March 2018

Isoperibolic Hydrogen Hot Tube Reactor Studies

TECHNICAL PROGRESS REPORT

FOR THE PERIOD JANUARY 1ST - DECEMBER 31ST 2017

SRI International Project P21429

Prepared by:
Francis Tanzella, Principal Investigator, Manager
Low Energy Reactions Research Program
Energy and Environment Center
Advanced Technology and Systems Division
SRI International
Menlo Park, California

Sponsored by:
Brillouin Energy Corporation
Berkeley, California

Attention:
Mr. Bob George II, Chief Executive Officer
Mr. Robert Godes, Chief Technology Officer
Mr. David Firshein, Chief Financial Officer

Table of Contents

EXECUTIVE SUMMARY

Introduction

In August 2012, SRI International (SRI - https://www.sri.com) was contracted by Brillouin Energy Corp. of Berkeley California ("Brillouin", "Brillouin Energy" or "the company" – http://brillouinenergy.com) to perform independent studies of Brillouin's low energy nuclear reaction (LENR) reactors, as well as advise on related Brillouin LENR research. We have operated these reactors to observe, monitor, analyze, advise on, and independently verify Brillouin's LENR evolving research & development work, test systems, and test results. This Report documents the most recent independent results obtained with Brillouin's prototype reactors located in SRI's laboratory, as well as verification and validation of results obtained with Brillouin's prototype reactors located in Brillouin's laboratory, over the course of the past year. Brillouin indicates that it has designed the control systems in its reactors to drive the underlying physics of LENR, as described in its Controlled Electron Capture Reaction (CECR) Hypothesis, which is how it believes its reactors generate controlled LENR Reaction Heat. This Report does not attempt to prove or disprove Brillouin's CECR Hypothesis.

The systems tested and described in this Report consist of three parts – cores, reactors and calorimeters. The cores are the reactive components of the system. (Brillouin energy is engineering the system with the intent of licensing production and the core design allows any core to operate in any similarly sized reactor). The reactors provide the environment and stimulation that causes the cores to produce LENR reaction heat. The calorimeter is used to measure the thermal efficiency and absolute heat produced by the core, and/or the reactor. The calorimeter was designed by both SRI and Brillouin personnel to be perfectly matched to the reactor for accuracy of measurement, whose results are described in this Report. During 2017, the calorimeter design was modified to match the analytical methodology suggested by an independent commercial third-party reviewer, who is also overseeing their suggested stimulation and analyses (see dynamic stimulation below).

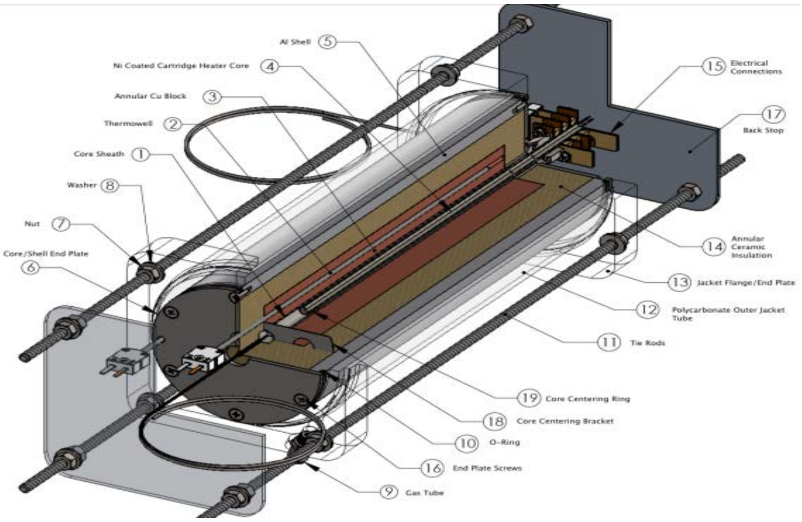
SRI has brought over 75 person-years of calorimeter design, operation, and analysis experience to this process. We have used our expertise in LENR calorimetry, the ability to measure input and output power in the form of electricity or heat (energy balance power gain), to validate the results that are summarized in this Technical Progress Report. Brillouin's system was designed to rely upon compensation calorimetry, which is an accepted method of examining the variables that affect power gains.

This Technical Progress Report is the second such Report that SRI International has issued to Brillouin Energy Corp., covering technical results achieved in 2017. It compares with the original (first) Progress Report that SRI issued to Brillouin covering results achieved in 2016.

Experimental

Since the start of SRI's independent advisory and independent experimental verification and validation role in August 2012, to date Brillouin has developed its uniquely fabricated, hydrogen "gas-based" reactors, known as its "Hydrogen Hot Tube" (HHT^{tm}), in order to prove that its CECR Hypothesis can generate controlled LENR heat on demand for potential industrially useful applications. During this time, Brillouin has run many experiments at its headquarters lab in Berkeley, as have SRI personnel at SRI in Menlo Park. These results have produced, at various times, a wide range of thermal output, which can be attributed to LENR Reaction Heat in Brillouin's HHT^{tm} prototype reactor test systems.

SRI has aided in the evaluation of the effectiveness of the two gas mass flow calorimeters used with Brillouin's first generation (GEN1) HHT^{tm} reactor using "ConFlat®" fittings. SRI has also been instrumental in the subsequent design & development of the isoperibolic calorimeter ("IPB" - see Theory of Isoperibol Calorimetry, E.D. West, Journal of Applied Physics 41, 2705 (1970); https://goo.gl/6Rc11x) used to measure and validate the energy balance of Brillouin's second generation IPB HHT^{tm} reactors (GEN2). Brillouin has built, calibrated and tested four identical IPB systems at Brillouin's lab. Two IPB HHT^{tm} reactors are now operating in Brillouin's laboratory and two at SRI. Cores have been transferred and operated successfully within the IPB HHT^{tm} reactors at SRI after operating successfully within the IPB HHT^{tm} reactors in Brillouin's facility. Because of their highly refined calorimetry, both Brillouin and SRI have concentrated on the extensive testing of these (GEN2) IPB HHT^{tm} reactors:



Schematic diagram of the isoperibolic hydrogen hot tube reactor/calorimeter

The design of the Brillouin IPB HHT^{tm} involves a conventional resistive heater used to maintain a constant temperature in the reactor while adding additional proprietary electrical "Q" pulses to the system to stimulate the specially designed core to yield LENR heat. This becomes evident if the total output heat measured is greater than that from the heater and the Q-pulse power imparted to the core. Upon generating a positive LENR coefficient (excess heat), the system reduces the heater power input, by an amount equal to the Q pulse power imparted to the core and the excess power generated, required to maintain the pre-set temperature. By this compensation calorimetry method, the measurements of net input and output power are carefully measured to within 5% accuracy to assure an exact calculation of the LENR coefficient.

SRI has closely followed and advised on the evolution of Brillouin's system design and materials and as such we are very familiar with the history of their efforts to build and advance their test systems, test protocols, manufacturing techniques, specifications and core components. We closely studied Brillouin's test data generated from extensive testing of two of their IPB HHTs, especially over the final quarter of 2017, which is the period during which they have produced their most impressive test results to date.

Results

We report here on the overall extensive testing of the four IPB HHT^{tm} reactors operating at both Brillouin and SRI. Together we have tested 34 cores during 2017 (16 cores in two reactors at SRI and 18 cores in two reactors in Berkeley).

In last year's Report, we were able to corroborate that the Brillouin IPB HHT^{tm} system that was moved to SRI continued to produce similar LENR Reaction Heat that it produced up in its Berkeley laboratory at Brillouin. Together with our prior data review, it is now clear that these very similar results are independent of any of these systems' location (Berkeley or Menlo Park) or operator (Brillouin's or SRI's personnel). This transportable and reproducible reactor system is extremely important and quite rare. These two characteristics, coupled with the ability to start and stop the reaction at will are, to our knowledge, unique in the LENR field to date.

