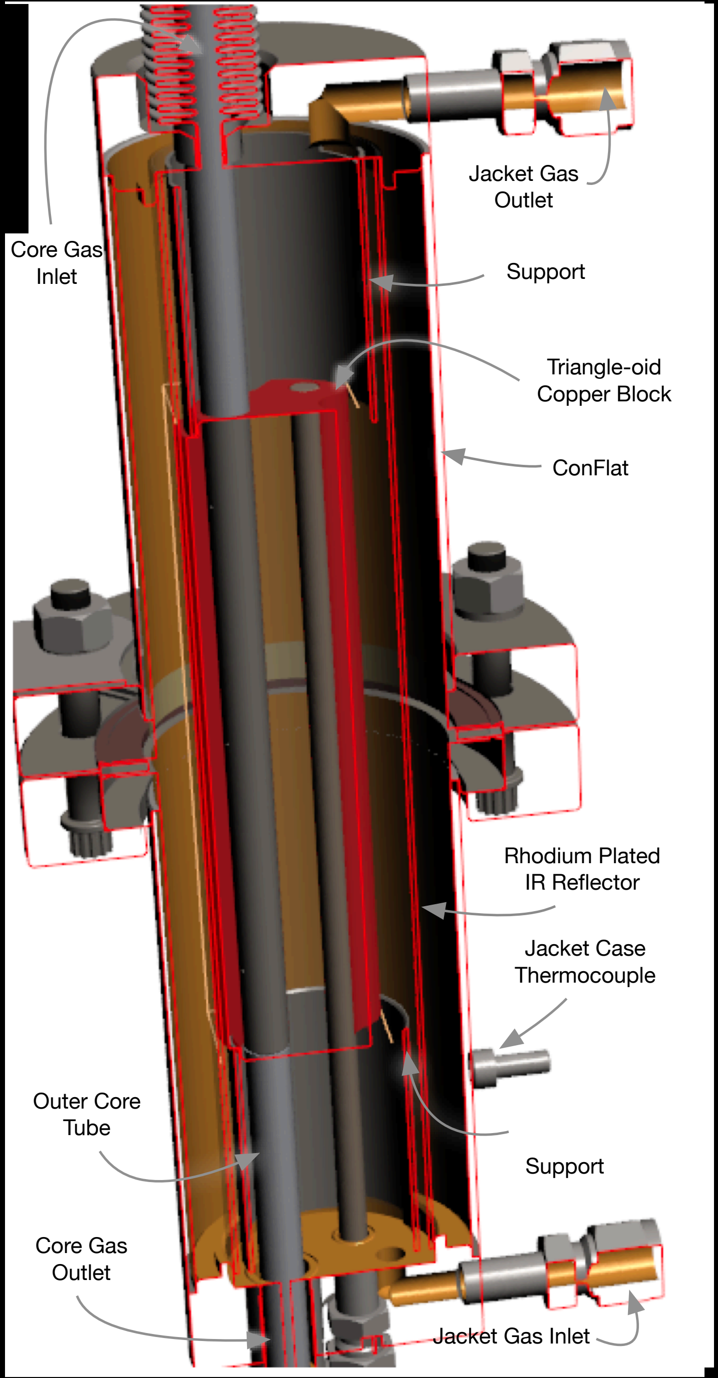
EXPERIMENTAL OBJECTIVES

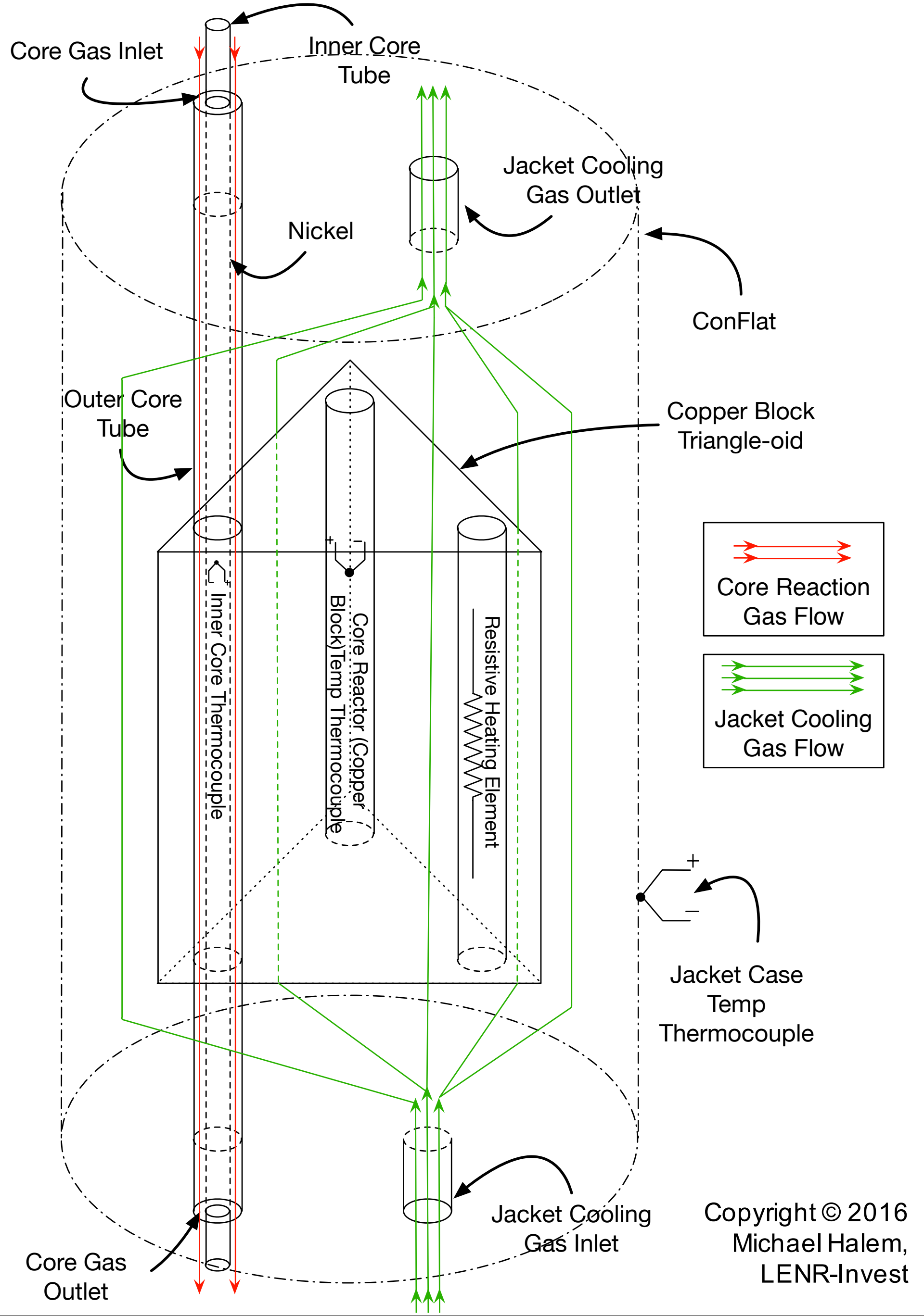
- Prove conclusively (if possible) that the HHT was producing excess energy not explained from other sources.
- Take the Agnostic Position (not knowing) of the internal physics
- Identify all possible sources of external energy provided to the rig
- Identify all possible sources of measurement error

