Robust Performance Validation of LENR Energy Generators

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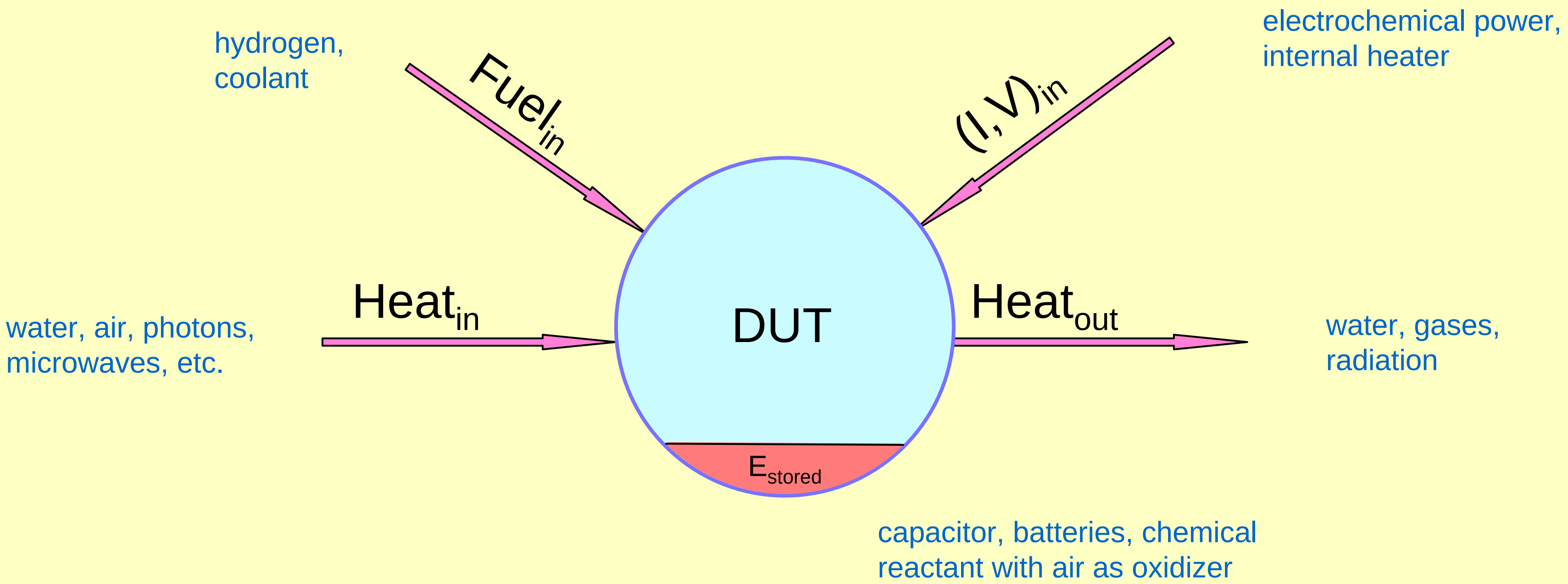
Motivation

Develop a robust test for a “Black Box” device, to show that more energy is produced than can be explained by conventional physics and chemistry.

Control Volume Description



$$Energy_{out} = \int [\, Heat_{out} - Heat_{in} - Fuel_{in} - (I*V)_{in} \,]\, dt - E_{stored}$$