Last year's Report suggested that Brillouin could produce repeatable, small scale LENR reaction heat on the order of a couple watts of power, on a fully controlled basis, on demand. This year's Report shows that such output has increased to as much as over five watts of power, on a fully controlled basis, on demand.

Brillouin has posited that this specific heat production is being generated from its CECR process, based on its interpretation of the precise calorimetric measurements of the input and output power in its IPB HHTs. The current results also suggest that the cores in three different IPB HHTs produced similar LENR heat outputs, using two different stimulation/analysis methods, and using different core materials (key components).

Using different batches of the same materials and standard industrial processing techniques, processed to a proprietary set of customized specifications, Brillouin has produced a variety of similar cores for its HHT^{tm} systems. This was done in order to test various materials and their fabrication techniques, which yield different material and electrical properties necessary to maximize the effect of the Q pulse.

In this year's Report, we have used two different methods of stimulation, each requiring its own analysis method. These are explained in more detail in the body of this Report. The "steady-state method" is very similar to that documented in last year's Report. The "dynamic method" provides a more precise and accurate analysis but is not directly comparable to the results presented in last year's Report. In last year's Report, we calculated the coefficient of performance (COP) by dividing the core's output power gain by the input pulse power. If we interrupt the dynamic stimulation to yield a steady-state, we can divide the core's apparent power gain by the input pulse power and compare that to last year's results. This analysis is comparable to but not identical to last year's calculation. The results of a dynamic stimulation with a corresponding legacy-type analysis from recent runs are shown next in Table E.1:

Table E.1 Coefficients of performance (COP) from recent runs using legacy analysis method

Temperature/°C	$Q_{REACTION}$/Watts	COP
300	3.62	1.56
340	2.71	1.37
300	3.59	1.55
340	3.22	1.43
300	3.90	1.62
340	3.58	1.44
300	4.91	1.56
340	5.29	1.52
300	4.99	1.58
340	5.35	1.53
300	4.85	1.58

In our extensive review of the test data generated from all four of Brillouin's IPB HHT^{tm} systems, from test runs made at both SRI's laboratory and Brillouin's laboratory during the past year, the test data showed and continues to show that LENR heat outputs of several watts were repeatedly produced from positive coefficients in the range of 1.2X to 1.6X, depending on various factors, including the dynamic analysis method, and the legacy-type analysis method. We feel that the calorimetry was studied exhaustively and validated to an extremely high level of accuracy (see further discussion and test data review below).

As core engineering and manufacturing continues to improve, and more protocols and parameters are tested and refined, we expect to see more of the higher COP's. When the legacy-type analysis method similar to that used last year is used to calculate the COP from the dynamic stimulation runs, we get significantly larger COP's than those measured last year. It is also important to note that the absolute LENR power outputs are significantly larger than those that were measured last year..

Conclusions

The LENR coefficients of performance (COPs) that have been produced in the Brillouin IPB HHTs in 2017, and the related power output levels of several watts are small-scale but obviously greater than those presented in last year's Report. Further, the consistent repeatability of their cores' production, together with ongoing refinement of their manufacturing techniques, specifications, and components, have led to independently verified repeatable results, unprecedented in the field. The transportability of the system, as documented in last year's Report, is also a remarkable achievement from an independent review basis. While these achievements are still being produced in a test laboratory at bench scale, they are uniquely pointing to an engineering pathway of a future commercial design. We know of no other independently verified results of this kind in the field today.

Importantly the results presented here, although modeled in a way to account for all input and output powers, do not use all of the heater power necessary to maintain temperature and the losses in the pulse generator, to calculate the COP. Brillouin engineers are confident that these power losses can be minimized or eliminated in future designs.

These results demonstrate that:

- ♦ The repeatability and the consistency of the system output are similar, regardless of in which reactor that any particular core is tested and which core components of a given design are being used, interchangeably.
- ♦ To our knowledge, this ability to demonstrate the production of a verifiable and repeatable LENR heat output with positive COPs, which are consistently initiated and uninitiated on command using system design control mechanisms are unique in this field.
- ♦ As documented in last year's Report, Brillouin has invented and built LENR reactor systems that have been shown to be transportable from its own laboratory while showing the same positive results in a new laboratory. In 2017, a second Brillouin IPB HHT^{tm} prototype unit was transported from the Brillouin laboratory to SRI, for purposes of independent operation, verification, and validation. Both reactor units at SRI produced excess power as did the other two reactor units in Berkeley.
- ♦ Significant progress in increasing the COP, and the absolute LENR reaction power output in total watts, has been made in 2017 vs. 2016.

In summary, when using cores constructed from similar metal compositions and built to the same industrial specifications, the Brillouin IPB HHT^{tm} LENR prototype reactors continue to show results that are potentially:

- Controllable on demand
- Reproducible
- Transportable
- Generated from multiple system components, made from relatively identical compositions, manufactured to the same industrial specifications, producing the same LENR heat output results
- Generating significantly greater, repeatable COP's and absolute LENR power outputs in 2017 than in 2016.

Side note: The above positive COP results were primarily produced at operating temperatures of between 300°C to 340°C. The ultimate operating temperature of an HHT commercial system is primarily related to the COP produced, and other engineering factors, and is not in itself a limiting factor per se. In fact Brillouin has had success using similar reactors and cores operating at up to 700°C, which is a much more desirable operating range for the commercial HHT systems that Brillouin anticipates building as it continues to scale its development.

INTRODUCTION

Since August 2012, SRI has been performing tests on two different versions of Brillouin Energy Corp.'s low energy nuclear reactors (LENR) under SRI project P21429. We have operated these reactors to independently attempt to verify results that Brillouin has found with these reactors and type of reactors. We have also monitored and advised Brillouin on the results found in reactors operated by Brillouin in their own laboratory. This Report documents the important results obtained by studies in SRI's laboratory, as well as verification and validation of important results obtained in Brillouin's laboratory during the calendar year 2017. Brillouin has indicated that it has designed the control systems in its reactors to drive the underlying physics of LENR, as described in its Controlled Electron Capture Reaction (CECR) Hypothesis, which is how it believes its reactors generate controlled LENR Reaction Heat. This study did not attempt to prove or disprove Brillouin's Controlled Electron Capture Reaction (CECR) Hypothesis.

The systems tested and described in this Report consist of three parts – cores, reactors and calorimeters. The cores are the reactive components of the system. The reactors provide the environment and stimulation that causes the cores to produce reaction heat. The calorimeter is used to measure the thermal efficiency and absolute values of electrical power input to versus heat or thermal power output from the core-reactor system. The calorimeter was designed by both SRI and Brillouin personnel to be perfectly matched to the reactor, whose results are described in this Report.

SRI has brought over 75 person-years of calorimeter design, operation, and analysis experience to this process. We have used our expertise in low energy nuclear reaction (LENR) calorimetry – the ability to measure input and output power in the form of electricity or heat (energy balance power gain), to validate the results that are summarized in this Report. Brillouin's system design utilizes compensation calorimetry, where the core and reference temperatures are held constant by varying the input heater power while applying different types of stimulation, which also input power to the reactor/calorimeter. In 2017 the Brillouin Energy team started working with an independent commercial third party to develop a thermal model based on System Identification. This "dynamic" method of analysis allows us to analyze all power entering or affecting the core as well as all power emanating from the core based on differential equations describing temperatures and power measurements. While this requires 100 hours of calibration and up to 40 hours of excitation to verify a calibration, it allows testing of 12 parameter variations per hour versus one or two in the steady-state method.

EXPERIMENTAL

DESIGN

The cores consist of a substrate, which in some configurations includes a heater and thermocouple, with several spray-coated layers. Generally, these coatings alternate between a hydrogen-absorbing metal and an insulating ceramic. One example is shown in Figure 1. Other designs may have more or less layers. All of the layers are porous, allowing the gas(es) in the reactor chamber access to all coatings. In some experiments, there is a heater and thermocouple in the center of the core. In other runs the heater is inserted into or attached to the inner block, as explained below. The power to the heater is measured directly from the voltage and current supplied by the direct current (DC) power supply.