II. EXPERIMENTAL SETUP

HHT Experimental Rig
@ SRI

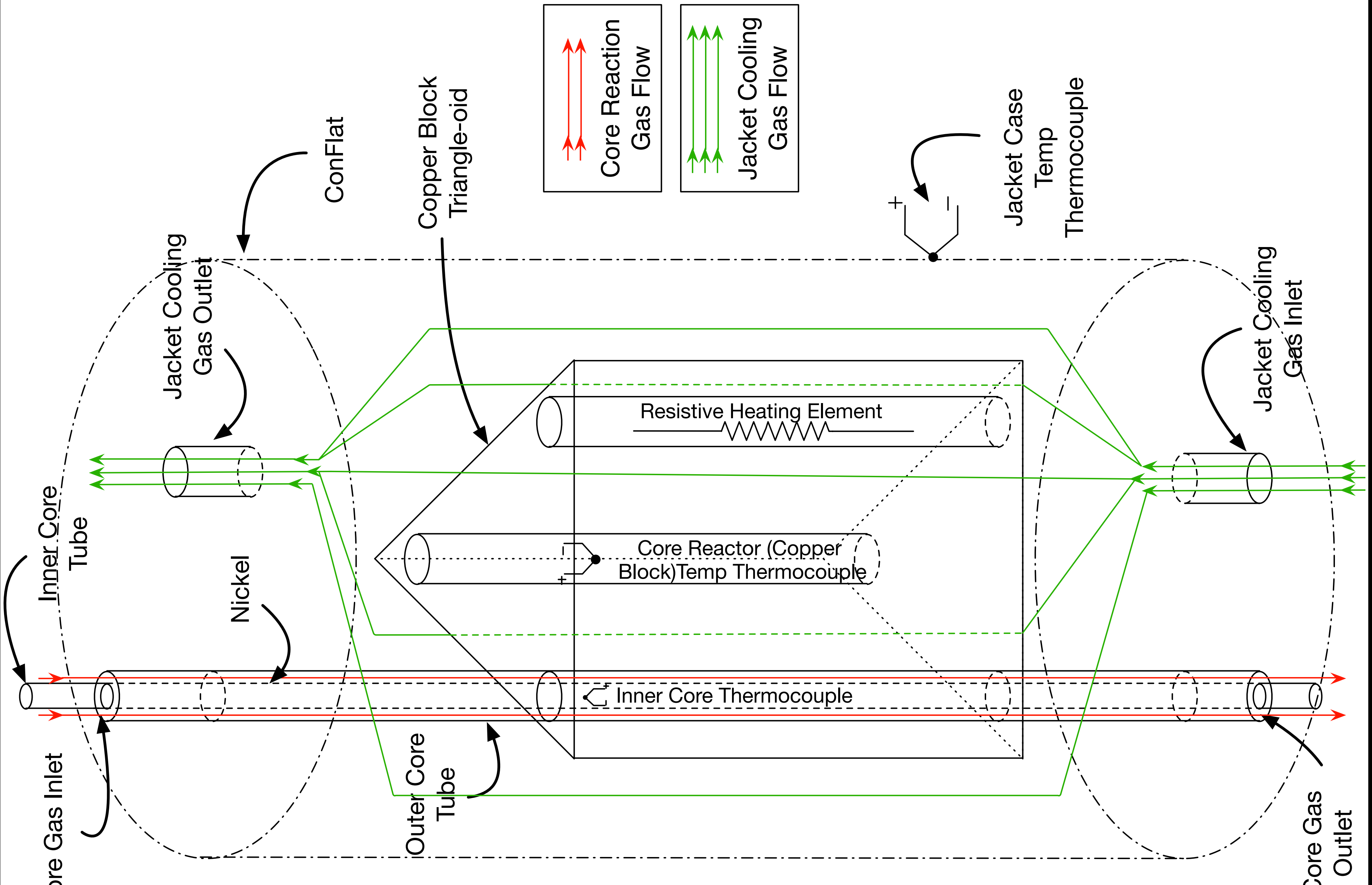
HOT TUBE + CONFLAT



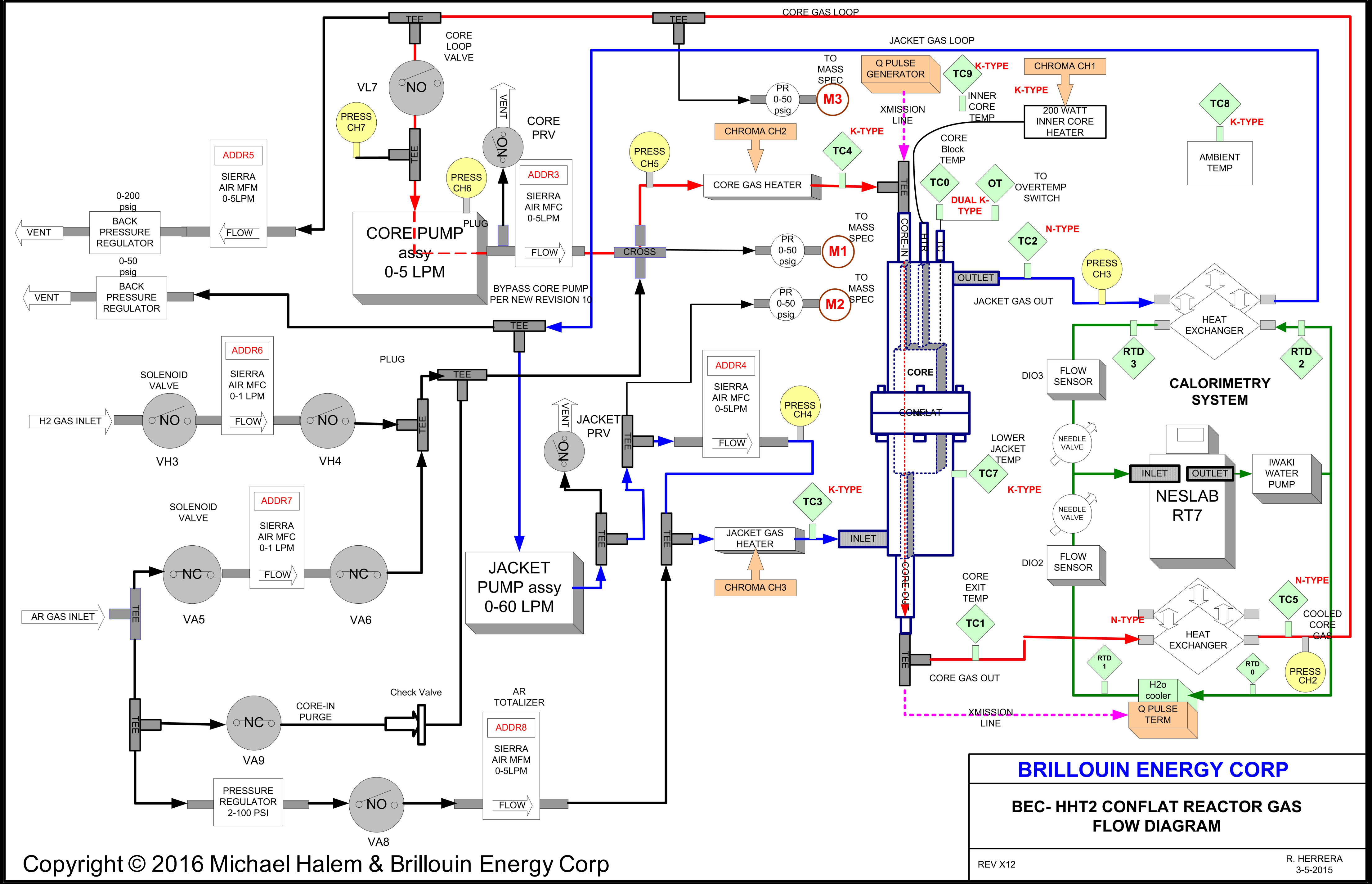


HHT DETAIL

(FLIPPED 90°)

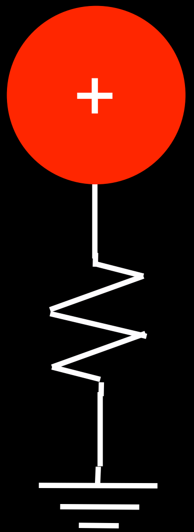


EXPERIMENT SCHEMATIC



III. THERMAL CALIBRATION PART I

- Newton's Law of Cooling



Isaac Newton
1643 -1727

$$\frac{dT}{dt} = -r(T - T_{env}) = -r\Delta T$$

The Decay Rate

$$r = hA / C$$

Where

$T \equiv$ Temperature of mass (K)
$T_{env} \equiv$ Temperature of environment (K)
$\Delta T \equiv T - T_{env}$ (K)
$r \equiv$ decay rate, i.e. $r = 1/\tau$ (s^{-1})
$\tau \equiv$ half life of temperature decay
$t \equiv$ time (s)

Where:

$h \equiv$ heat transfer coefficient ($W/m^2/K$)
$A \equiv$ heat transfer surface area (m^2)
$C \equiv$ heat capacity of the lump (J / K), i.e. how many joules must be added to raise the temperature 1 degree K

Newton's Law Modified for Addition of Heat (Power):

$$\frac{dT}{dt} = \frac{P}{C} + -r\Delta T$$

where

$P \equiv$ external power being added to the mass (w).

- Yields ***Exponential*** Decay Solution to Differential Equation:

$$\Delta T(t) = (\Delta T_0 - \Delta T_\infty)e^{-rt} + \Delta T_\infty$$

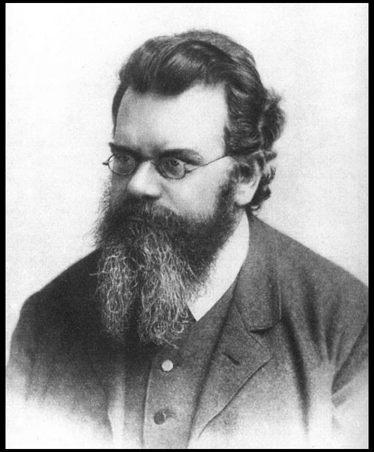
ADD IN RADIATION (STEFAN-BOLTZMANN)

Josef Stefan
1835-1893

$$\frac{dT}{dt} = \frac{P}{C} + -r\Delta T - \frac{A\varepsilon\sigma(T^4 - T_{env}^4)}{C}$$

where

$\varepsilon \equiv$ emissivity of the element (dimensionless); and
$\sigma \equiv$ Stefan-Boltzmann's Constant (W $m^{-2}K^{-4}$).



Ludwig Boltzmann
1844-1906

- No closed form solution to differential equation
- Solved numerically adding ***two*** exponential decays is a good fit

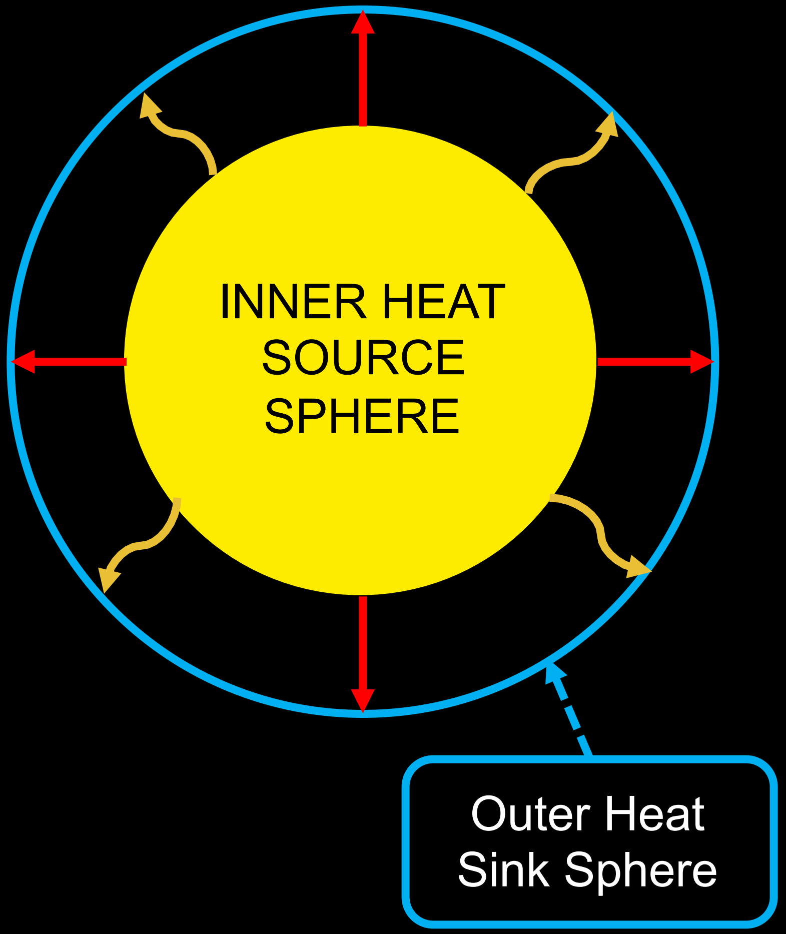
SIMPLIFIED SPHERE WITHIN A SPHERE MODEL

- Heat Transfer from Inner Sphere to Outer Sphere
- Outer Sphere ≅ Environment
- Conduction + Convection = Newton
- Radiation = Stefan-Boltzmann

$$\boxed{P = k_r T^4 - k_r T_{en}{}^4 + k_c T - k_c T_{en}}$$

where

$P \equiv$ Power transfer from sphere to environment
$k_r \equiv$ Radiation Coefficient = $A\varepsilon\sigma$
$k_c \equiv$ Combined Conduction/Convection Coefficient = hA
$A \equiv$ surface area of the sphere (m^2)
$\varepsilon \equiv$ effective combined emissivity (dimensionless)
$\sigma \equiv$ Stefan-Boltzmann's constant ($W\ m^{-2}\ K^{-4}$)
$T \equiv$ Temperature of the Sphere (K)
$T_{en} \equiv$ Temperature of the Environment (K)
$h \equiv$ Conduction/Convection heat transfer coefficient between sphere and the environment (W/m^2 K)