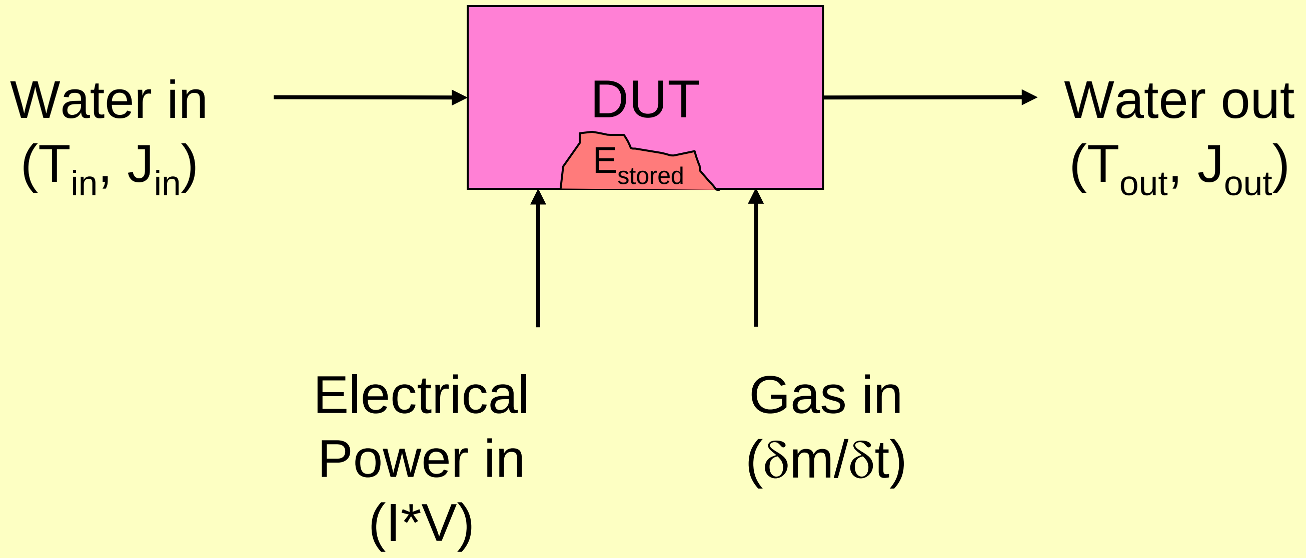
DUT: Device Under Test

Main Features of LENR Calorimeters

	Isoperibolic			Mass Flow	Heat Flow	Ice
	Single Wall	Double Wall	Seebeck			
Principle Mechanism	Heat Conductivity	Heat Conductivity	Heat Conductivity	Heat Capacity	Heat Conductivity	Heat Capacity
Hotter Region	Source electrolyte	Source jacket	Inside of Barrier	Source jacket	Metal Plate	Source
Colder Region	Source jacket	Outer bath	Outside of barrier	Flowing fluid	Source and jacket	Ice-water
Measured	Power	Power	Power	Power	Power	Energy
Sensors	Temperature	Temperature	Temperature	Temperature & flow	Temperature	Weight
Signals	Voltage	Voltage	Voltage	Voltage	Voltage	Voltage

Many types of calorimeters are applied to LENR research, but for testing of “black box” devices of variable size and shape, the mass flow type is more simple and flexible.

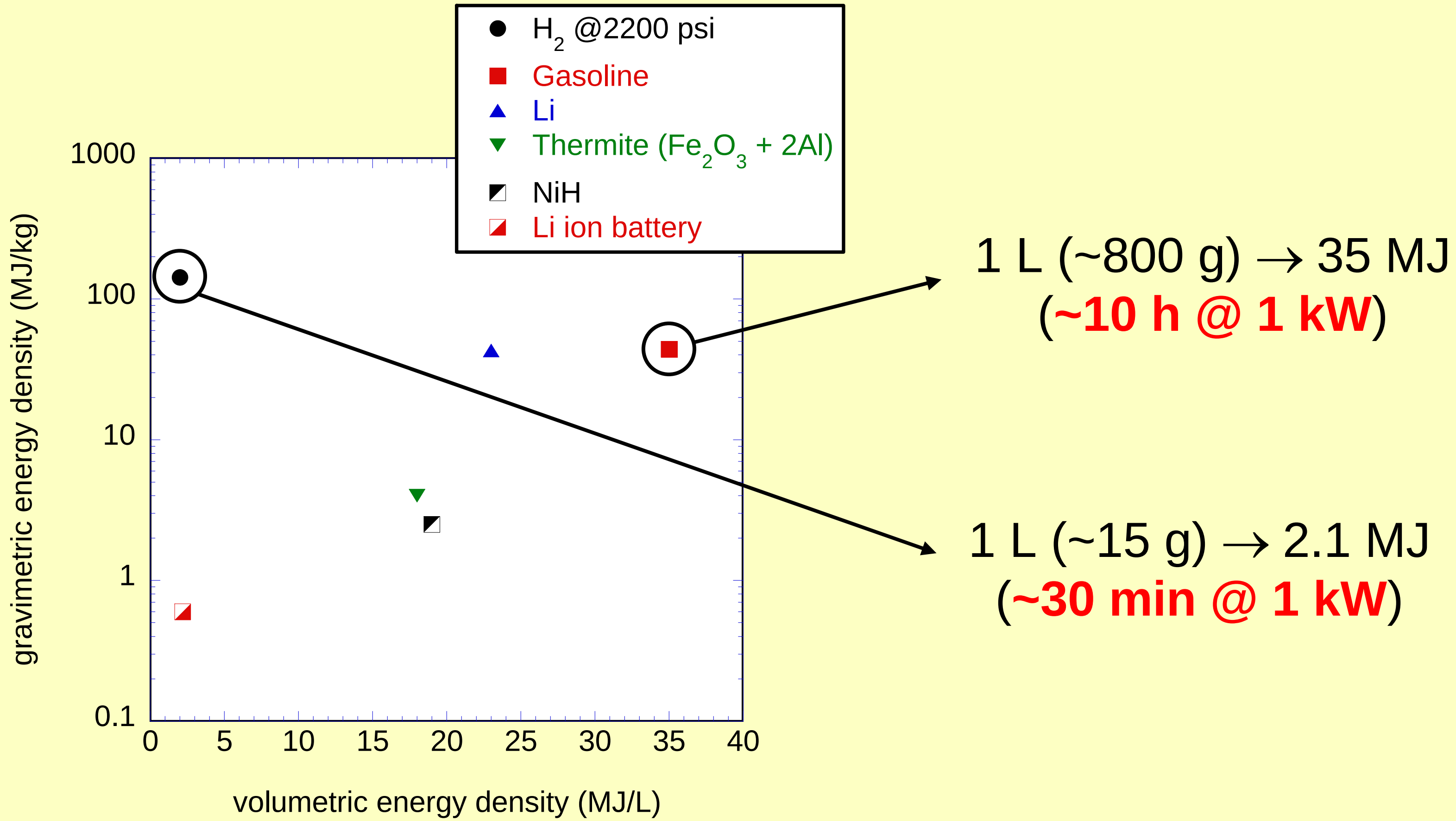
Mass Flow Calorimeter Concept for Gas Loading Cell