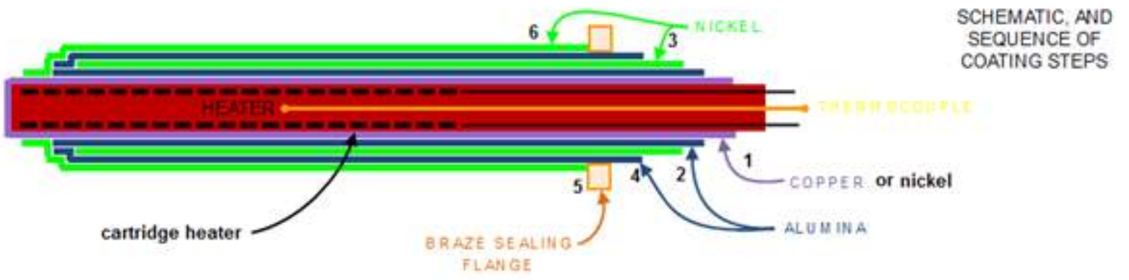


Figure 1. Example of Brillouin’s fourth generation Hydrogen Hot Tube Cores

A photograph of the reactor/calorimeter system is shown in Figure 2. The system is contained in an acrylic container filled with argon gas, which serves several functions. The first function is to minimize the probability of a hydrogen-oxygen reaction from any H_2 that might leak from the system. The second function is to keep the inside of the reactor from oxidizing. The third function is to control the conduction of heat between the sections of the calorimeter. A schematic diagram of the reactor/calorimeter system is shown in Figure 3.

Figure 2. Photograph of the reactor/calorimeter system

In a traditional isoperibolic calorimeter, the reactor temperature is distributed along a massive thermal block (inner block) surrounded completely by a thick insulating layer, which itself is surrounded by another thermally conductive metal mass (outer block). This latter block is kept at a constant reference temperature.

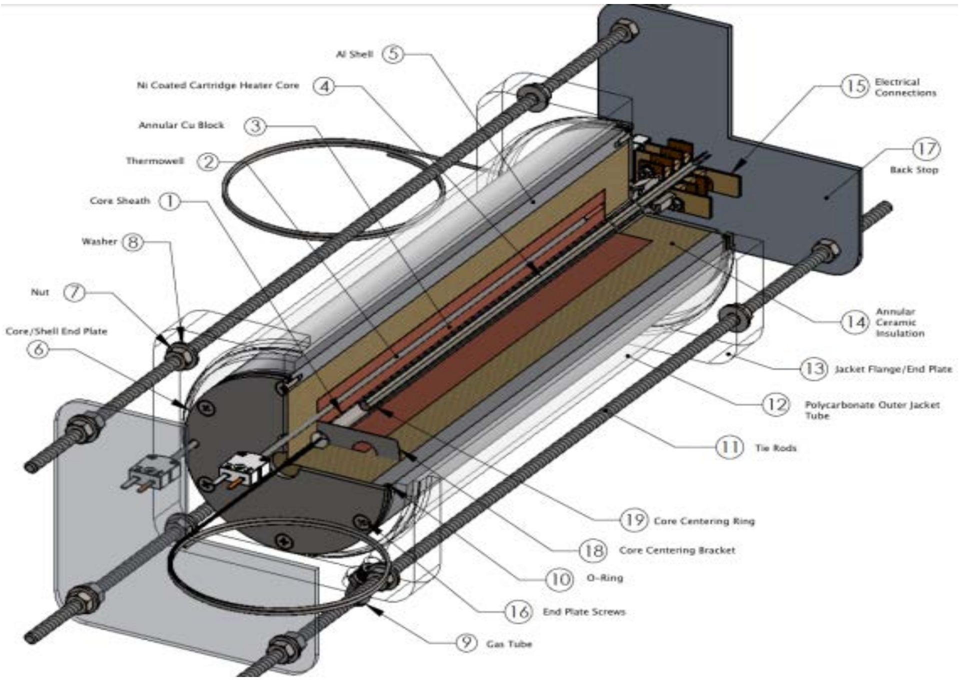


Figure 3. Schematic diagram of the isoperibolic hydrogen hot tube reactor/calorimeter

Referring to the labeled parts of Figure 3, the core (4) is centered in and insulated from a metal sheath (1). This core/sheath combination together with the electrical connections (15) comprise the reactor. An annular steel block (3) is in intimate contact with the reactor sheath and contains a thermowell, (2) and thermocouples and acts as the inner block. Either a cartridge heater was inserted into this block or band heaters were clamped to the block. This steel block is surrounded by an annular ceramic insulator (14). Argon gas is used to purge this insulated chamber. Surrounding this insulator is an aluminum shell (5) with thermowell and thermocouples. This shell, kept at constant temperature by flowing temperature-controlled water between it and the outer acrylic sleeve (12), serves as the outer block. Argon gas is circulated through the insulated chamber outside of the calorimeter.

A description of the various cores used this year are documented in Appendix A.

MEASUREMENT

The outer active layer of the core is stimulated by sending pulses through the outer layer or layers and returning electrically through the innermost layer. The nature of the pulses is such that its current travels primarily on the surface of the metal in contact with the ceramic (the "skin effect"). This effect is caused by the conductivity and magnetic permeability of the metal and initiated by the very fast rise time of the pulses, similar to that seen with very high frequency sine or square waves. An example of this pulse design, which Brillouin refers to as a "Q Pulse", is shown in Figure 4. The pulse width is now from ~30 – 10,000ns with a duty cycle normally of less than 1%. See the patent for more detail on the pulse trains[1].

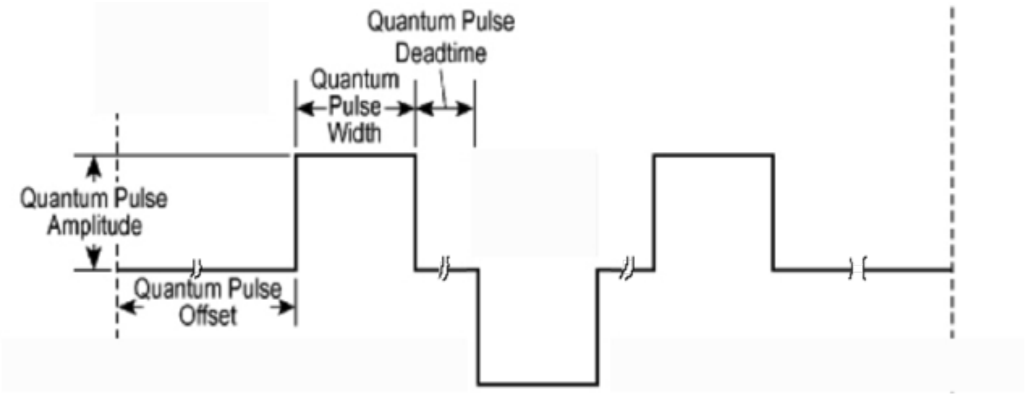


Figure 4. Example of Brillouin's "Q Pulse".

The stimulation power imparted to the core is measured using a circuit shown in Figure 5. The pulse is generated by a proprietary Q Pulse board and delivered to the core using series and termination resistors, which help match the load impedance to that of the pulse board output. Using a high-speed oscilloscope, the voltage across the end of the core nearest the pulse board is measured as well as the voltage across the opposite end of the core across the termination resistor (Zterm). Zterm also acts as a current measuring resistor. The root mean square (rms) voltage across Zterm is then converted to the rms current.

