ENERGY RESEARCH CENTER LLC

Brillouin's LENR Reactor and System Identification
A Worked Example

ARPA-E Workshop on Low-Energy Nuclear Reactions

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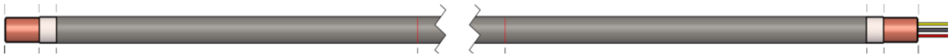
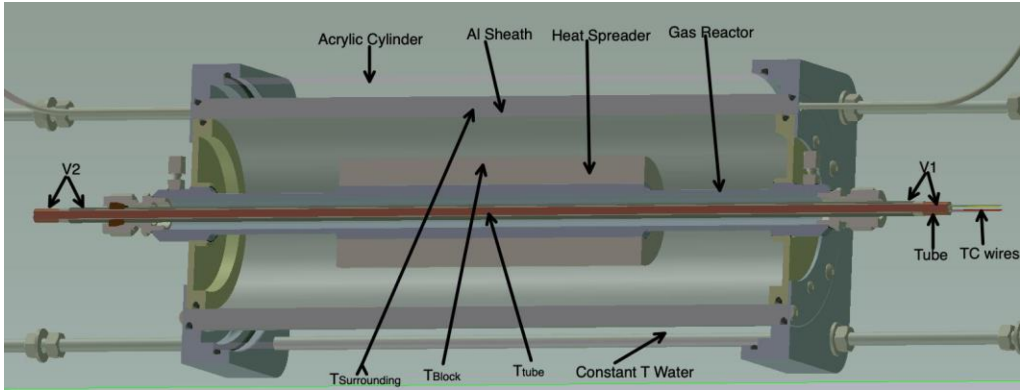
F. Tanzella et al. / Journal of Condensed Matter Nuclear Science 33 (2020) 33–45

Brillouin's Reactor/Heat Flow Calorimeter

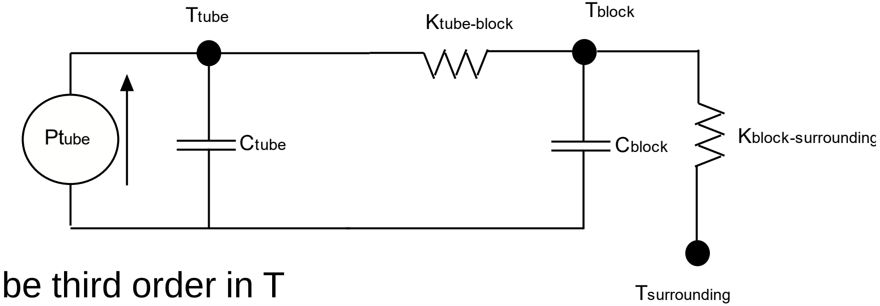




- Ni-H_2 with high V, high I, fast-rise-time pulses across Ni/dielectric/Cu tube
- Plasma sprayed on alumina substrate
- V & I measured by calib'd oscilloscope
- T_{tube} inside coated tube 200-600°C
- Tube sheath with static 3 - 10 atm H_2 inside steel block
- T_{block} sensor in steel block
- Ceramic insulation outside of block
- Constant T H_2O cooled Al shell with $T_{surrounding}$ sensor
- Constant low duty-cycle pulse power

- Thermocouples, current shunt, and oscilloscope calibrated
- Dielectric from contract synthesis group, metals from Oerlikon Metco
- Control: Using automated sequence with low voltage, wider low repetition rate pulses (LVP)
    - Seven-hour steps including no power
    - Adjust repetition rate to control at different pulse powers
- Stimulation: Using automated sequence and high-voltage, narrow pulses (HVP)
- Measure and record pulse generator, and actual pulse powers, all temperatures, H_2O flow rates, and pressures
- Compare calculated output power with high-voltage versus low-voltage pulses
    - Plot both input and output power

Model used for Brillouin's System Identification Calorimetry



1) Each parameter can be third order in T
2) All coefficients are found by fitting to one LVP calibration data set
3) Coefficients determine what percentage of input power is influencing reactor tube
4) Output power is calculated by applying those coefficients to temperature outputs measured with HVP stimulation using appropriate time derivative equations.