LOCAL APPROXIMATION T^4: NEWTONIAN

Let

$r_{eff} \equiv$ the effective radiation +
Newtonian (convective/conductive) temperature decay coefficient

Then collecting on RHS coefficients in terms of the non-constant variable *T*:

$$\frac{dT}{dt} - \frac{P}{C} - r\,T_{env} - A\varepsilon\sigma\frac{T_{env}^4}{C} = -r\,T - A\varepsilon\sigma\frac{T^4}{C}$$

$$r_{eff} = r + A\varepsilon\sigma\frac{T^3}{C}$$

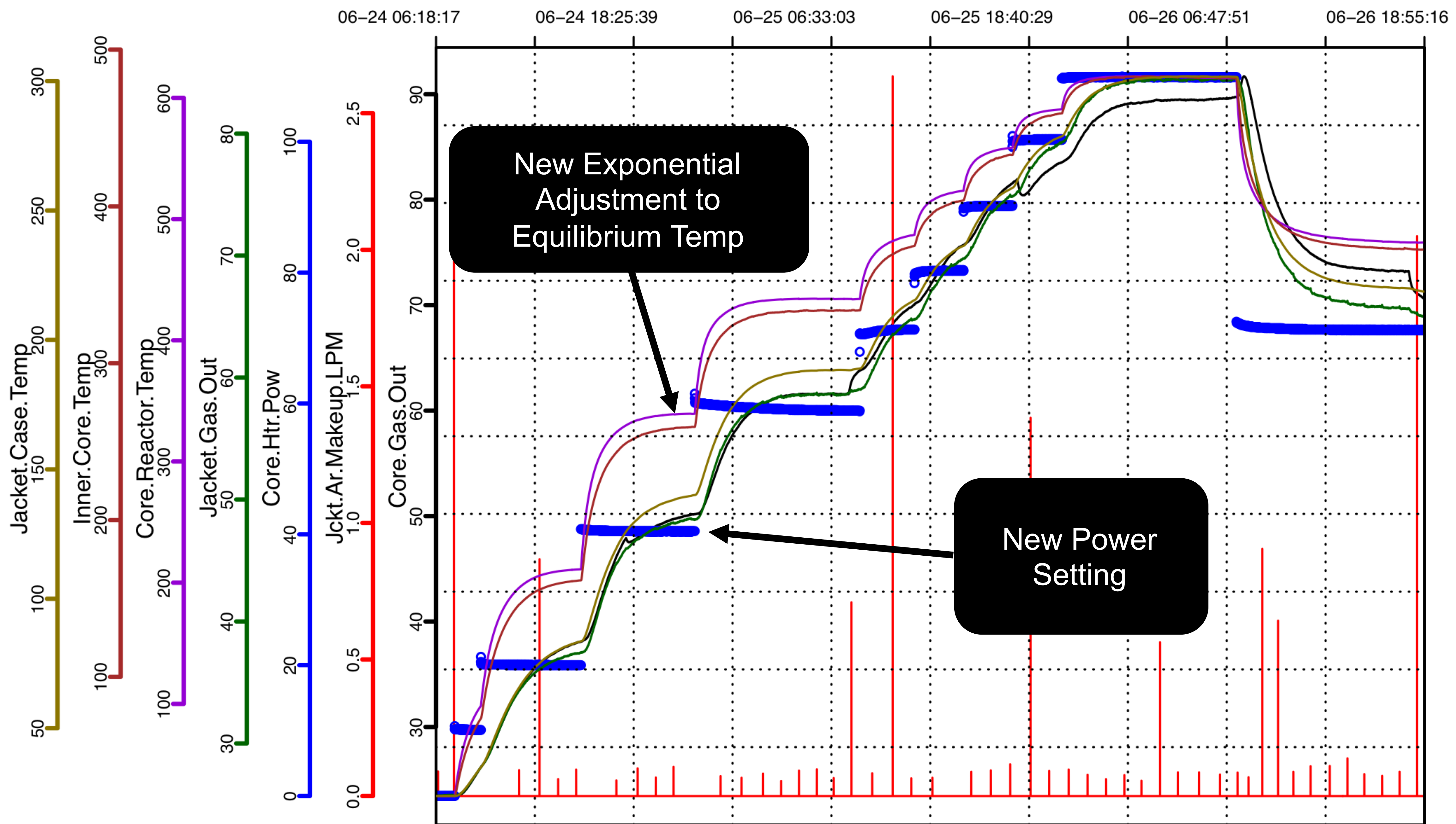
The above coefficient is used to yield the approximate solution in Newtonian Form:

$$\Delta T(t) = (\Delta T_0 - \Delta T_\infty)e^{-r_{eff}t} + \Delta T_\infty$$

IV. THERMAL CALIBRATION, PART 2

- Temperatures Observed Must be Correlated to Thermal Power Supplied During Calibration Runs
- Calibrated with (Hypothesized) Inert Helium in the Core
- Equilibrium Temperatures Measured at Different Power Levels

SRI 6/24 thru 6/26 Thermal Calibration Data



POWER VS TEMPERATURE CALIBRATION: SOLVING FOR k_r AND k_c

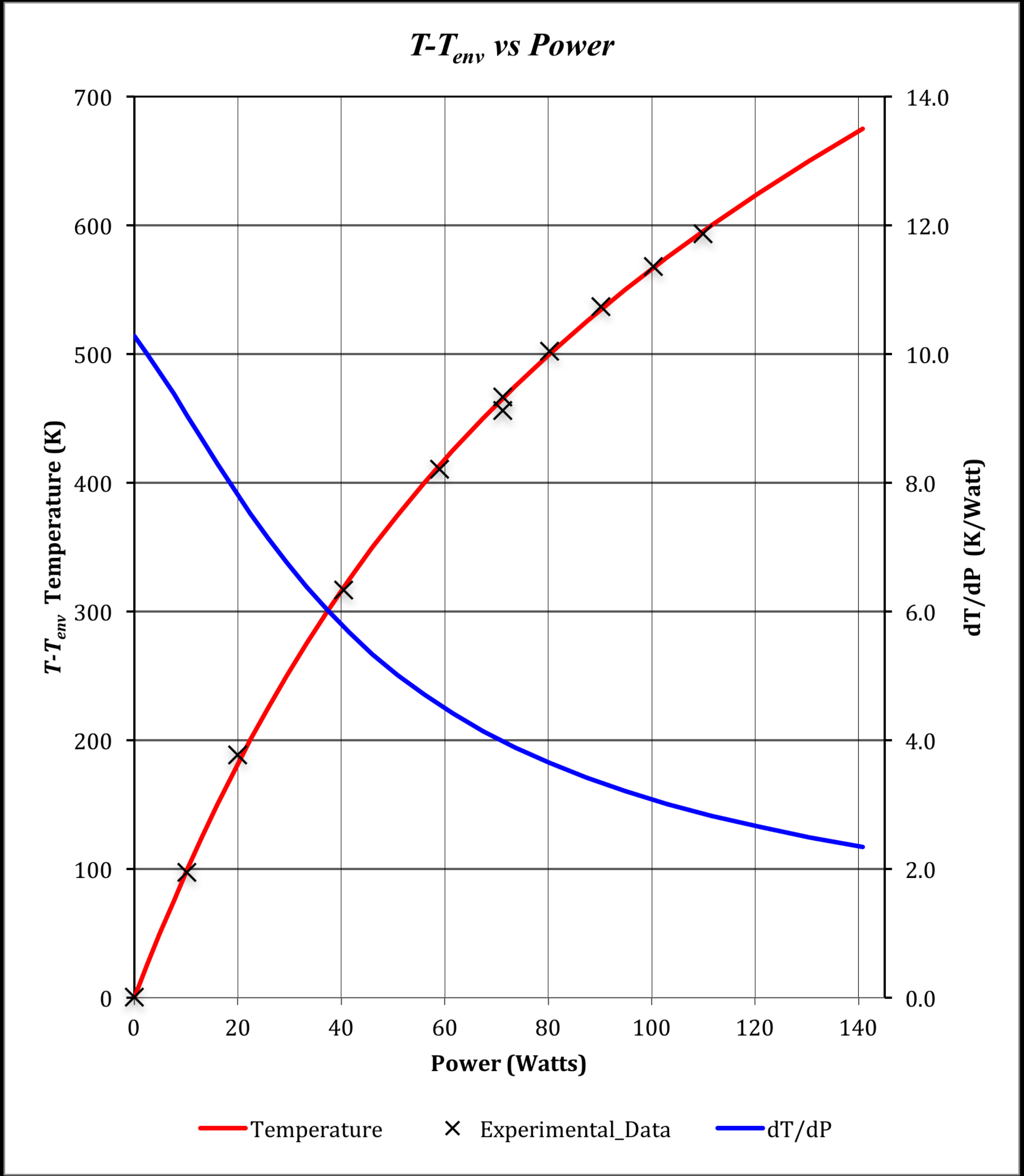
- Assumptions: inner and outer sphere surface areas “similar” to triangloid core surface area (but ***doesn’t matter*** – ***cancels out***)
- Calibration model solution ***does NOT require actual emissivity, surface area, or convection coefficient***
- ***Only the solved products*** $\boldsymbol{k_r = A\varepsilon\sigma}$ ***and*** $\boldsymbol{k_c = hA}$ ***are determined***. Area, emissivity, and the convection coefficient are not determined.
- ***Least Squares Minimization Solves*** for a unique calibrated k_r and k_c that produces the least mean square error in the model.

...PRODUCED THIS CALIBRATED POWER TABLE...