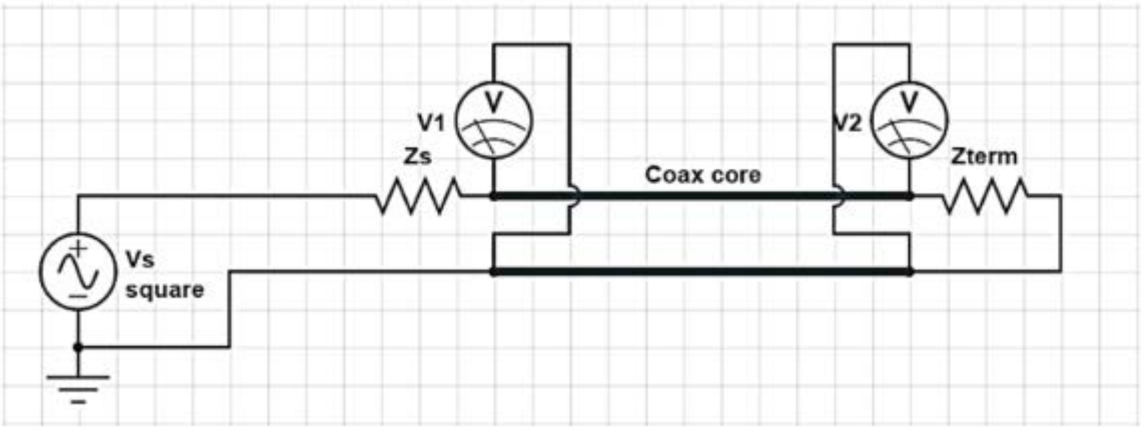


Figure 5. Pulse power measurement circuit

The voltage across the core is determined using the method shown in Figure 6. Figure 6a shows the two voltage traces being aligned in a way that minimizes the time difference. This overestimates the power imparted to the core by a small amount since any phase lag between voltage and current would impart less input power. This voltage difference is shown in the upper plot of Figure 6. The current is shown in the middle graph and the product of these two (power) is shown in the lower plot. It has been shown that the power calculation is essentially the same (within measurement error) whether it is calculated by multiplying the current and voltage plots point by point or by multiplying the calculated rms voltage by the rms current.

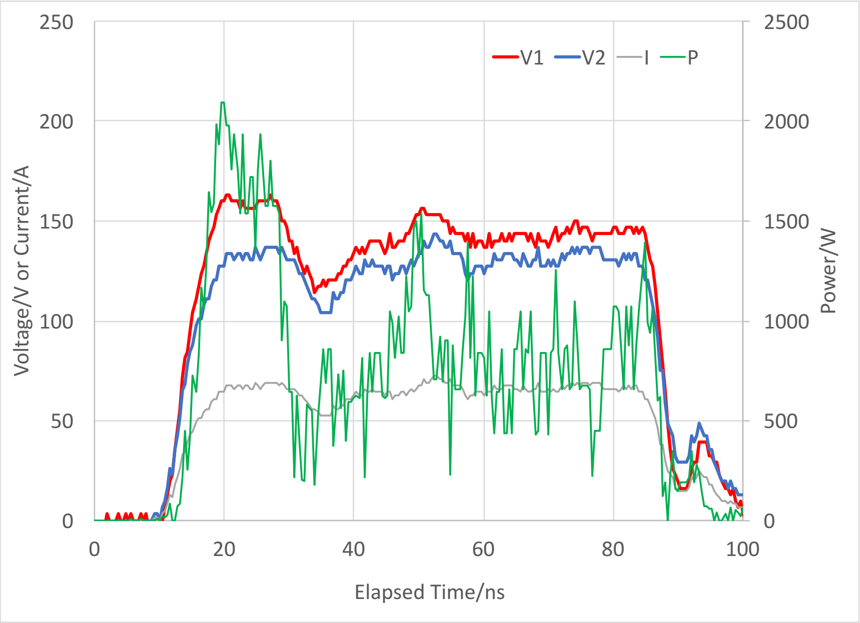


Figure 6. Measurement of the Q-pulse power across the core

In compensation calorimetry the heater power is varied to keep either the core or inner block at constant temperature, which generally also keeps the other at a constant temperature. The difference between the heater power with and without stimulation determines the effect of the stimulation. If this difference is greater than the stimulation that reaches the core, then energy is being produced in the core. Approximately 50 different parameters are collected allowing for calculation of Reaction Power (the power produced by the process induced by the pulse stimulation). Several calculation methods are possible from these parameters. In addition two different stimulation sequences are used. In the Analysis section we describe these two sequences and the calorimetry method used for each of them.

OPERATION

Figure 7 shows a screenshot from the specially-designed proprietary automation and data collection computer program used to control and collect results from the IPB reactor/calorimeter system. The program has several panes allowing for control of temperature, pressure, pulse voltage, pulse power, pulse width, and pulse repetition rate and gas composition. The program also collects the heater power, the pulse power at the generator as well as at the core, all temperatures, water flow rates and gas pressure. Hydrogen and oxygen concentrations in the argon blanket are also measured and collected. In all, approximately 50 different parameters are collected and stored every 10 seconds. As mentioned above, a sequence file can be used to automatically change any or all of the input parameters at specified intervals over a multi-day or multi-week period.

The sheath containing the core is operated with a static fill of hydrogen, helium, or argon gas held at constant pressure up to 10 bar. The temperature of the core is held constant using whichever heater is installed, and controlled from 200°C to 600°C. The outer block temperature is held at 25°C by constant temperature water flowing from a Neslab® chiller.