$$Energy_{out} = \int [(T_{out} - T_{in}) \cdot C_p \cdot J - \delta m/\delta t \cdot \Delta H - (I^*V)_{in}]\, dt - E_{stored}$$

(heat capacity of water) (gas burned) (conservative estimate, e.g., gasoline)

Potential Energy Storage (Important for "Black Box" Validation)



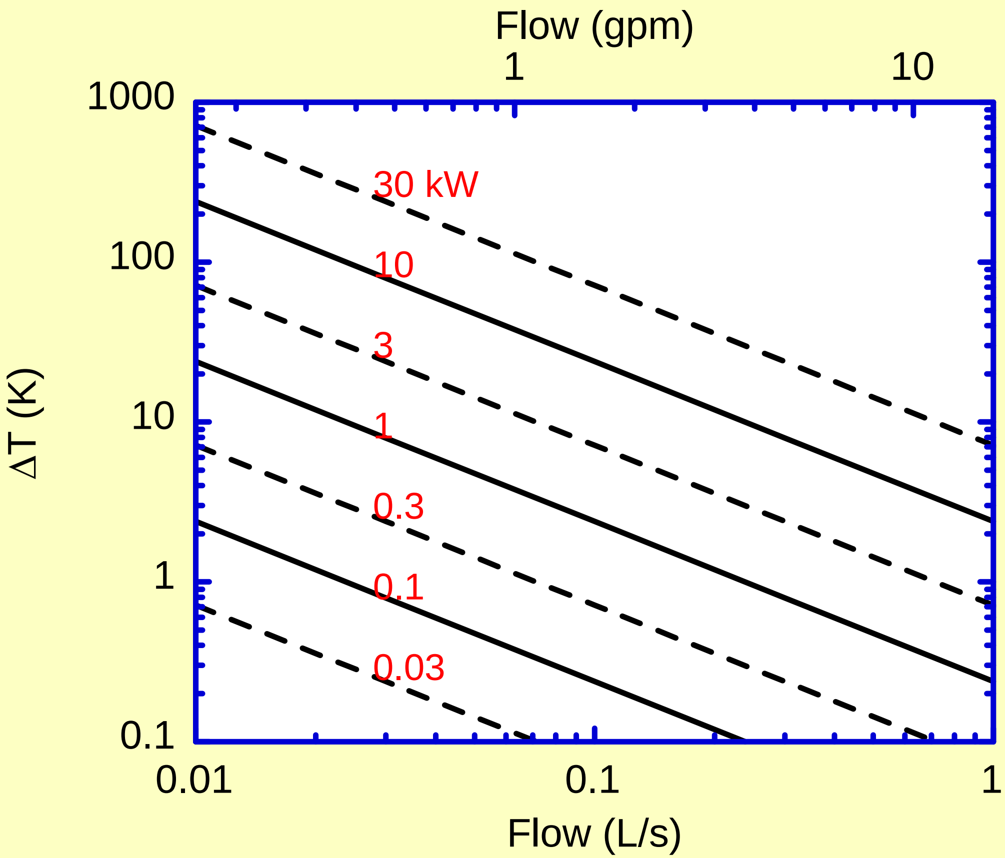
How to Overcome E_{stored}?

- If possible, ascertain contents of “Black Box” before and after test to limit quantity of stored energy available
- Otherwise, must consider worst case scenario, requiring:
  - Knowledge of mass and volume of “Black Box”
  - High power output device (i.e., > kW), compared to inputs
  - Long time measurements (days?) if at lower power
  - Limited mass and volume available for fuel