   e.g. $dT_{tube}/dt = (1/C_{tube})(P_{tube} - k_{t\text{-}b}(T_{tube} - T_{block})$ & $P_{stored} = C_{tube}(dT_{tube}/dt) + C_{block(}(dT_{block}/dt)$

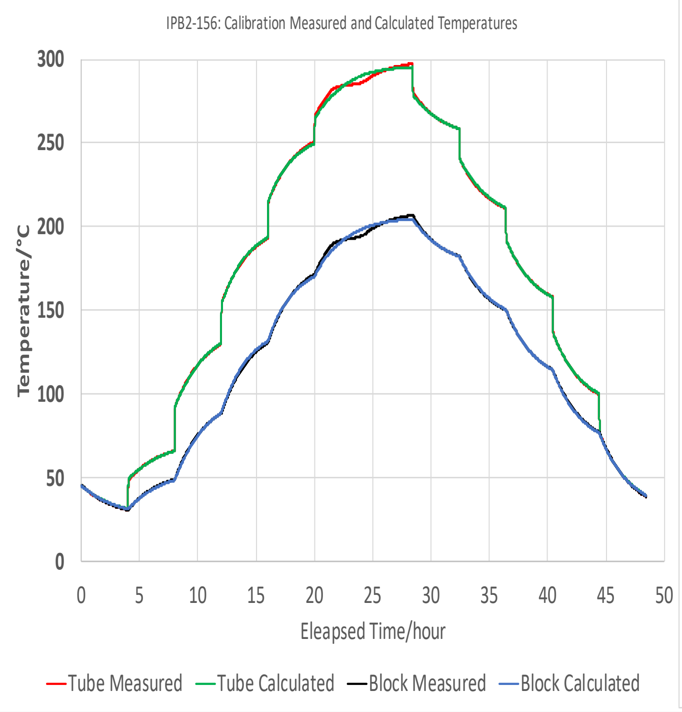
1) Coefficient of performance (COP) = calculated power divided by input power influencing tube
2) This requires more than 100 hours of calibration and up to 40 hours of excitation, but allows testing of 12 parameter variations; Much faster than the steady-state method.

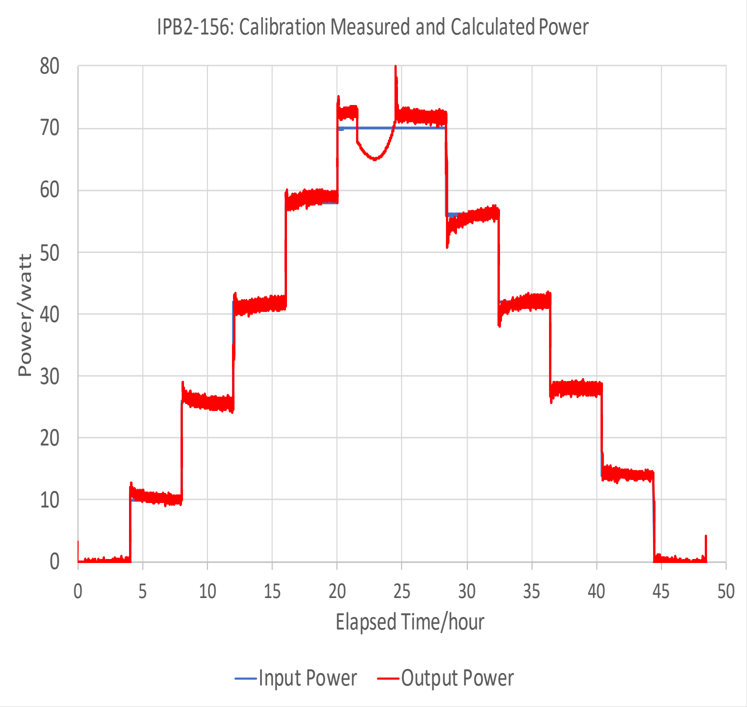
Berlinguette et al, "Revisiting the cold case of cold fusion", Nature Perspective, https://doi.org/10.1038/s41586-019-1256-6