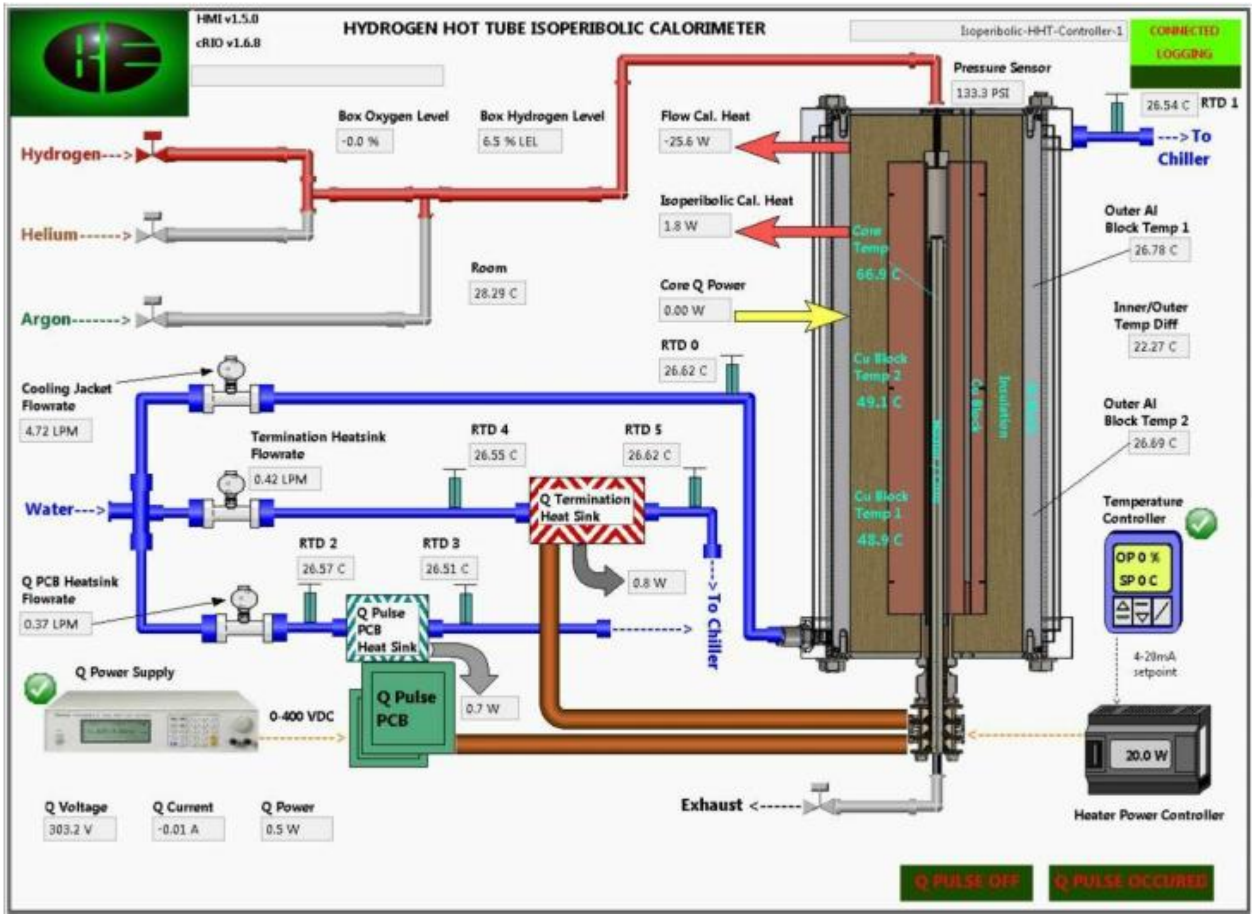

HYDROGEN HOT TUBE ISOPERIBOLIC CALORIMETER
HMI v1.5.0
cRIO v1.6.8
Isoperibolic-HHT-Controller-1
CONNECTED
LOGGING
Box Oxygen Level: -0.0 %
Box Hydrogen Level: 6.5 % LEL
Flow Cal. Heat: -25.6 W
Isoperibolic Cal. Heat: 1.8 W
Room: 28.29 C
Core Q Power: 0.00 W
RTD 0: 26.62 C
Pressure Sensor: 133.3 PSI
RTD 1: 26.54 C
Core Temp: 66.9 C
Cu Block Temp 2: 49.1 C
Cu Block Temp 1: 48.9 C
Outer Al Block Temp 1: 26.78 C
Inner/Outer Temp Diff: 22.27 C
Outer Al Block Temp 2: 26.69 C
Temperature Controller: OP 0 % SP 0 C
Heater Power Controller: 20.0 W
Cooling Jacket Flowrate: 4.72 LPM
Termination Heatsink Flowrate: 0.42 LPM
Q PCB Heatsink Flowrate: 0.37 LPM
RTD 4: 26.55 C
RTD 5: 26.62 C
RTD 2: 26.57 C
RTD 3: 26.51 C
Q Termination Heat Sink: 0.8 W
Q Pulse PCB Heat Sink: 0.7 W
Q Voltage: 303.2 V
Q Current: -0.01 A
Q Power: 0.5 W

Figure 7. Screenshot of the automation and data acquisition computer program in operation

The power emanating from the Q-pulse generator board is held constant as chosen by the program's front panel or the sequence file. Generally, the pulse amplitude (voltage) and pulse width are chosen. The repetition rate is adjusted automatically to maintain the chosen pulse power. Only a minor fraction of this power reaches the core as most of it is lost as heat in the termination resistor. This is necessary to get an accurate measure of energy actually dissipated in the core by preventing reflections of the Q pulse from damaging the electronic components. Of that reduced power only a portion of it influences the heater power as explained in the "Measurement" subsection above. The actual pulse power is measured directly via the methodology presented above. In some sequences, the repetition rate is adjusted to keep the power across the core constant at a chosen voltage and pulse width.

During this year several stimulation methods were tried to find one that can act as a blank (no excess power) using similar Core Q Power. The DC resistive heating of the core surface coat, mentioned in last year's Report, was discontinued because it required changing connections and using measurement hardware different from that used for the real-time Core Q Power calculation. These methods needed to be compatible with the data collection's software's calculation designed for the low duty cycle Q pulse square waves and ideally not require hardware changes. Some of the methods tried and abandoned were: (1) straight sine waves; (2) low duty cycle square waves; (3) large pulse widths with long rise times. Ultimately, calibration runs used Q pulse parameters that were known not to produce LENR heat (low voltage pulses) but impart the same power to the core as parameters expected to show LENR heat (high voltage pulses). The hardware was modified to allow pulsing at much higher repetition rates.

There were two major methods of operation employed in 2017, each requiring a different analysis method. The first method operated with the reactor at a steady-state temperature and input powers, which we refer to as the steady-state stimulation (SSS) method. In our second approach, the dynamic stimulation (DS) method, the heater power was ramped smoothly through a maximum and back down while smoothly ramping Q power up and down several times. The DS method was developed to allow for many Q pulse parameters to be tested in less time. On occasion we would interrupt the DS to allow the system to achieve a steady-state for several hours.

The steady-state stimulation (SSS) method was operated in power compensation mode, where the computer kept the temperature constant at either core or the inner block. When power was imparted from the Q-pulse, the heater power was reduced to compensate and maintain a constant temperature. Hence, when the inner and outer block temperatures are held constant, the core temperature will respond to the stimulation. The output power (calculated from the inner minus outer block temperatures) did not change as the input power compensates for the total power emanating from the core. The total core power included the stimulation power and the power due to reaction heat (*i.e.* LENR power).

ANALYSIS

Two different types of core/reactor systems were used during this year. Early in the year we used cores built up on top of a cartridge heater with a built-in thermocouple. In this design, the inner block thermocouples were imbedded in the middle of the block. With this design, essentially all of the heater power was imparted into the core. Later in the year the core heater system was replaced with two band heaters wrapped around the outside of the inner block, directly over the center six inches of the core. In this design, one inner block thermocouple was held directly under one band heater while the other was strapped to the outside of the block toward an axial end of the block. In this latter design, only a fraction of the heater power is imparted into the core since a significant fraction is lost to the cooling fluid.

During the year various core designs were also implemented. One particular change that affected the calorimetry was applying the active metal coating (Ni or Pd/Ni) over only the middle 6 inches of the core instead of over the whole portion of the core inside the calorimeter. In this design, essentially 100% of the Q pulse power imparted to the core influenced the core thermocouple's measurement. This is true because only a few percent of the measured Q power was imparted to the very highly conductive Cu coating, which acted as leads to the active metal. When using the design with the active metal running almost the whole length of the core only a fraction of the imparted core power was seen by the core thermocouple and hence compensated for by the heater.

For this Report, we will concentrate on the cores with the middle 6 inches of active metal coating, and using the band heaters design. We will also consider the low voltage Q pulse, with higher repetition rates, as the reference run unable to produce LENR heat (excess power).

SSS METHOD

In this method the absolute heater power necessary to maintain constant temperature without Q pulses present is not part of the output power calculation. We realize that only a fraction of the heater power may be imparted to the core because the heater/thermocouple combination has measurable losses to the rest of the calorimeter and to the environment. Instead the temperature controller is instructed to keep the inner block at a constant temperature while low voltage calibration pulses are imparted to the core and measuring the heater's response at different temperatures. The difference between the heater power with and without the low voltage pulses (LVP) is called P_{drop}. At each temperature, a linear function ($P_{drop} = m*P_{LVP} + b$) is determined. The b offset parameter is always insignificant and is not used in the analysis.

P_{drop}, also called heater power compensation (HPC), is determined for different amounts of LVP calibration power. This method is analogous to the traditional isoperibolic calorimeter analysis except that it substitutes heater power compensation for the temperature difference. In order to calculate $Q_{reaction}$ as output power minus input power, we compare the heater power compensation (HPC) from LVP calibration to that from high voltage pulse (HVP) stimulation. Using this LVP calibration the relationship between input power and HPC is determined so that with input pulse power the HPC can be used to back calculate the power from the pulses imparted into the core. Q_{LVP} and Q_{HVP} are the actual Q pulse powers measured when low voltage and high voltage pulses are applied, respectively.

First, the linear relationship between HPC and Q_{LVP} is found by fitting a linear equation to HPC vs Q_{LVP} when Q_{LVP} is varied across the same range of powers as Q_{HVP}. These linear coefficients are then applied to the measured Q_{HVP} to calculate HPC(LVP), the amount of HPC measured at the same temperature and pulse power at low voltage, where no reaction heat is expected. $Q_{reaction}$ is then calculated as shown in Equation 1, where HPC(HVP) is the actual HPC measured when the high voltage pulse is applied. Equation 2 is then used to calculate COP. An alternate calculation is shown in Equation 3. In the latter equation, the COP is calculated as the ratio of the HPC over the Core Q Power at high and low voltage:

$Q_{reaction}$ = HPC(HVP) - HPC(LVP) Equation 1

□□□ = $Q_{reaction}/Q_{LVP}$ = (HPC(HVP) - HPC(LVP)) /Q_{LVP} Equation 2

□□□ = (HPC(HVP)/Q_{HVP})/(HPC(LVP)/Q_{LVP}) Equation 3

DS METHOD

The DS method employs a model with several components, each representing individual components of the calorimeter. Linkages between these components (and from a component to the reference room temperature) are either conductive or storage. One differential equation (in time) models the heat imparted to the Core using a function of the difference of the core and outer block temperature, a function of the core and inner block temperatures, and divided by the function of the ability of the core to store heat. Each of these three components have a coefficient that is determined fitting the temperature data to the actual power measured using low voltage pulses as described above. A second equation does the same for the inner block. The model then yields a simple equation for power equal to a coefficient time the difference between the core and inner block temperatures.