Run	Input Run Power (W)	Input Measured Temp T (K)	T-Tenv	Model Conductive& Convective Power	+ Model Radiation Power In	− Model Radiation Power Out	= Total Model Power (W)	Model Power Error (W)
624_0618	0.0000	297.15	0.5	0.044	0.715	0.720	0.049	0.0486
624_0727	10.1290	394.09	97.44	8.536	0.715	2.227	10.048	-0.0811
6-24 09:05	20.0390	485.30	188.65	16.526	0.715	5.122	20.932	0.8935
6-24 15:12	40.5240	613.11	316.46	27.722	0.715	13.048	40.054	-0.4695
6-25 03:59	58.9730	707.30	410.65	35.973	0.715	23.109	58.367	-0.6056
6-25 09:33	71.2350	763.38	466.73	40.886	0.715	31.357	71.528	0.2929
6-25 12:53	80.3070	798.80	502.15	43.989	0.715	37.595	80.868	0.5612
6-25 15:33	90.2020	833.61	536.96	47.038	0.715	44.589	90.912	0.7096
6-25 17:39	100.2900	864.60	567.95	49.753	0.715	51.598	100.636	0.3458
6-25 20:42	109.8900	890.27	593.62	52.001	0.715	58.004	109.291	-0.5993
6-26 11:58	71.2520	752.76	456.11	39.955	0.715	29.648	68.889	-2.3633
							Std. Dev=	0.5155

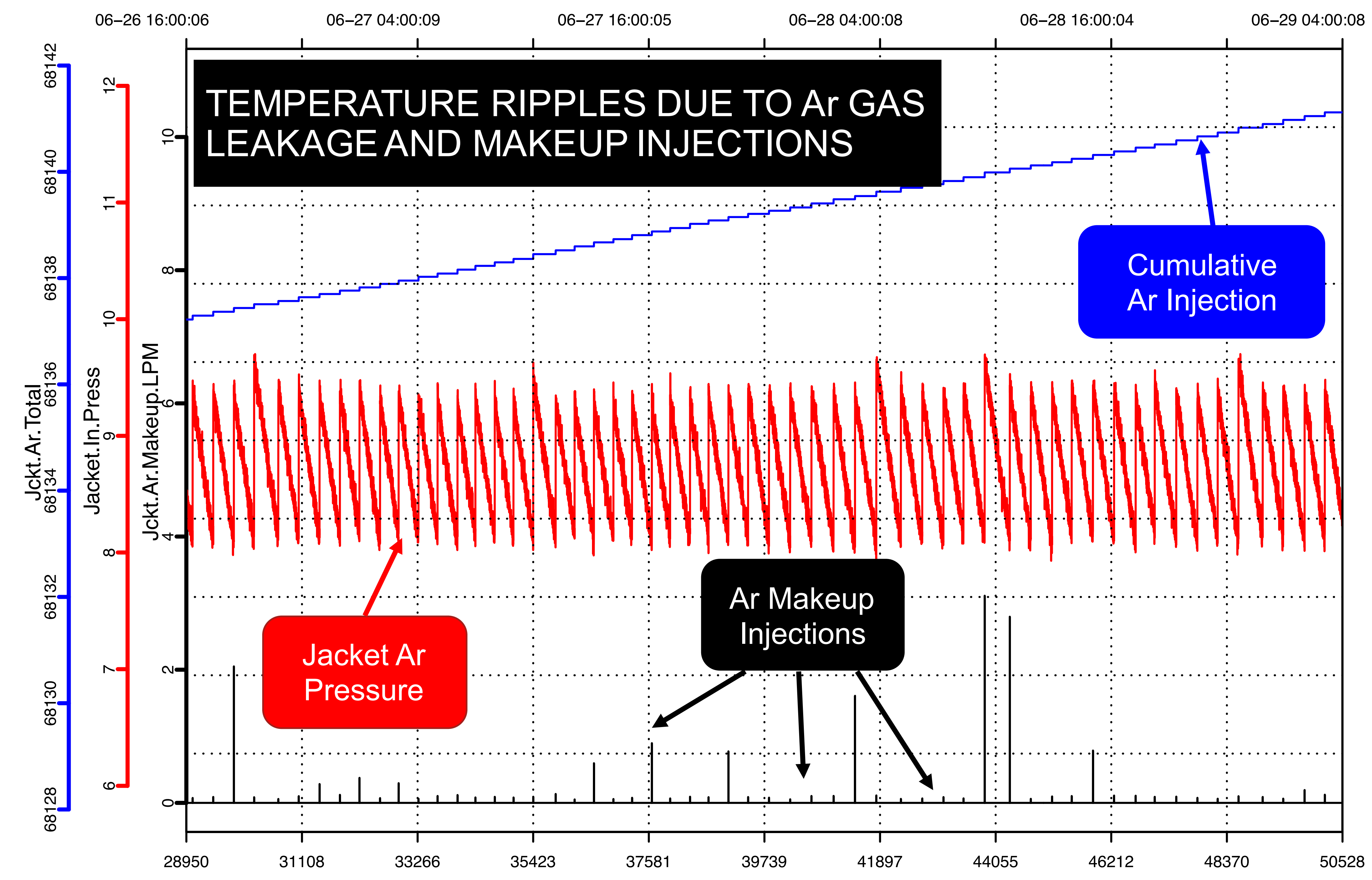
Mini-mized RMS Error (W)

...AND THIS VISUALLY EXCELLENT CALIBRATION MODEL FIT



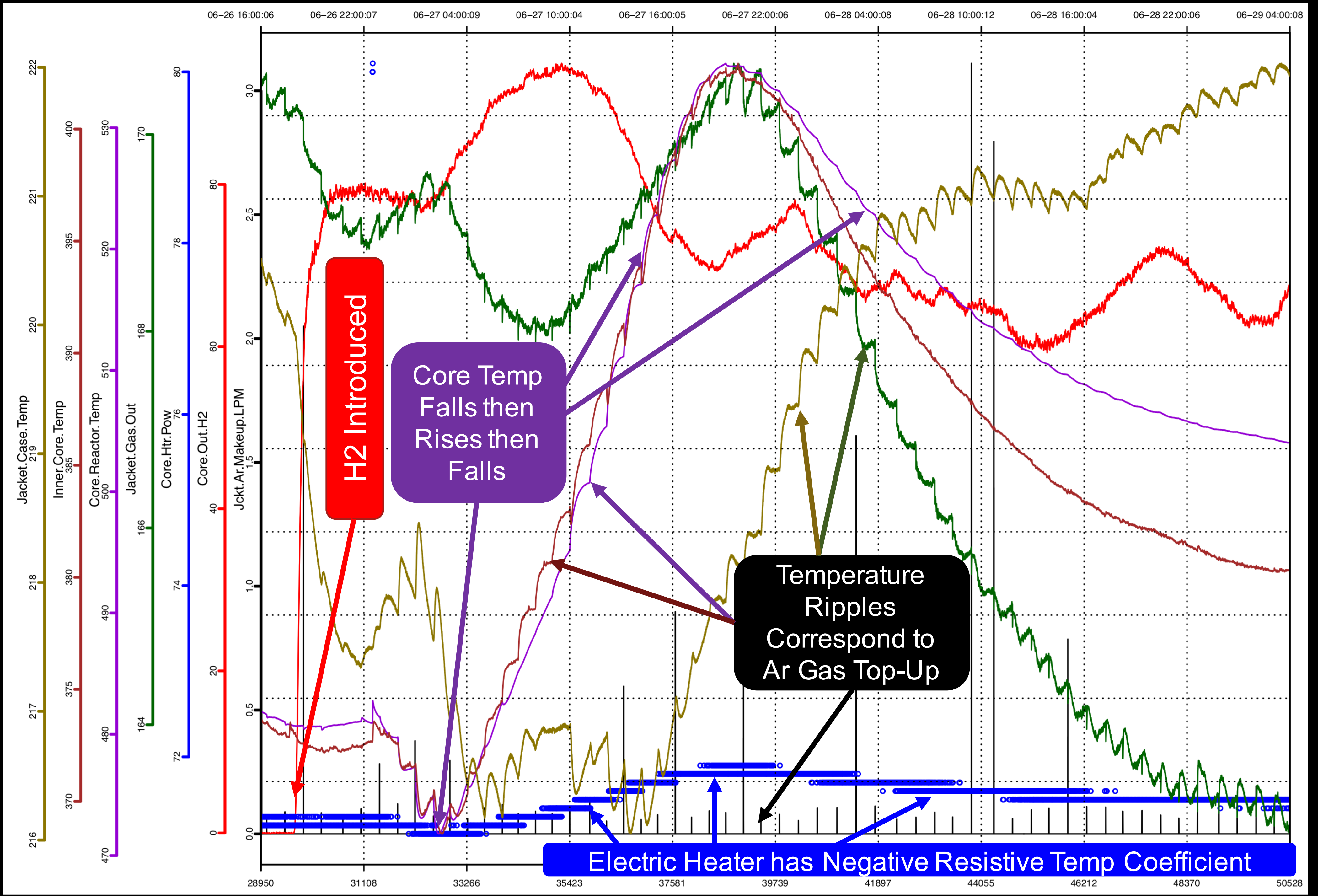
V. HEAT GENERATED ON SWITCHING TO H2 GAS (27 JUNE 2015 TEST)