B. P. MacLeod, D. K. Fork, et al, "Calorimetry under non-ideal conditions using system identification", Journal of Thermal Analysis and Calorimetry, https://doi.org/10.1007/s10973-019-08271-z (2019)

Brillouin's IPB Reactor: Heat Flow Results

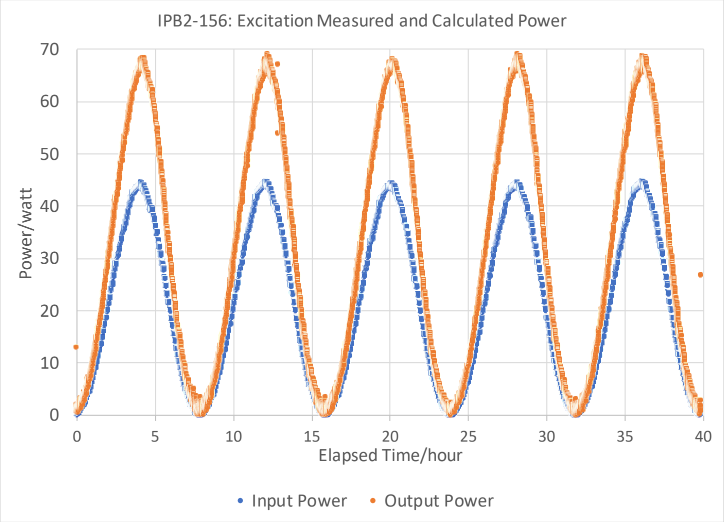
Measured and Calculated Power and Temperature during Calibration





$c_{tube}0$	$c_{tube}1$	$c_{tube}2$	$c_{block}0$	$c_{block}1$	$c_{block}2$	$K_{b\text{-}s}0$	$K_{b\text{-}s}1$	$K_{b\text{-}s}2$	$K_{t\text{-}b}0$	$K_{t\text{-}b}1$	$K_{t\text{-}b}2$
37.60	-9.14E-02	1.22E-04	21589	-9.79E+01	1.31E-01	0.40	-5.62E-04	1.15E-06	0.18	2.54E-04	1.93E-07

Brillouin's IPB Reactor: Heat Flow Results



- Overall thermal gain = 1.3; 3 hours around max = ~1.6; Peak P_{excess} = 25W
- Performed many times in Brillouin lab across >20 tubes and 4 reactors
- Tube #72 showed thermal gain of 1.23 at Brillouin lab and 1.15 at SRI in 4 reactors
- No nuclear diagnostics performed
- 19 recent SI results shown below
- Enthalpy of CuO and NiO reduction ➔ ~70kJ, assuming all Cu and Ni are oxidized much less than ~700kJ E_{excess}
- Probably less than 10% of Ni and Cu are oxidized

Reactor	1	1	1	1	1	1	2	2	2	
Tube	182	187	204	213	223	217	206	220	221	
Date	3/30/20	5/19/20	9/17/20	10/8/20	11/2/20	11/19/20	9/23/20	12/3/20	4/6/21	
SI CoP	1	0.8	0.9	1.01	0.8	0.8	1.3	1.1	0.9	
Reactor	3	3	4	4	4	4	4	4	4	4
Tube	222	216	72	214	215	233	215	241	224	276
Date	10/29/20	12/23/20	7/23/20	11/19/20	12/2/20	12/18/20	2/10/21	5/26/21	6/21/21	9/17/21
SI CoP	1	0.9	1.4	1.4	1.4	1.5	1.4	1.3	1.3	1.3

Assessment of Needs

- The following improvements would make the Brillouin experiments more believable

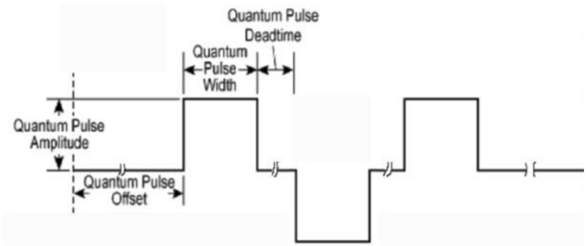
  - A better sealed reactor for 1 ppm He sensitivity and H_2 leak tightness.
  - A 10x more sensitive prompt gamma detection system
  - Better gamma shielding to lower the background by an order of magnitude.
  - Better coating processes to form 10x smoother, >90% dense coating
  - Higher impedance system to use COTS equipment (50, 75 ohm, etc.)
  - An order of magnitude better EMI shielding for reliable data collection.
  - Complete envelope calorimetry, including electronics to yield 96-99% heat recovery
  - 100% wall power measurement downstream
  - >95% heat-flow and mass-flow heat recovery in the calorimeter