Flow and ΔT Requirements for Water

$$\text{Power} = \text{Flow}\cdot\rho\cdot C_p\cdot\Delta T; \quad \rho\cdot C_p = 4.2\ \text{kJ}\cdot\text{L}^{-1}\cdot\text{K}^{-1}$$

$$\Delta T(\text{K}) = 0.24\ \text{Power(kW)} / \text{Flow(L/s)}$$



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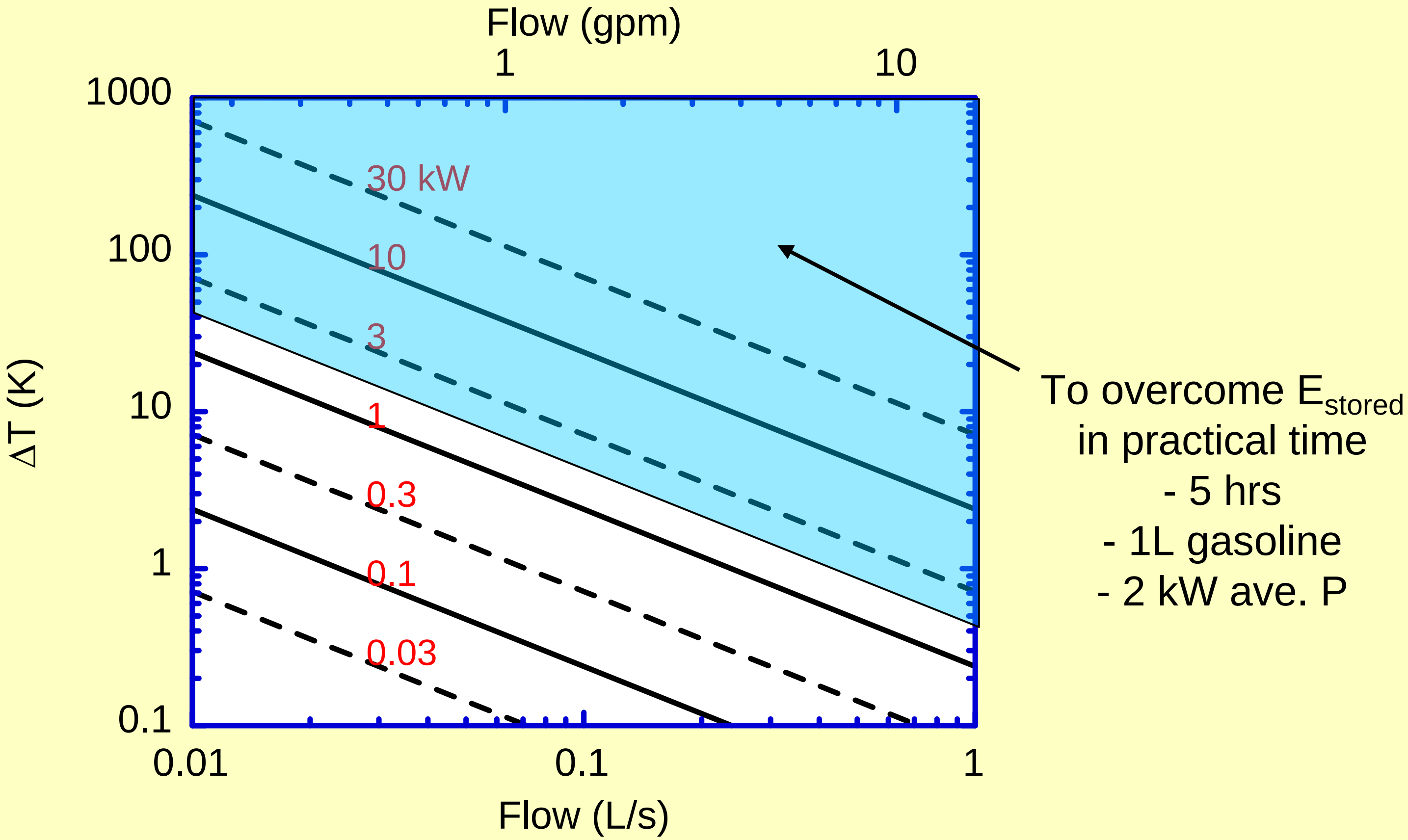