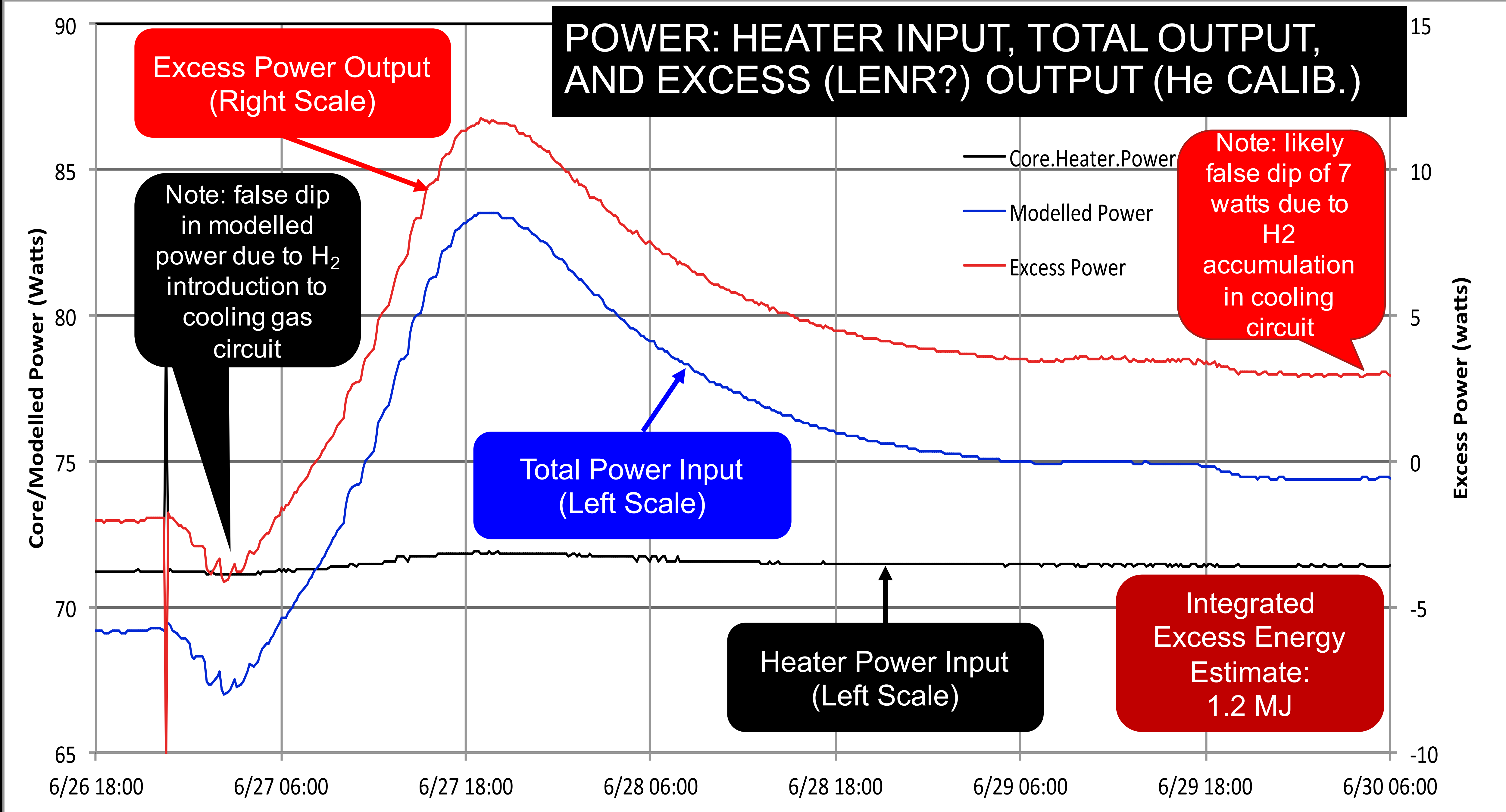
- Core has been calibrated as per above method and is approximately stable with:
  - Set Amount of Power delivered to Core Resistive Heating Element
  - Near constant regulated pressure in the Ar gas cooling circuit
  - He (which is presumed to be inert) control gas in the core gas circuit
  - NO Q-Pulse RF power signal delivered to core (because measuring Q-Pulse power to the core accurately is not possible with 2015 HHT experimental setup)
- H2 gas then replaces He in the core gas circuit (all other variables same)
- Temperature Increases following H2 gas introduction.
- Excess Heat power is computed from Calibration
- Sources of experimental error are analyzed



TEMPERATURE RIPPLES DUE TO Ar GAS LEAKAGE AND MAKEUP INJECTIONS
06–26 16:00:06
06–27 04:00:09
06–27 16:00:05
06–28 04:00:08
06–28 16:00:04
06–29 04:00:08
Jckt.Ar.Total
Jacket.In.Press
Jckt.Ar.Makeup.LPM
Cumulative Ar Injection
Jacket Ar Pressure
Ar Makeup Injections
28950
31108
33266
35423
37581
39739
41897
44055
46212
48370
50528

27-JUN-15
HEAT PRODUCTION EVENT AT SRI'S LAB

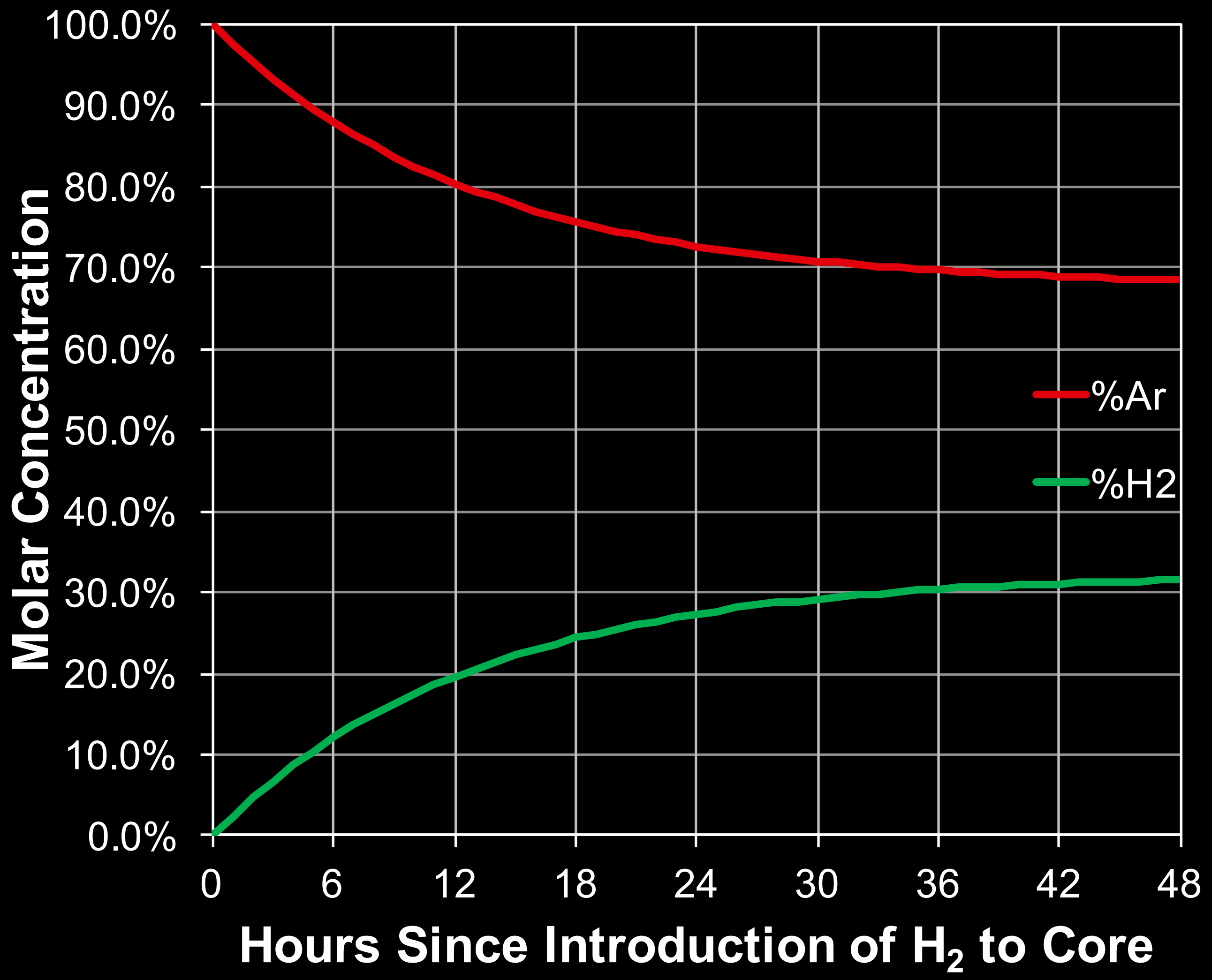


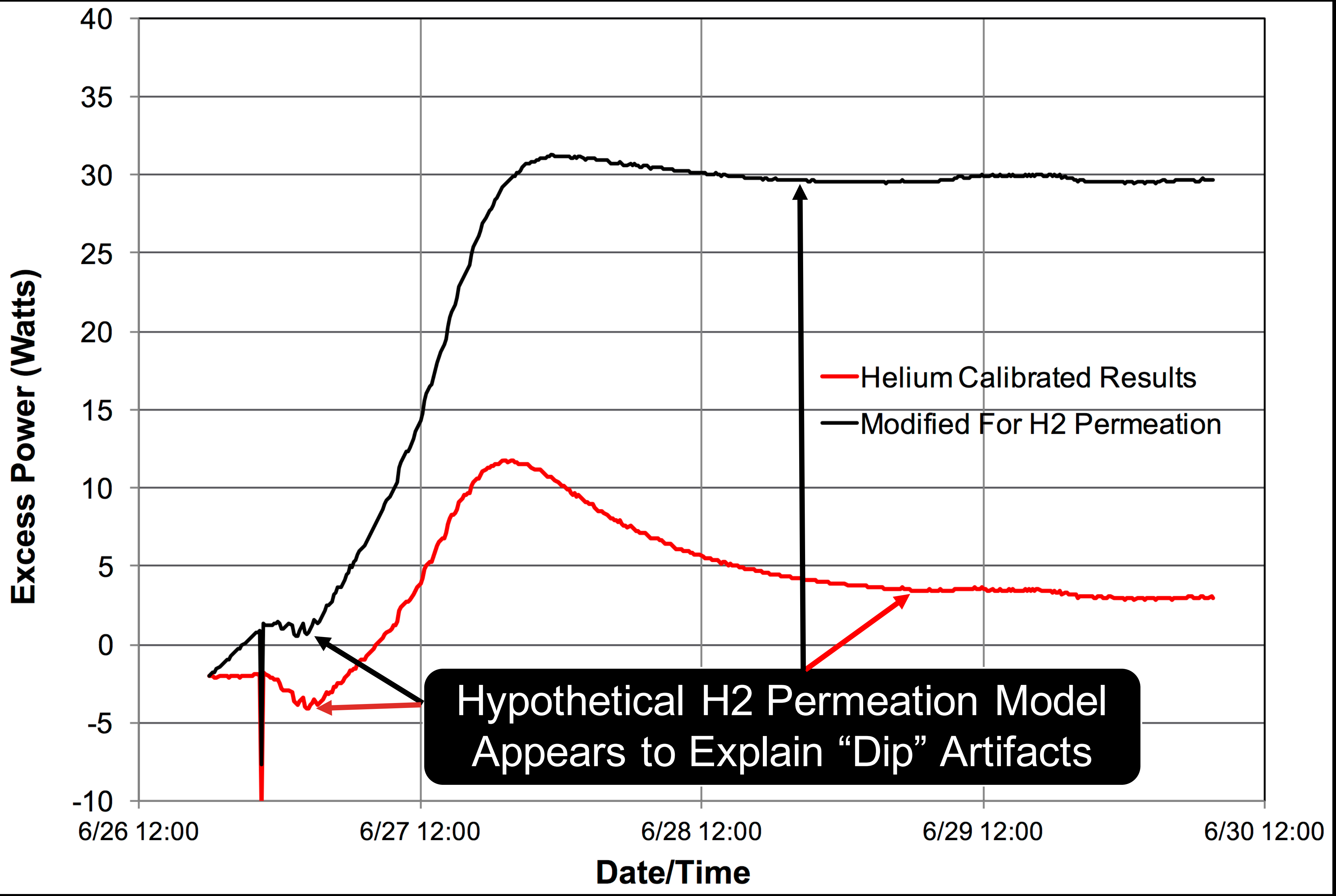


POWER: HEATER INPUT, TOTAL OUTPUT, AND EXCESS (LENR?) OUTPUT (He CALIB.)
Excess Power Output (Right Scale)
Note: false dip in modelled power due to H_2 introduction to cooling gas circuit
Core.Heater.Power
Modelled Power
Excess Power
Note: likely false dip of 7 watts due to H2 accumulation in cooling circuit
Total Power Input (Left Scale)
Heater Power Input (Left Scale)
Integrated Excess Energy Estimate: 1.2 MJ
Core/Modelled Power (Watts)
Excess Power (watts)
Date/Time
90
85
80
75
70
65
15
10
5
0
-5
-10
6/26 18:00
6/27 06:00
6/27 18:00
6/28 06:00
6/28 18:00
6/29 06:00
6/29 18:00
6/30 06:00