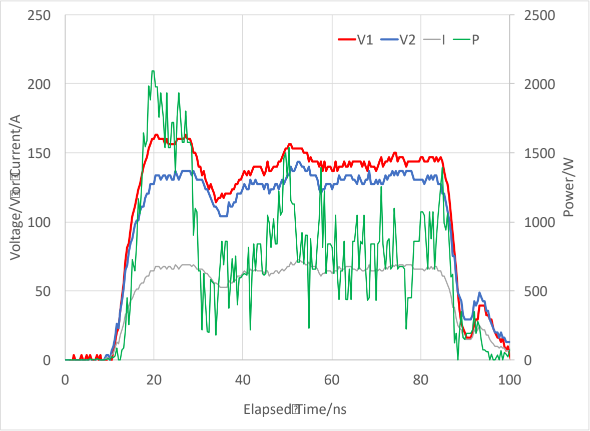
The Brillouin Crew

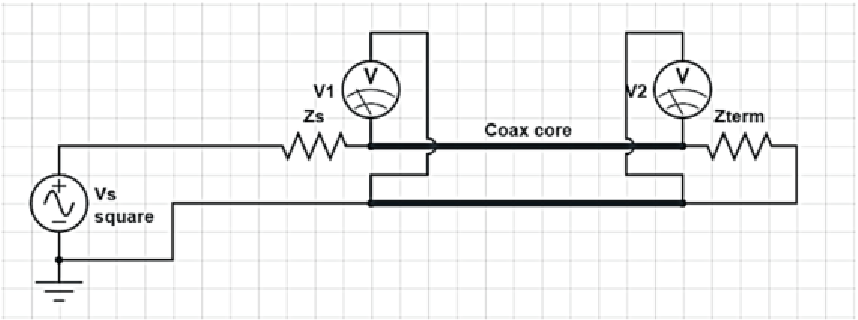
Thank You

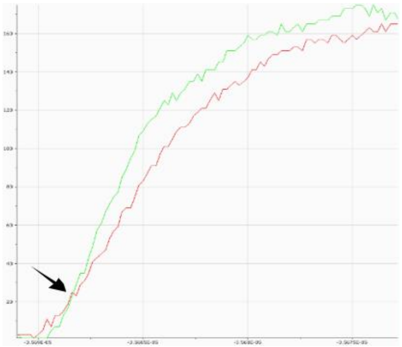
EXTRA SLIDES

Brillouin's IPB Reactor Cores
Stimulation and Measurement

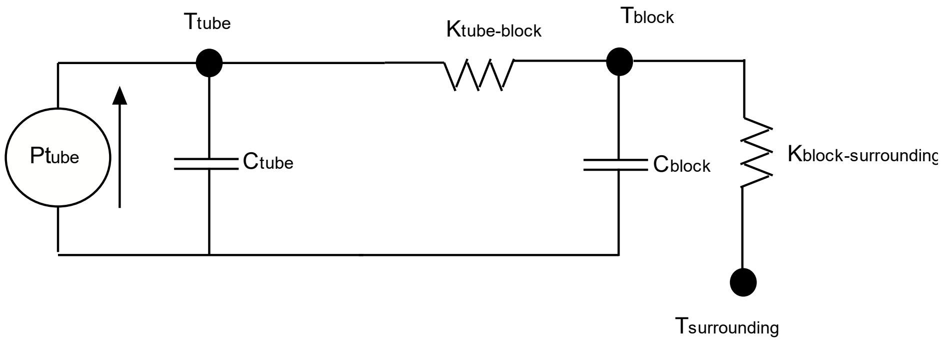








System Identification[1,2,3]