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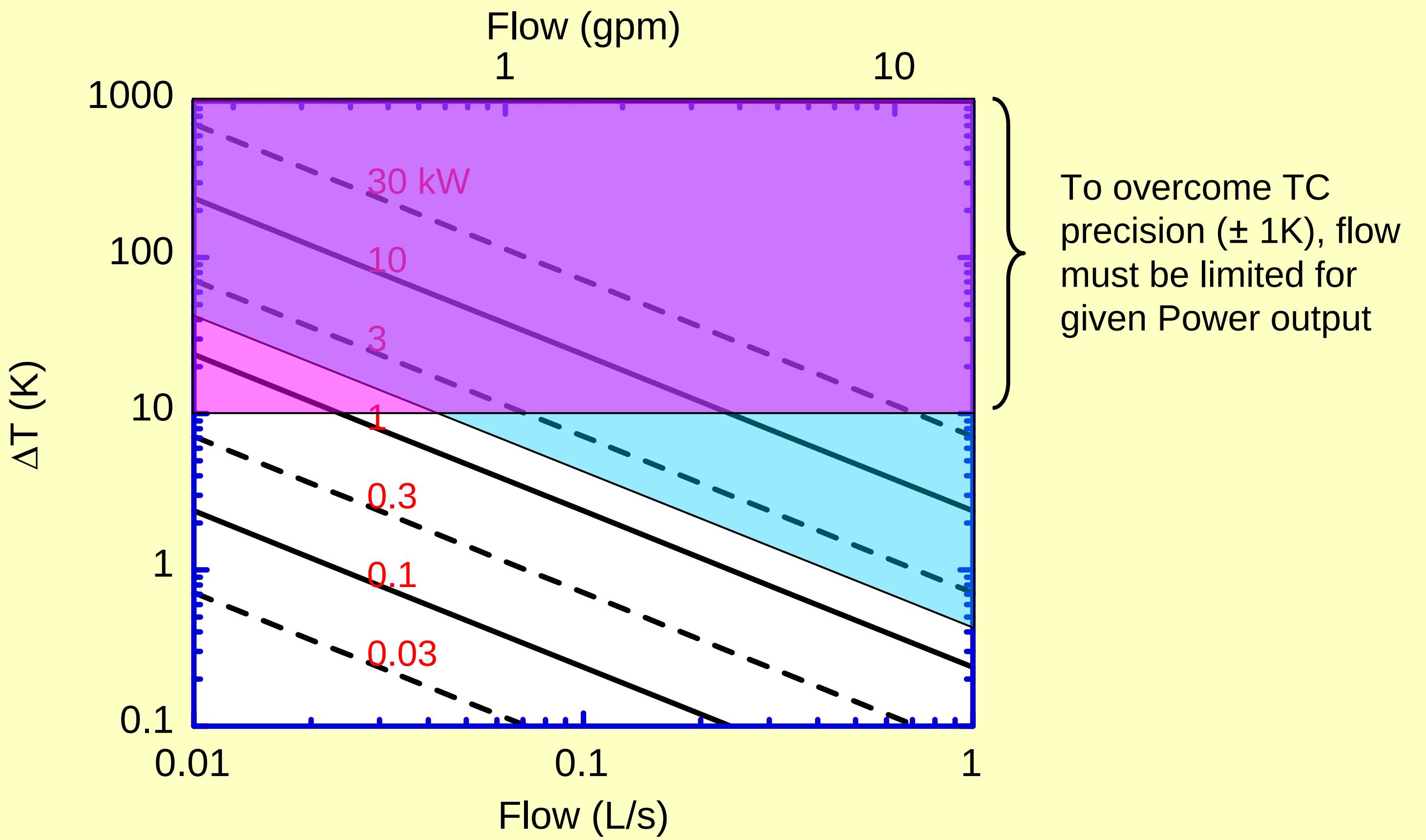