SIMULATION OF H_2 PERMEATION INTO Ar JACKET GAS

- H_2 has 10x higher thermal conductivity and 2.5x lower dynamic viscosity than Ar: ***H_2 is a much better coolant gas***
- H_2 permeation rate of approximately 3.2×10^{-7} mol/s calculated thru 60 cm^2 of the HHT 316 Stainless Steel tube at 875 K
- Ar Jacket replenishment rate of 6.7×10^{-7} mol/s of Ar with equal amount of combined gas being leaked to the environment
- 10% H_2 achieved after only 4 hours
- Elevated H2 readings in Jacket corroborated by spot mass-spec readings





Note: Hypothetical H2 Permeation Model NOT Calibrated

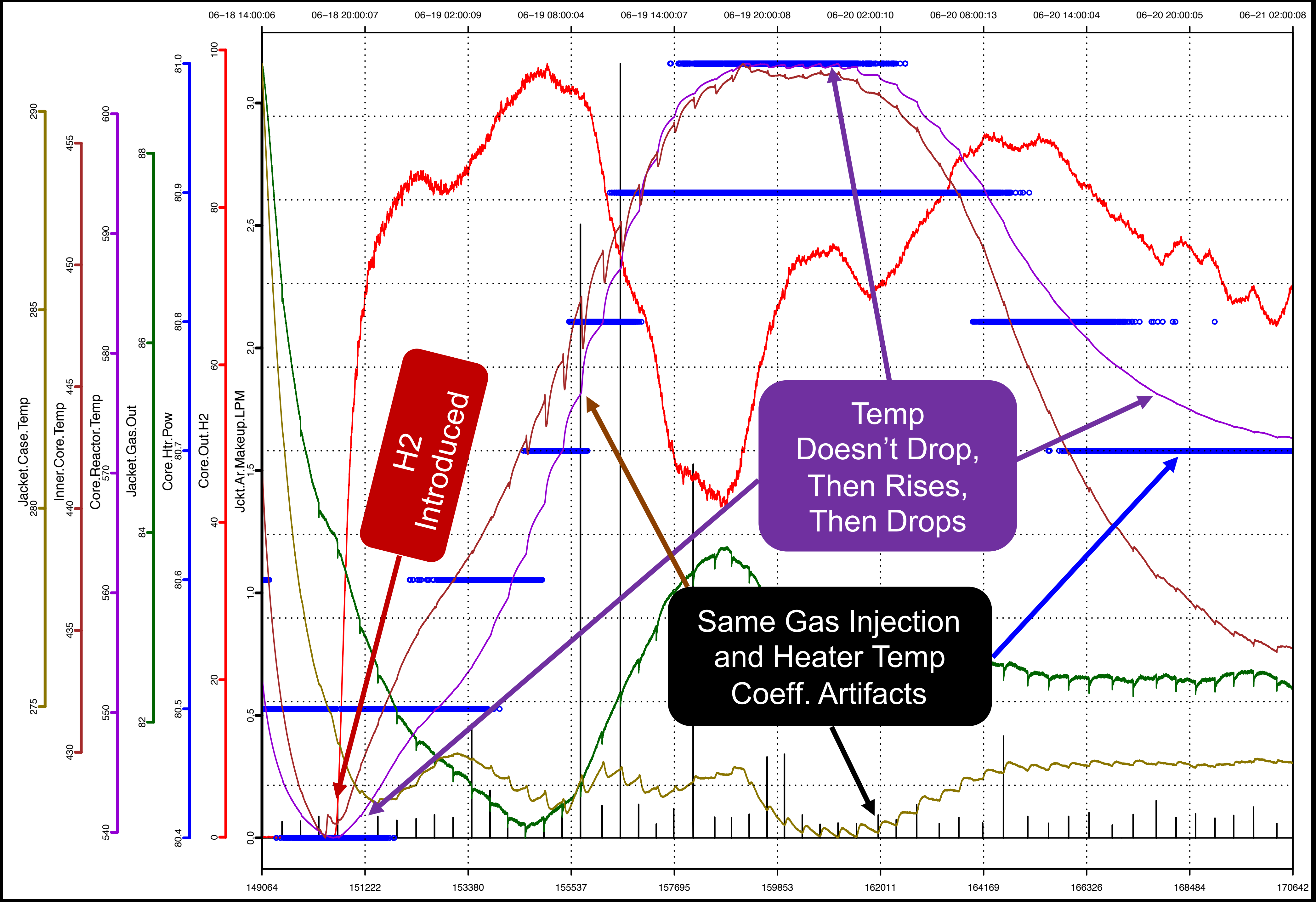
VI. POSSIBLE H2 COMBUSTION? FOLLOWING DIFFUSION OR LEAKAGE THRU THE INNER CORE

- H_2 Diffusion into inner core (exposed to air) at 110 psig and 900K: ~9x10-7 g/s => 0.13 watts if combusted (insignificant)
- ***Worst case Hypothesis: pinhole leak of H2 creating 15*** watts excess energy in (lengthwise) middle of inner core tube (unlikely but possible)
- Assume the nickel, the bonding element and the 316 stainless all have the thermal conductivity of the stainless, about 15 W/(m·K)
- Cross sectional area ≅ 23.75 mm^2, length is 20 cm from middle to exit of Conflat. ***15 Watts COULD be dissipated at 850 C by radiation.***
- Need Non-oxidizing atmosphere to rule out (follow-up coming next year)

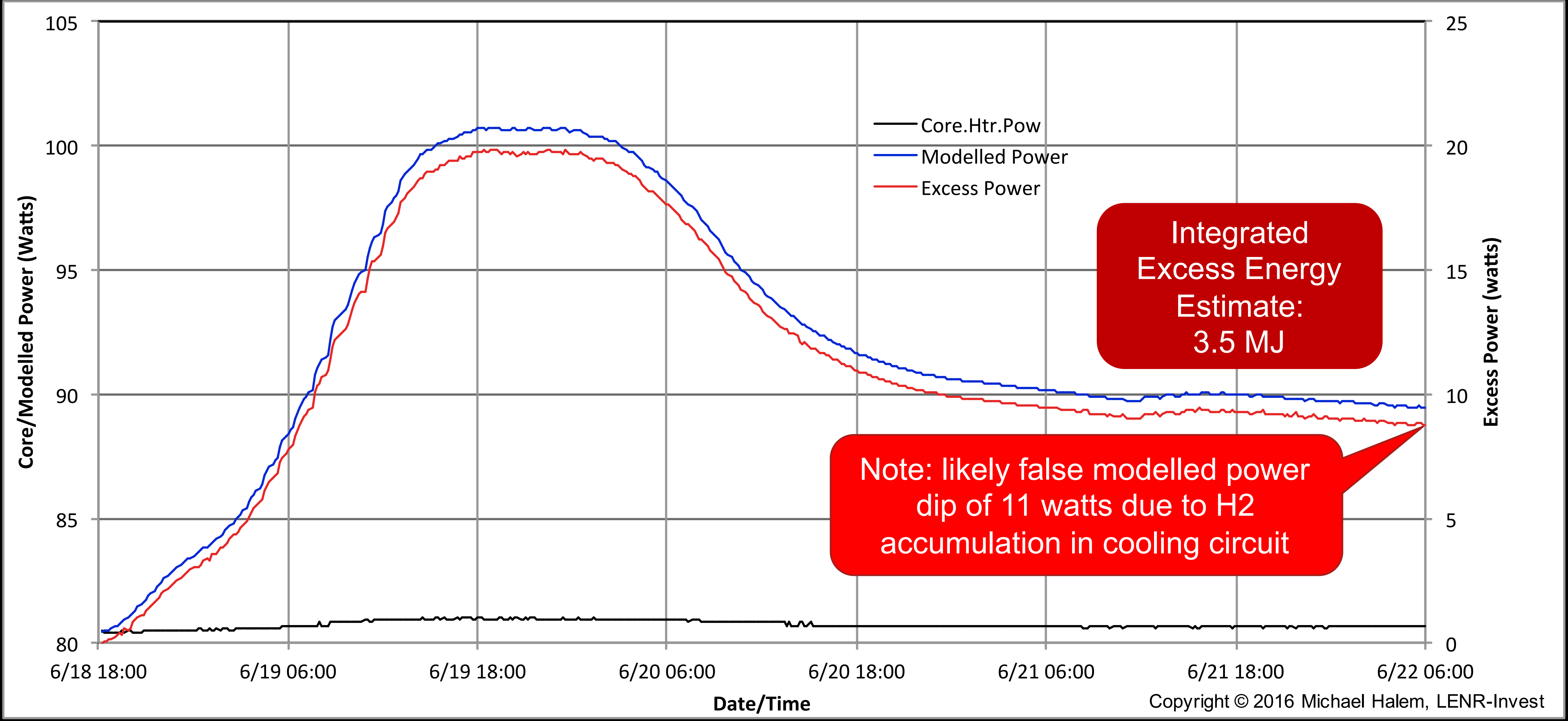
POSSIBLE H2 COMBUSTION

- More than likely any combustion would be near oxidizer (air) source as the positive pressure of the H2 and its combustion products would force the combustion products out the HHT and away from the pinhole.
- Combustion in the middle is unlikely, as ***the inner core is only 3 mm in diameter and has the thermocouple plus leads within***.
- Inner Core surrounded by H2 and Ar (no oxidizer)
- ***Absent a Chimney flue like air supply (due to unintentional natural convection) air would have difficulty entering*** at the bottom to exit at the top through the fittings against the heated combustion products