$dT_{tube}/dt = (1/C_{tube})(P_{tube} - k_{t\text{-}b}(T_{tube} - T_{block})$

$dT_{block}/dt = (1/C_{block})(k_{tube\text{-}block}(T_{tube} - T_{block}) - k_{block\text{-}surrounding}(T_{block} - T_{surrounding}))$

$P_{in} = P_{tube}$ (pulse, DC or internal heater)

$P_{out} = k_{block\text{-}surrounding}(T_{block} - T_{surrounding})$

$P_{stored} = C_{tube}(dT_{tube}/dt) + C_{block}(dT_{block}/dt)$

Compare measured and calculated $T_{tube}(t)$, $T_{block}(t)$, respectively & solve for the k's and c's

- [1] Berlinguette et al, "Revisiting the cold case of cold fusion", Nature Perspective, https://doi.org/10.1038/s41586-019-1256-6
- [2]MacLeod, B. P. et al. High-temperature high-pressure calorimeter for studying gram-scale heterogeneous chemical reactions. *Rev. Sci. Instrum*. **88**, 084101 (2017).
- [3] B. P. MacLeod, D. K. Fork, et al, "Calorimetry under non-ideal conditions using system identification", Journal of Thermal Analysis and Calorimetry, https://doi.org/10.1007/s10973-019-08271-z (2019)

Estimates of Thermal Conductivity and Heat Capacitance Coefficients from 1st Principles

Path 1:

Inner Block Outer Circumferential A = 3.14 * 0.05m * 0.15m = 0.024 $m^{2.}$

Outer Block Inner Circumferential A = 3.14 * 0.089m * 0.15m = 0.042 $m^{2.}$

Average area = 0.033 $m^{2.}$, Distance = 0.019 m

Path2:

Inner Block Axial Face A = 3.14 * $(0.025m)^2$ - 3.14 * $(0.0125m)^2$ = $0.0015m^2$

Endcap Axial Block Face A = 3.14 * $(0.0445m)^2$ - 3.14 * $(0.0125m)^2$ = $0.0057m^2$

Average area = 0.0036 m^2 , Distance = 0.064 m

Path 3:

Reactor Outer Circumferential A = 3.14 * 0.019m * 0.127m = 0.0076 $m^{2.}$

Outer Block Circumferential A = 3.14 * 0.089m * 0.127m = 0.035 $m^{2.}$

Average area = 0.022 $m^{2.}$, Distance = 0.07 m

Path 4:

Reactor Cross Section area = 3.14 * $(0.0095m)^2$ - 3.14 * $(0.00635m)^2$ = $0.00015m^2$

Reactor Cross Section area = 0.00015 $m^{2.}$, Distance = 0.14 m

Calculating the conductance from above using **rock wool's** room temperature value of 0.038 W/(m*K), we get:

Path 1: 0.038 W/(m*K) * 0.033 $m^{2.}$/ 0.019 m = 0.066 W/K ➔ 30 K/W. Path 2: 0.038 W/(m*K) * 0.0036 m^2/0.064 m = 0.0021 W/K ➔ 470 K/W

Path 3: 0.038 W/(m*K) * 0.022 m^2/0.07 m = 0.012 W/K ➔ 84 K/W. Path 4: 0.038 W/(m*K) * 0.00015 m^2/0.14 m = 0.012 W/K ➔ 84 K/W