These functions are simple 3-coefficient binomial equations, yielding 15 possible parameters. These parameters are then used to calculate the amount of heat emanating from the core during an attempt to produce LENR heat. A comparison between the calculated power emanating from the core during an active run and that from the calibration run at the same temperature and with the same Core Q Power is used to determine the amount, if any, LENR heat was produced. When the DS runs were interrupted to achieve a steady-state, the amount of heater power determined to affect the core was subtracted from both the input and output powers before calculating COP. This analysis is comparable to but not identical to last year's calculation. The computer application MatLab® is used to determine the best fit parameters. A more detailed description of the DS analysis method is given in Appendix B.

RESULTS

A tabulation of all experiments run in the IPB calorimeters in 2017 is shown in Appendix C. We will concentrate on the experiments run in the latter half of the year.

SSS METHOD RESULTS

The runs detailed in this analysis generally used a 100ns pulse width with similar Q power on the core at different voltages. Figure 8 shows a plot of the heater power, CoreQPow (the actual power measured as applied across the core) and the core temperature all versus elapsed time. We attempted to keep the CoreQPow relatively constant at each temperature.

Figure 9 shows Q voltage and pulse width plotted versus the ratio of HPC/CoreQPow at 250°C to 35°C. This is from an earlier experiment where the pulse width was not held constant. Using the COP as defined in Equation 3, this shows the COP to be much greater at 250°C (1.27) than at 400°C (1.00).

Note that the power compensation/CoreQPow is very dependent on the pulse voltage at 250°C but is essentially unchanged at 400°C. Although the total pulse power from the generator is constant, the pulse power measured at the core does vary with pulse voltage, as shown in Figure 8, even though we attempted to keep Core Q Power constant by also varying the repetition rate and/or pulse width. Still, the magnitude of the power compensation is a greater percentage of the pulse power at 350 v than at 35 v. Calculations show that $Q_{reaction}$ is greater at 350 v than at 35 v. Table 4 summarizes the COP results from recent SSS runs.

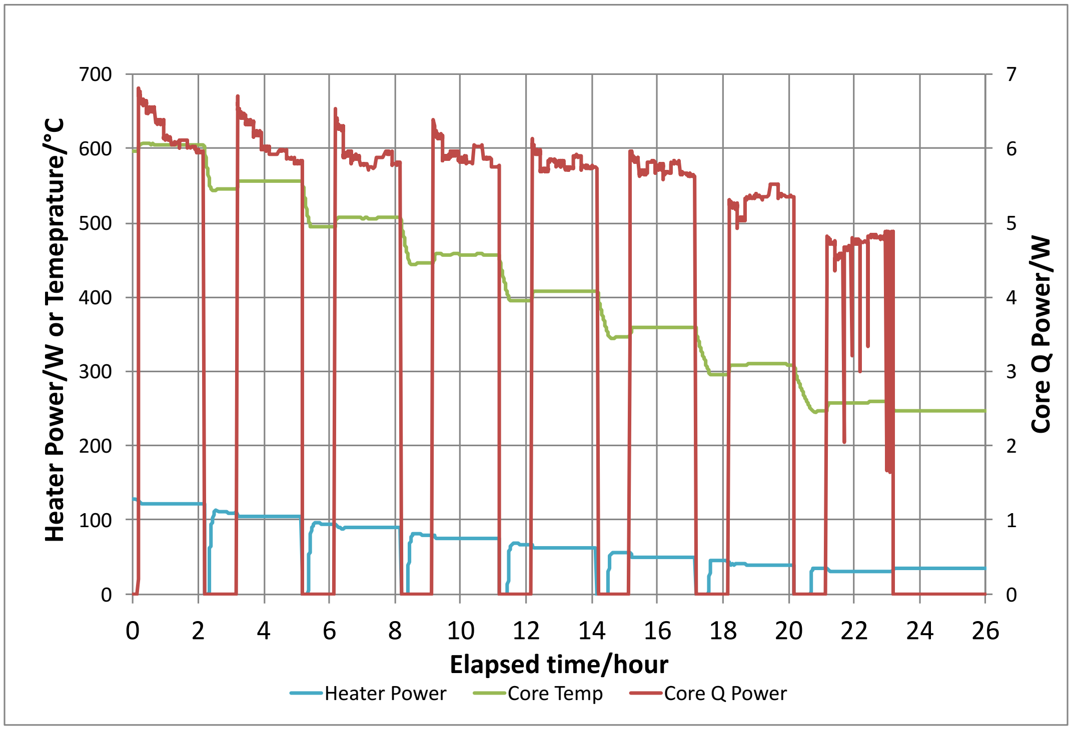


Figure 8. Plot of core Q pulse power, heater power, and core temperature from 250 to 600°C.

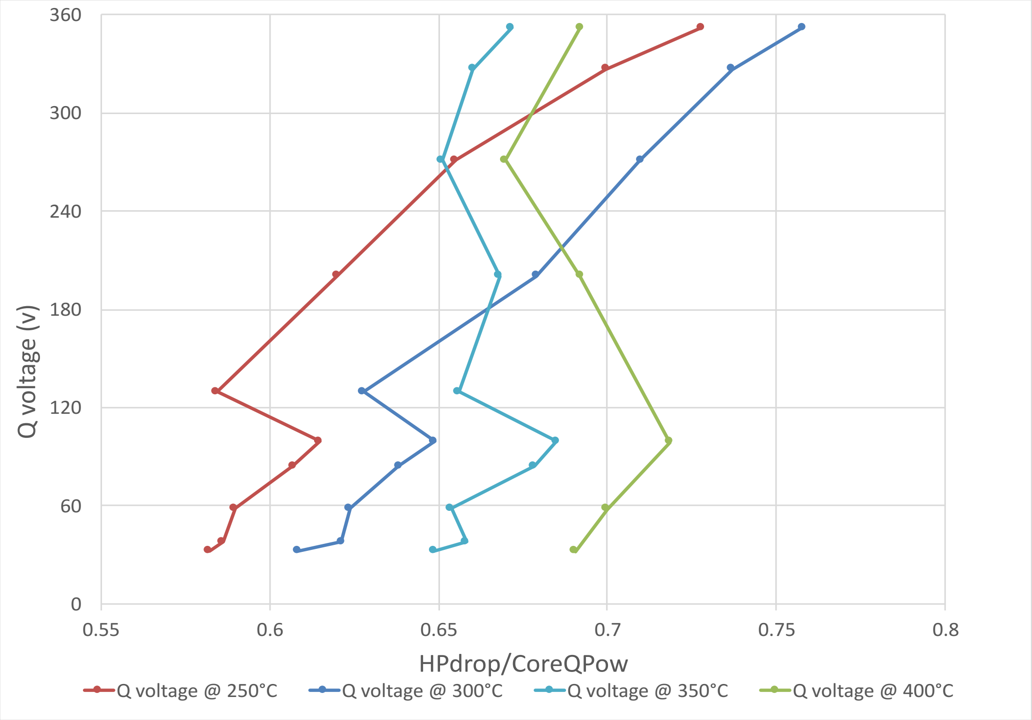


Figure 9. Plot of Q voltage and pulse width versus heater power compensation/CoreQPow from 250 to 350°C.