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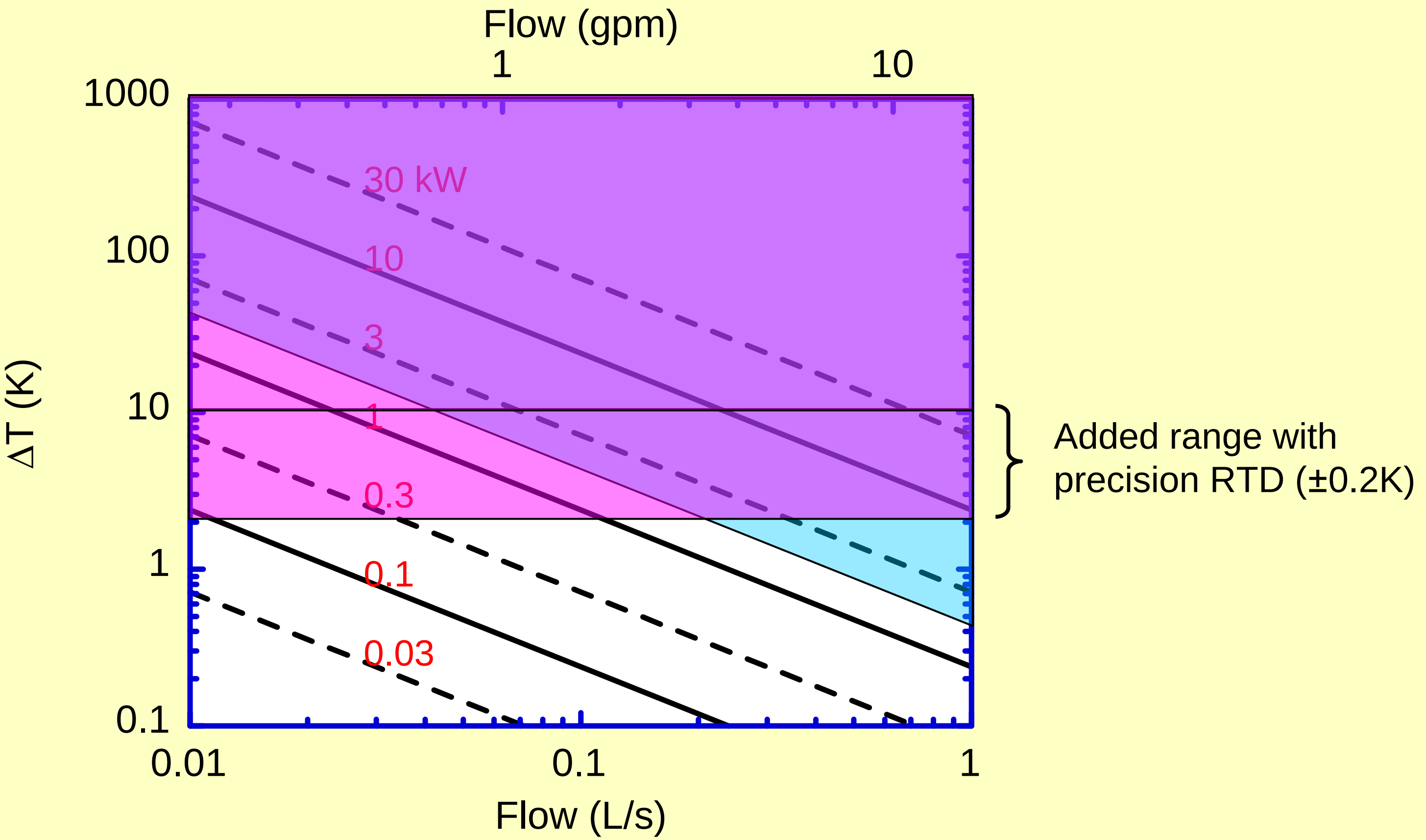
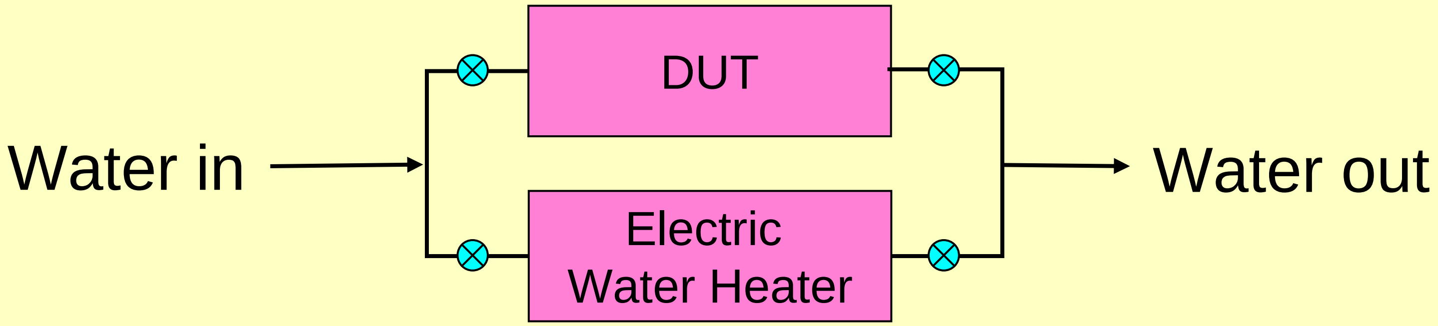


Calibration of all Sensors Required

- Repeated measurements to document precision of each sensor
- Reasonable standards to document accuracy, such as weighing known volume of water on a mass balance, or using multiple pressure gauges
- Digital mass flow sensor calibrated with stop watch and mass balance or graduated cylinder, and/or against analog flow meter
- T sensors measured collectively in stirred ice and boiling water baths
- I*V power meter should measure known power source and load, and its bandwidth verified. High frequency capability must be demonstrated.
- Volume and T of hydrogen storage bottle must be known, and pressure measured with suitable precision. Pressure response to T changes should be documented. If gas employed becomes liquefied at storage pressure, then mass of gas in tank must be measured instead.