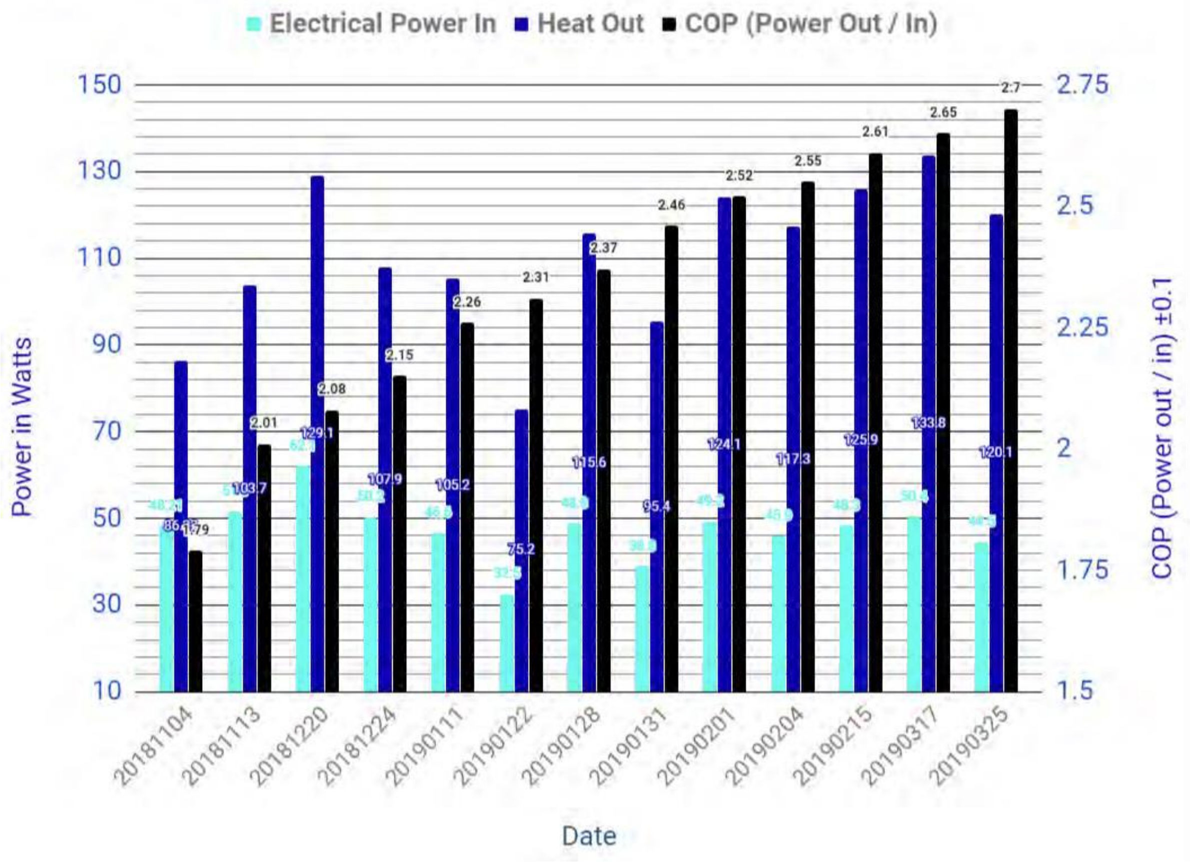
This yields a total thermal conductance for inner block to surroundings (K_{is}) of ~0.081 W/K or ~12 K/W.