Table 4. Summary of COP calculations from steady-state stimulation runs:

Temperature/°C	COP : IPB2-33	COP: IPB2-74	COP IPB1-45	COP IPB1-48
250	1.27	1.14		
275	1.4	1.15	1.11	1.13
300	1.25	1.13	1.11	
325	1.26	1.09	1.08	1.27
350	1.05	.94		
400	1.00	.89		

DS METHOD RESULTS

The DS method employed in the latter half of 2017 calculated two different COP results. The first was the average COP over the complete stimulation run. The other result calculated instantaneous COP, especially at the point of greatest stimulation amplitude. (See the description of the dynamic stimulation method in the Operation section above). Two cores showed particularly good COP's both in the average and instantaneous calculations. Table 5 shows a representative example of some of the better average COP's achieved this year. We also found that the best COP's were achieve between 250 and 350°C, confirming the results that were Reported in last year's Report. The result in the last row was from figure 10 (b). The results in the last column were calculated by subtracting the heater power affecting the core from both the input and output powers allowing for direct comparison to last year's results.

Table 5. Average COP's from recent DS runs using the latest IPB design and 100ns pulse width

Temperature/°C	$Q_{REACTION}$/Watts	COP using DS method	COP using legacy method
300	3.62	1.25	1.56
340	2.71	1.16	1.37
300	3.59	1.26	1.55
340	3.22	1.19	1.43
300	3.90	1.27	1.62
340	3.58	1.21	1.44
300	4.91	1.31	1.56
340	5.29	1.27	1.52
300	4.99	1.31	1.58
340	5.35	1.27	1.53
300	4.85	1.31	1.58

Figure 10a shows an example of the instantaneous COP calculated using the DS analysis method from a recent run. To prove that this COP is stable the stimulation parameters were held constant for 4 hours. This latter result is shown in Figure 10b. Although the numbers presented seem no better than last year's, when the method similar to that used last year is used to calculate the COP, we get significantly larger results shown in the right-most column of Table 5. It is also important to note that the absolute LENR powers ($Q_{reaction}$) are significantly larger.

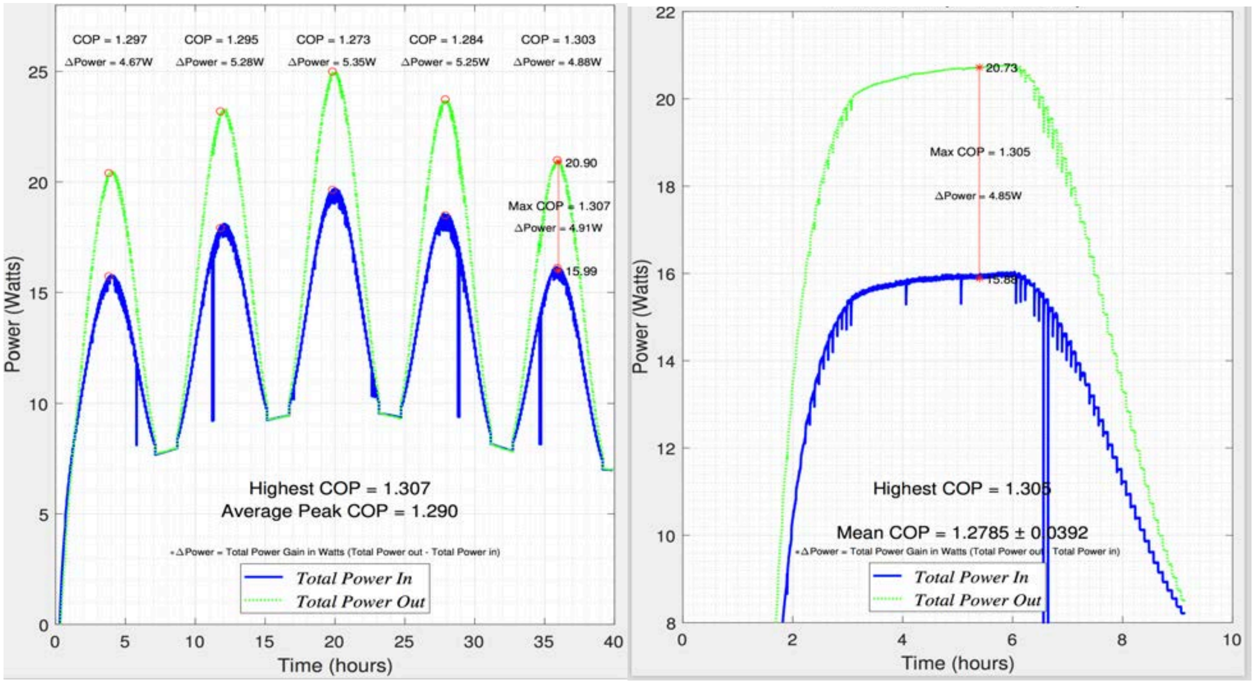


Figure 10. (a) Instantaneous COP during DS run, (b) COP during 4 hours at maximum stimulation.

CONCLUSIONS

Low energy nuclear reactions (LENR) can produce thermal power when Ni, and other metal, coated tubes are stimulated using fast rise-time pulses. These experiments operated in H_2 or He gas from 200°C – 600°C. The exact same procedure was performed in each gas. Comparative thermal measurements were performed between heater-only power and heater and pulse power.

These runs were performed in isoperibolic calorimeters operated in power compensation mode, where the heater adjusts its power to keep the inner and outer temperature-difference constant. Over 100 runs were performed on 34 different Ni-coated cores. Additional cores were also tested for other experimental purposes. 2017 was spent optimizing core design, stimulation protocols, calorimeter design, and calorimetric analysis methods. The accuracy and precision of this year's best results have been considerably better than the prior year's best results.

The most recent methodology has required design compromises that caused the capture efficiency of the heater power entering the calorimeter to be reduced. Advances in core designs have allowed essentially all of the stimulation power entering the calorimeter to be captured and measured accurately. Also, a significant amount of the stimulation power generated at the power supply is not imparted to the calorimeter. It is expected that via straightforward engineering design advances we will be able to minimize the heat not imparted to the core by the heater and also to minimize the electrical losses seen in the production of the Q pulse. Although the raw numbers presented seem no better than last year's, when the method similar to that used last year is used to calculate the COP, we get significantly larger results than those measured last year. It is also important to note that the absolute LENR powers ($Q_{reaction}$) are significantly larger.

In summary, we feel that it is obvious that important progress has been made in 2017. We also feel that continued progress can be made in 2018 with even greater expanded effort and focus on increasing the COP and optimizing the calorimeter design.

ACKNOWLEDGEMENTS

We would like to acknowledge Dr. Michael McKubre (SRI Emeritus) for his work on the calorimeter design. We would also like to thank Brillouin Energy engineers Roger Herrera and Jin Liu for their aid in the calorimetric analysis. We particularly would like to thank David Correia for his invaluable efforts in the laboratory as well as for his troubleshooting skills. We would like to thank everyone at Brillouin Energy Corp. for their highly creative, disciplined and highly professional technical work, which continues to show that they are a leader in this field.