Testing of Measurement Apparatus

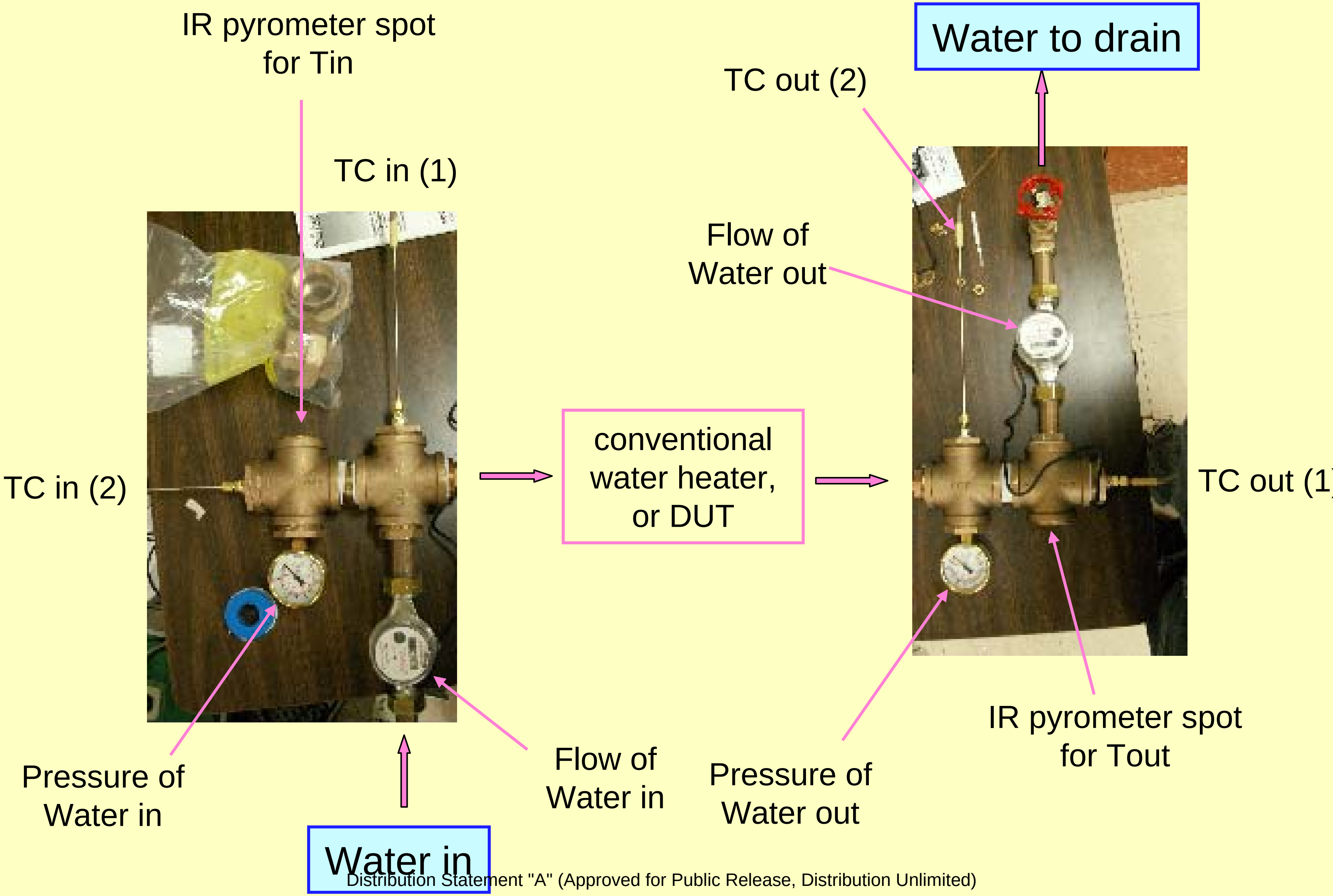
- A known heat source should substitute for DUT to document performance of measurement apparatus
- Parallel configuration is preferred, since flow requirements may be incompatible with serial flow