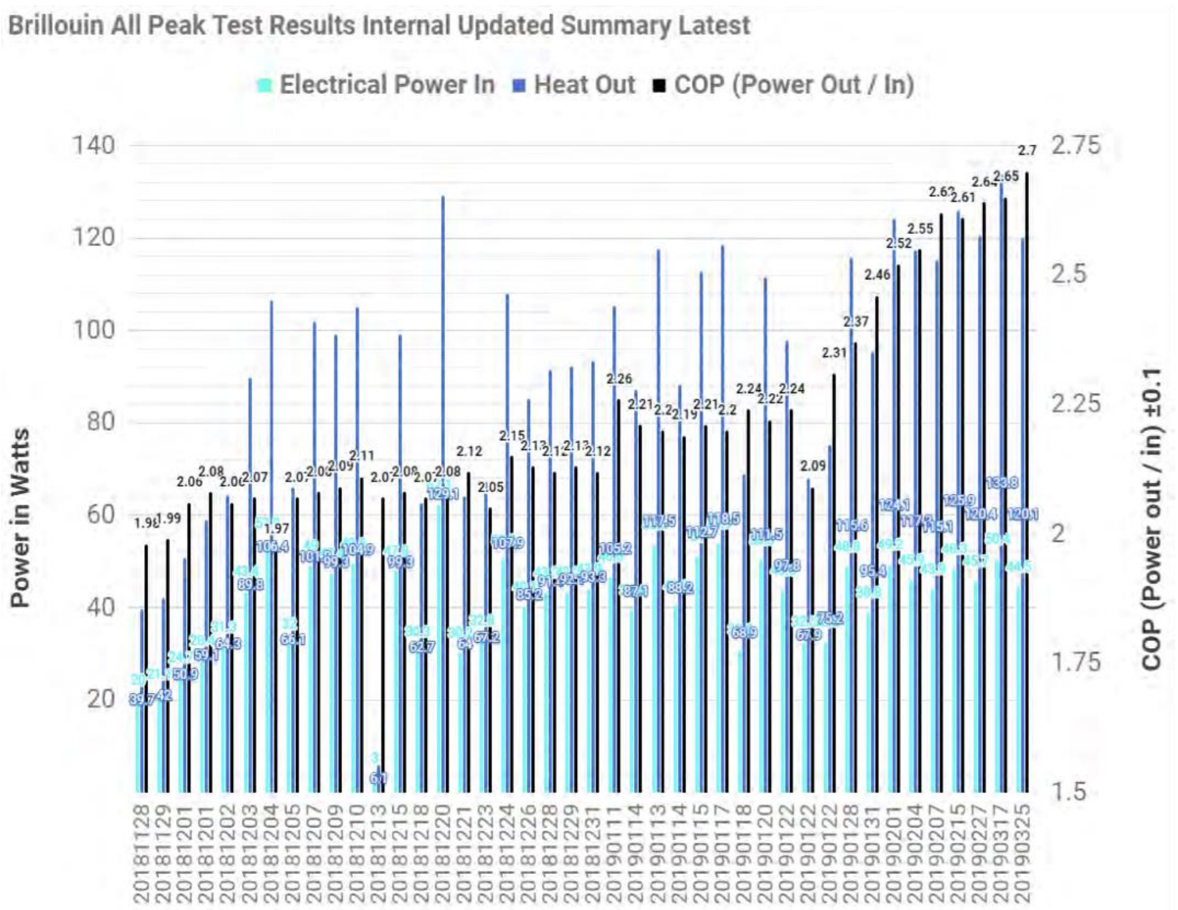
Estimates of Thermal Conductivity and Heat Capacitance Coefficients from 1st Principles

- Path 5 is the conductance ($K_{tube\text{-}block}$) through the hydrogen from the radial face of the alumina tube to the inner block, represented by the inner face of the reactor. Path 6 is the axial conductance along the cross section of the alumina tube to the surroundings ($K_{tube\text{-}surrounding}$).
-
- Following the same logic as above:
-
- Path 5:
- Reactor's Inner Circumferential A = 3.14 * 0.0127m * 0.15m = 0.0058 m^2.
- Tube's Outer Circumferential A = 3.14 * 0.0072m * 0.15m = 0.0034 m^2.
- **Average area = 0.0046 m^2.**
- **Distance = 0.005 m**
-
- Calculating the conductance from hydrogen's thermal conductivity of ~2.0 W/(m*K) at 125°C and 8 bar, we get (since H2 is not an ideal gas its conductivity will not scale with pressure, so there can be large errors):
- 2.0 W/(m*K) * 0.0046 m^2/0.005 m = 1.84 W/K ➔ 0.54 K/W
- Using 1 bar we and 0.23 W/(m*K) we get 0.21 W/K or 4.7 K/W.
-
- Path 6:
- Tube Cross Section area = 3.14 * $(0.0036m)^2$ - 3.14 * $(0.0016m)^2$ = 0.000033m^2
- **Tube Cross Section area = 0.000033 m^2.**
- **Distance = 0.14 m**

Calculating the conductance from above alumina's thermal conductivity of ~27 W/(m*K) at 175°C, we get:
27 W/(m*K) * 0.000033 m^2/0.14 m = 0.0064 W/K ➔ 157 K/W

HIGHLIGHTS OF ACTUAL TEST RESULTS




Brillouin All Peak Test Results Internal Updated Summary Latest
Electrical Power In
Heat Out
COP (Power Out / In)
Power in Watts
COP (Power out / in) ±0.1
140
120
100
80
60
40
20
2.75
2.5
2.25
2
1.75
1.5
20181128
20181129
20181201
20181201
20181202
20181203
20181204
20181205
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