VIII. 19-JUN-15 EXCESS HEAT EVENT

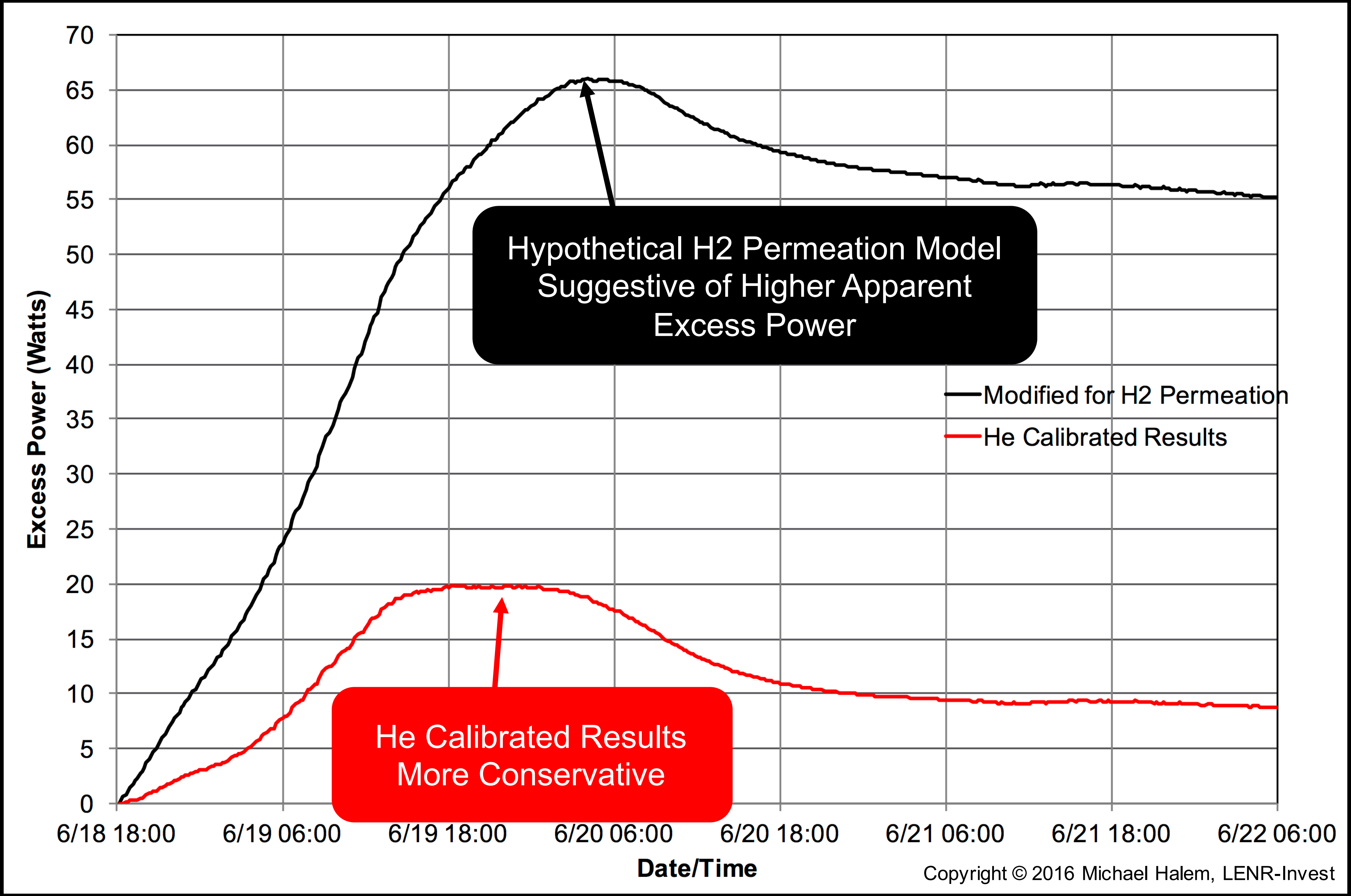


6/19 EVENT: INPUT, OUTPUT, AND EXCESS POWER (PURE He CALIBRATION)