APPENDIX A: CORE DESIGNS TESTED IN THE SECOND HALF OF 2017

reactor + core	Date	status	properties
sri-ipb1-45	7/25/2017 – 8/15/2017	good	Ni-Pd
sri-ipb1-43	8/16/2017 – 10/17/2017	good	Ni-Pd
sri-ipb1-54	10/17/2017 – 10/27/2017	good	Ni-tube(he)
Sri-ipb1-66	10/27/2017 – 11/06/2017	in-service	Ni-ceramic-tube
Sri-ipb1-66	11/06/2017 – 11/10/2017	changed probe	Ni-ceramic-tube
Sri-ipb1-66	11/10/2017 –	sanded	Ni-ceramic-tube
sri-ipb2-33	09/26/2016 – 9/15/2017	good?	Ni-Pd
Sri-ipb2-55	09/15/2017- 10/19/2017	good?	Ni-Pd
Sri-ipb2-83	10/19/2017 – 10/27/2017	good	Ni-Pd-Cu-ends
Sri-ipb2-67	10/27/2017 – 11/7/2017	in-service	Ni-ceramic-tube
Sri-ipb2-67	11/7/2017 – 11/10/2017	changed probe	Ni-ceramic-tube
Sri-ipb2-74	11/10/2017 –	in-service	Ni-ceramic-tube
ipb3-43	5/15/2017 - 8/1/2017	good	Ni-Pd
ipb3-39	8/3/2017 - 8/9/2017	good	PD-RH foil
ipb3-56	8/9/2017 – 8/28/2017	bended	Ni-Pd
Ipb35-51	8/28/2017 – 10/3/2017	bend	Ni-tube
Ipb35-62	10/3/2017 – 10/26/2017	good	Ni-Pd-Cu-ends
Ipb35-72	10/26/2017-11/06/2017	in-service	Ni-ceramic-tube
Ipb35-72	11/6/2017	changed probe	Ni-ceramic-tube
ipb41-44	6/12/2017 - 7/10/2017	ridged	Ni-Pd
ipb41-50	7/10/2017 - 7/24/2017	good	Ni-tube
ipb41-53	7/24/2017 - 8/10/2017	rippled	Ni-tube
ipb42-52	8/10/2017 - 8/14/2017	good	Ni-tube
Ipb43-14	08/16/2017 – 8/25/2017	in-service	Ni-tube
Ipb43-14	08/26/2017 – 8/31/2017	in-service	Ni-tube-NP-11nf
Ipb43-14	09/04/2017 –	in-service	Ni-tube-NP-22nf
Ipb43-14	09/07/2017 – 9/25/2017	bend and peel	Ni-tube-NP-32nf
Ipb45-58	09/26/2017-11/03/2017	in-service	Ni-ceramic-tube
Ipb45-58	11/03/17	changed probe	Ni-ceramic-tube
Ipb45-63			Ni-electroform-mesh

APPENDIX B: DS ANALYSIS METHOD DETAILED DESCRIPTION

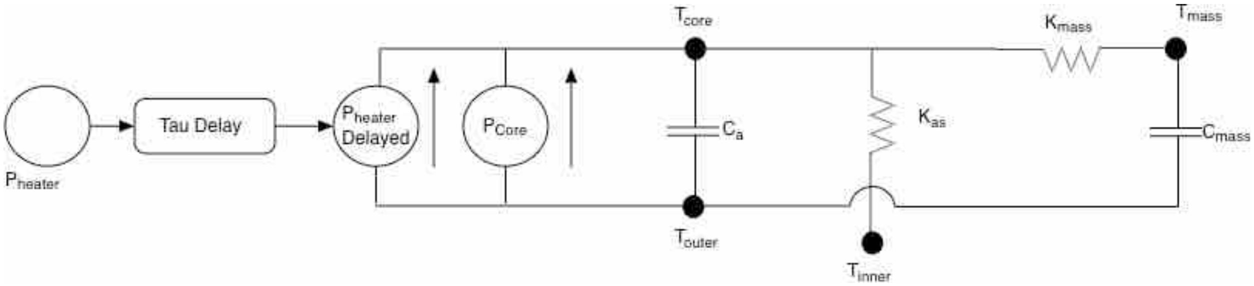


Figure B.1 Equivalent circuit representation of the IPB calorimeter's thermal conduction and storage

Figure B.1 gives a representation of the thermal conduction and loads of the IPB reactor using an electronic equivalent circuit. Each of the thermal components are represented by one of the electronic components. Every important thermal component has a thermocouple as part of it. The resistance to thermal conduction between two thermal components are represented by a resistor. Storage in the thermal mass of a component is represented by a capacitor. Heat sources are represented as power supplies.

Starting from the left side of the figure, the heater power is delayed in reaching the core by the thermal mass of the inner block. This thermal time constant is represented by tau. This "$P_{heater,delayed}$" is easily handled in the analysis by simply using the measured heater power from an earlier time in the data file. The Q pulse stimulation power is (P_{core}) is closely couple to the core and does not require a temporal delay. The individual thermal components are labeled T_{core}, T_{mass}, T_{inner} and T_{outer}. Each of these components has a thermocouple associated with it. T_{mass} is associated with the thermocouple in the inner core positioned axially near one end of the inner block, as described in Figure 3. T_{inner} is measured via the thermocouple placed between the band heater and the inner block. T_{core} is measured in the annular cavity inside the core. T_{outer} is measured by a thermocouple inserted into the outer block, kept at constant temperature via cooling water.

The ultimate goal of this analysis is to determine the appropriate coefficient equations, that when operated on the measured temperatures will yield the amount of power emanating from the core. This is done by first setting up differential equations in time for changes in T_{core} and T_{mass}.

$$dT_{core}/dt = (1/c)\{\alpha P_{heater,delayed} + P_{core} - k_{as}(T_{core} - T_{inner}) - k_{mass}(T_{core} - T_{mass})\} \quad \text{Equation B1}$$

$$dT_{mass}/dt = (k_{mass}/c_{mass})(T_{core} - T_{mass}) \quad \text{Equation B2}$$

where c is a representation of both c_a and c_{mass}. Input and output powers are represented by:

$$P_{in} = \alpha P_{heater,delayed} + P_{core} \quad \text{Equation B3}$$

$$P_{out} = k_{as}(T_{core} - T_{inner}) \quad \text{Equation B4}$$

The coefficient k_{as} is actually a binomial equation, which is found using the heater only runs and the runs with low Q voltage where no LENR power is expected. This coefficient is then used to calculate the output power present during a high Q voltage run using Equation B4 using T_{core} and T_{inner} measured during that run. Similarly, Equation B3 is used to calculate the input power present during the high Q voltage run. COP is found by dividing the calculated P_{out} by the calculated P_{in}.

In order to validate the model P_{stored} is calculated using Equation B5:

$P_{stored} = c(dT_{core}/dt) + c_{mass}(dT_{mass}/dt)$

Matlab® is used to find all of the coefficient binomial equations which yield the best fit to the measured data. Then Equations B3 and B4 are used to calculate COP's during the high Q voltage run as shown in Figure 10.

APPENDIX C: EXPERIMENTS OPERATED IN 2017

IPB1: Cores Tested from 5 Apr to 31 Dec 17

Core #	Start Date	End Date
41	4/5/17	7/5/17
48	6/29/17	7/25/17
45	7/25/17	8/17/17
43	8/15/17	10/19/17
54	10/17/17	10/27/17
66	10/27/17	12/15/17
94	12/15/17	11/19/18
98	1/19/18	present

IPB2: Cores Tested from 25 June 16 to 31 Dec 17

Core #	Start Date	End Date
27	6/26/16	2/10/17
33	2/10/17	9/14/17
55	9/14/17	10/16/17
83	10/19/17	10/27/17
67	10/27/17	11/10/17
74	11/10/17	12/15/17
93	12/15/17	1/5/18
89	1/5/18	present

IPB3: Cores Tested from 5 Dec 16 to 31 Dec 17

Core #	Start Date	End Date
32	12/5/16	1/19/17
37	1/19/17	3/23/17
42	4/28/17	5/12/17
43	5/15/2017	8/1/2017
39	8/3/2017	8/9/2017
56	8/9/2017	8/28/2017
51	8/28/2017	10/3/2017
62	10/3/2017	10/26/2017
72	10/26/2017	11/06/2017
72	11/6/2017	present

IPB4: Cores Tested from 12 Jun to 31 Dec 17

Core #	Start Date	End Date
44	6/12/2017	7/10/2017
50	7/10/2017	7/24/2017
53	7/24/2017	8/10/2017
52	8/10/2017	8/14/2017
14	08/16/2017	8/25/2017
14	08/26/2017	8/31/2017
14	09/04/2017	9/7/17
14	09/07/2017	9/25/2017
58	09/26/2017	11/03/2017
58	11/03/2017	11/28/2017
58	11/28/2017	12/13/2017
86	12/14/2017	12/19/2017
64	12/19/2017	1/4/2018
63	01/04/18	present