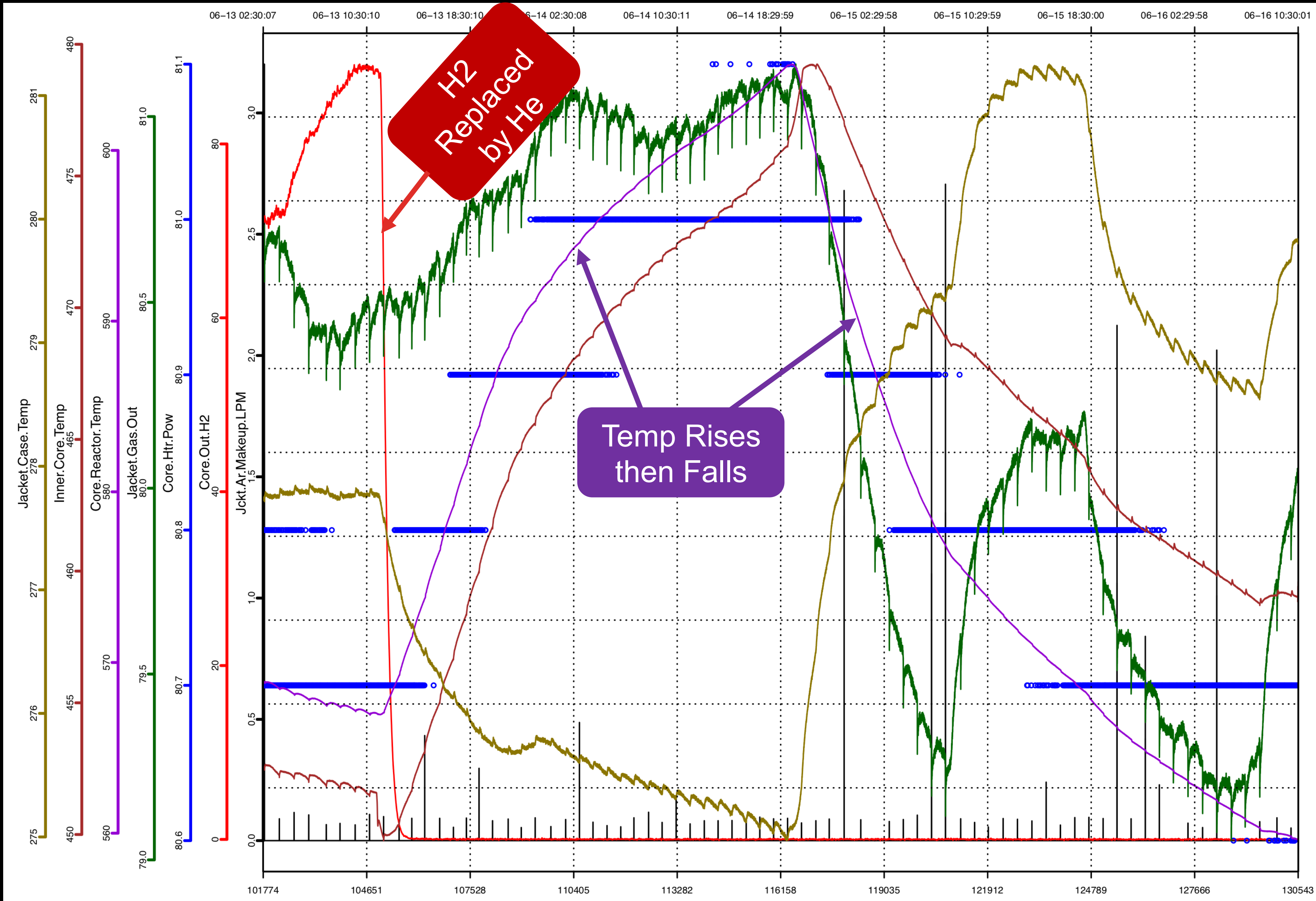


Hypothetical H2 Permeation Model

Note: Hypothetical H2 Permeation Model <u>NOT</u> Calibrated

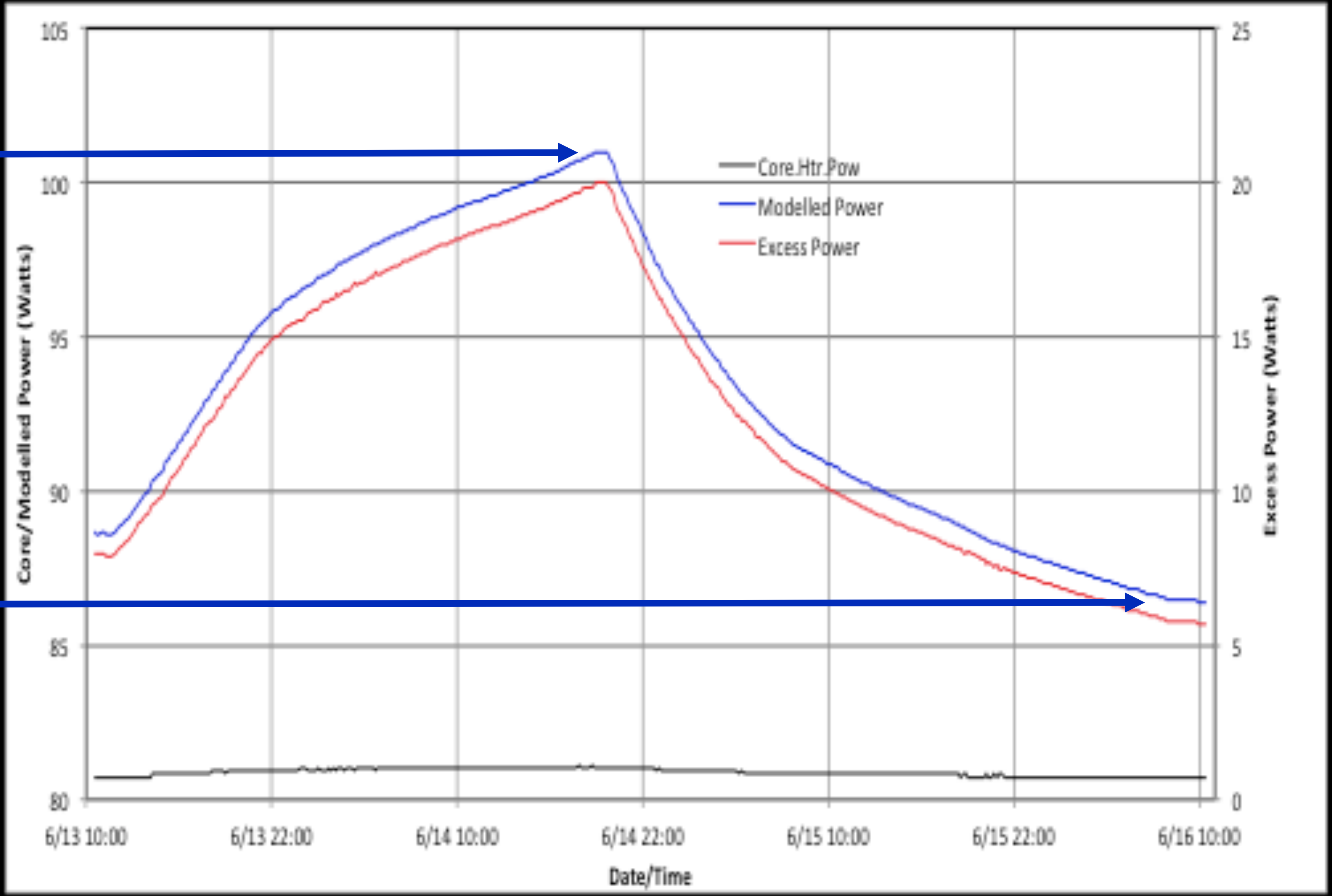


IX. 13-JUN-15 TEMP RISE ON H2 REMOVAL EVENT

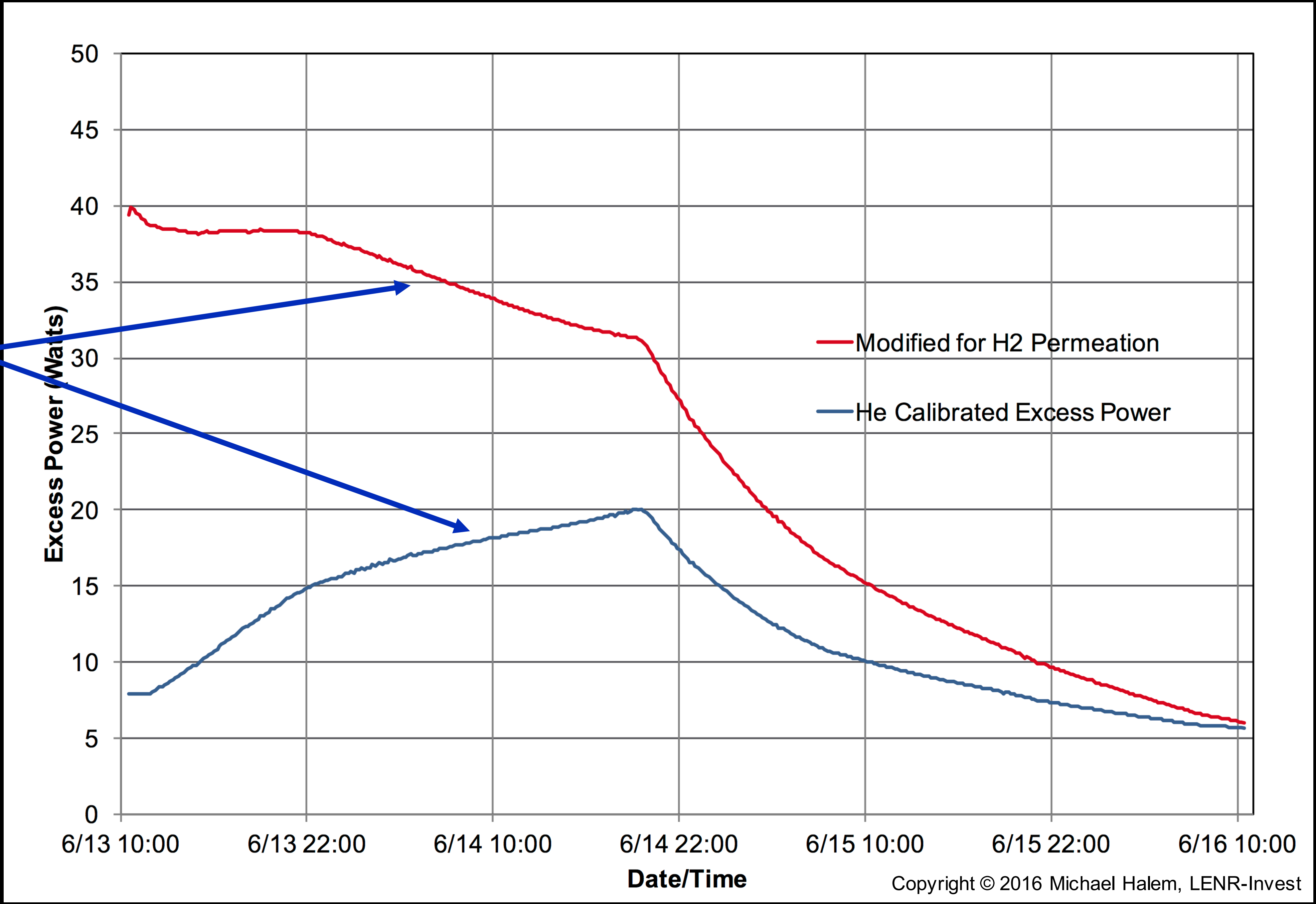


6/13 Event: Input, Output, and Excess Power (Pure He Calibration)

12 watt indicated power increase on H2 removal, followed by 14 watt loss: likely due to slow unloading of H2 from cooling circuit while "LENR" heat generation continues in core.



H2 Permeation Model Appears to Eliminate the "Heat Increase After H2 Removal" Artifact



Note: Hypothetical H2 Permeation Model <u>NOT</u> Calibrated

X. COMPARISON TO OTHER KNOWN ENERGY SOURCES (COMBUSTION)

- 16.2 g of Ni in this core
- Minimum 1.2 MJ/Cycle
- At least 7.9 MJ for these runs (using conservative He Calibration)
- Most Exothermic Chemical/gram Fuel = $H_2 + O_2$ (142 kJ/g)
- Combusting 16.2 g H_2 ***only 2.3 MJ << 7.9 MJ***

XI. WEAKNESSES AND PROBABILITY OF ERROR

- *Author's subjective Probability assessment of NOT LENR materiality in parentheses ()*
- ***Possible H2 combustion in the inner tube. (<2%)***
- Possible Stainless steel combustion in the inner tube. Should be obvious from oxidation. Can be eliminated with an inert gas in the inner tube. (1 to 2%)
- Possible HHT Thermocouple does not measure inner tube by thermal contact. Suggest correction by using a high temperature thermal cement like Al2O3. Power supplied to resistive heating element varies with temperature. (0.5%)
- Possible Stainless steel participation in nuclear reaction. (Not material)
- Possibility of Neutrons changing conductivity of Nichrome Inconel heating element. (Not material)

WEAKNESSES & PROBABILITY OF ERROR (continued)

- Possible Temperature measurement error. (<0.1% this being material)
- ***Possibility of insulating effect of H_2 diffusion***. (2%)
- Possibility of new hitherto unknown chemical effect with no material economic benefit. (<0.5%)
- Possibility that proprietary substrate layer has participated in a chemical reaction. (0.5%)
- Possibility that unusual internal convection or movement of the rhodium radiation reflector have increased the calibrated temperature of the experiment. (1%)
- ***Possible H_2 permeation through core into Ar jacket throwing off calibration adversely. (2%)***

XII. OPEN ISSUES TO RESOLVE OR IMPROVE

- ***Elimination of combustion possibility by fully surrounding apparatus with inert gas.*** Post reaction hardware analysis of stainless steel and nickel to confirm.
- Eliminate substrate chemical reaction by post reaction hardware analysis of substrate layer.
- Elimination of slight power variation in the heater due to positive coefficient of conduction by implementing a constant power voltage adjustment program in the Labview control software.
- ***Continuous monitoring of the Jacket circuit for H2 concentration. Consider flushing the jacket continuously with Ar, or alternatively running the jacket under vacuum so that only radiation and conduction are active outside the HHT.***
- Elimination of the rhodium reflector to prevent the accumulation of higher concentrations of H2 between the rhodium reflector and the ConFlat wall.

OPEN ISSUES TO RESOLVE OR IMPROVE (continued)

- ***Thermal calibration of the Jacket circuit with known mixtures of H2 and Ar.***
- ***Accurate calibration of the mass spectrometer circuit to provide useful quantitative*** inputs to thermal calculations.
- ***Elimination of thermal variances due to gas convection and leakage*** by use of isoperibolic (solid block conduction) method of calorimetry.
- Construction of a strong fluid dynamic model of the interior convective and conductive heat transfer within the ConFlat. This is likely to be costly in terms of development effort, so other means of elimination of complex gas transport issues, such as the isoperibolic calorimeter may be more time efficient.
- Increase power output to get higher signal to noise (COP) ratio and larger absolute power, thereby making small variations in measurement less significant

XIII. CONCLUSIONS

- ***LENR Demonstrated at the author's 90% confidence level producing peak power of 12 to 20 watts with an apparent sustained power of 3 to 8 watts***
- Could be more due to H2 contamination in Ar Cooling Jacket
- ***Remaining Open Issues to Be Closed with Redesign of the Experiment***
- Brillouin currently developing Isoperibolic Design which may eliminate some of the issues.
- Brillouin, the author, and third party designing and validating a Q-Pulse power calibration so that future runs using Q-Pulse can be incorporated.

XIV. DISCLOSURE

The author is an investor in Brillouin Energy Corporation and other LENR related companies indirectly through his ownership interest in LENR-Invest LLC, LENR-Invest Fund I and LENR-Invest Fund II. The author anticipates that his investments may benefit from third party investment in Brillouin Energy Corporation and other LENR related companies subsequent to the release of this paper.

XVII. REFERENCES IN FULL PAPER

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XV. ACKNOWLEDGEMENTS

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Homage to Delacroix
Artists of the1863
Salon des Refusés
Henri Fantin-Latour 1864
Musée d'Orsay

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Le Moulin de la Galette
Auguste Renoir, 1870
Musée d'Orsay