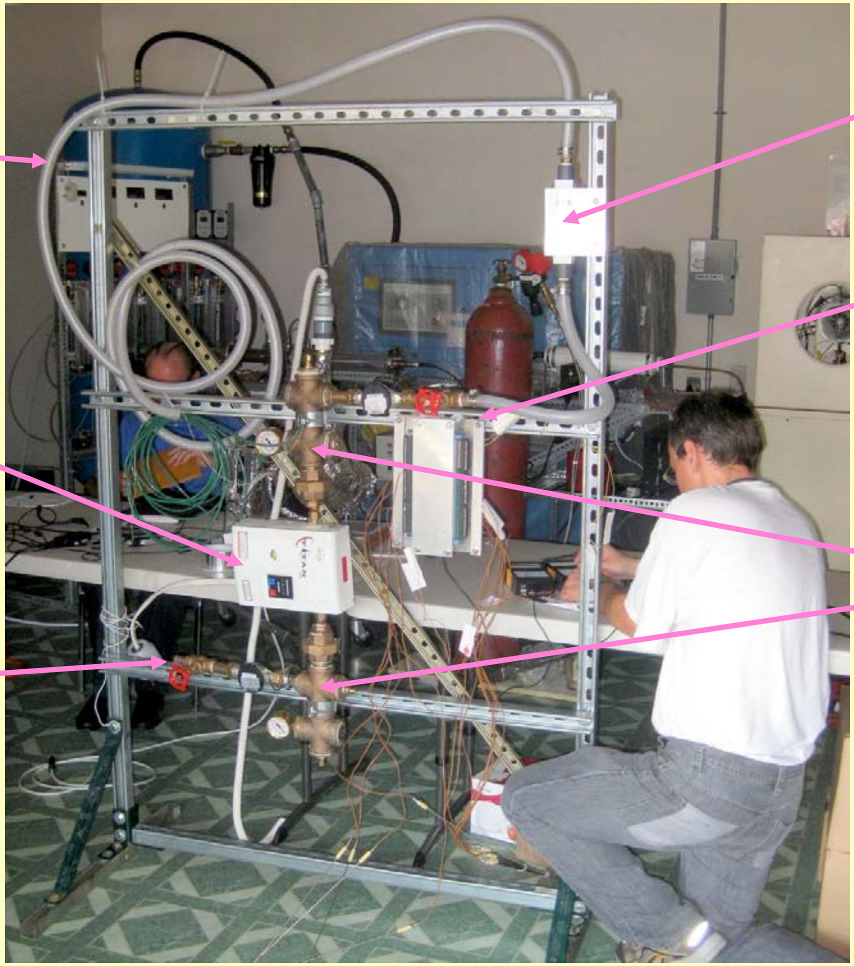
Redundancy

- Redundancy needed for sensors, as they sometimes fail or are impacted by environmental factors
- Orthogonal methodology should be used to overcome common mode failures, for example:
  - Thermocouples are sensitive to ground loop problems, so an IR pyrometer which can be decoupled from apparatus is useful
  - Pulses from digital flow meters may not be properly counted by computer, so analog meter (while less precise) can be indicator of error
- Such redundancy is needed for all critical parameters: T, water flow, V, I, gas flow

Structure of Measurement Apparatus



Apparatus in Preparation for Test



Water outlet

Analog flow meter

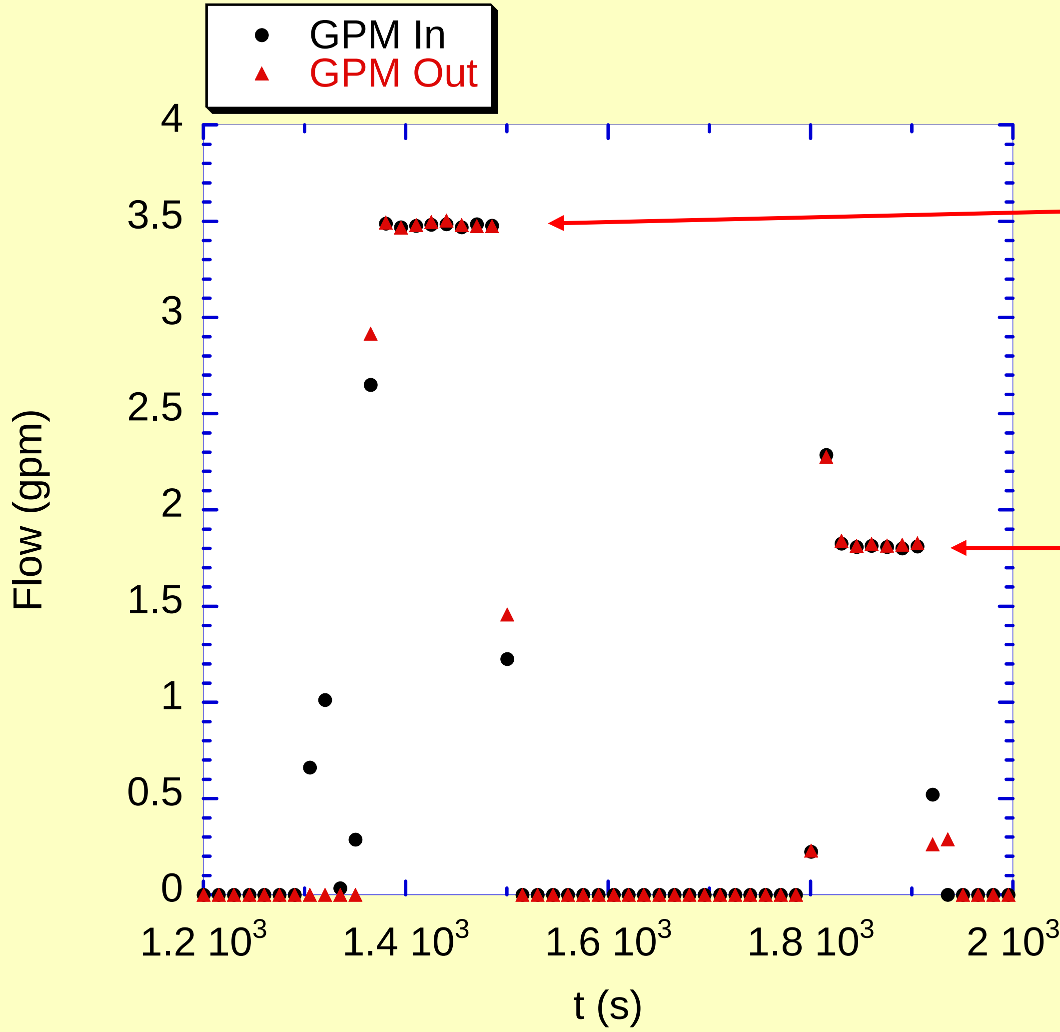
16 ch TC interface
(0-10 V DC output)

12 kW water heater

Sensor manifolds

Water inlet

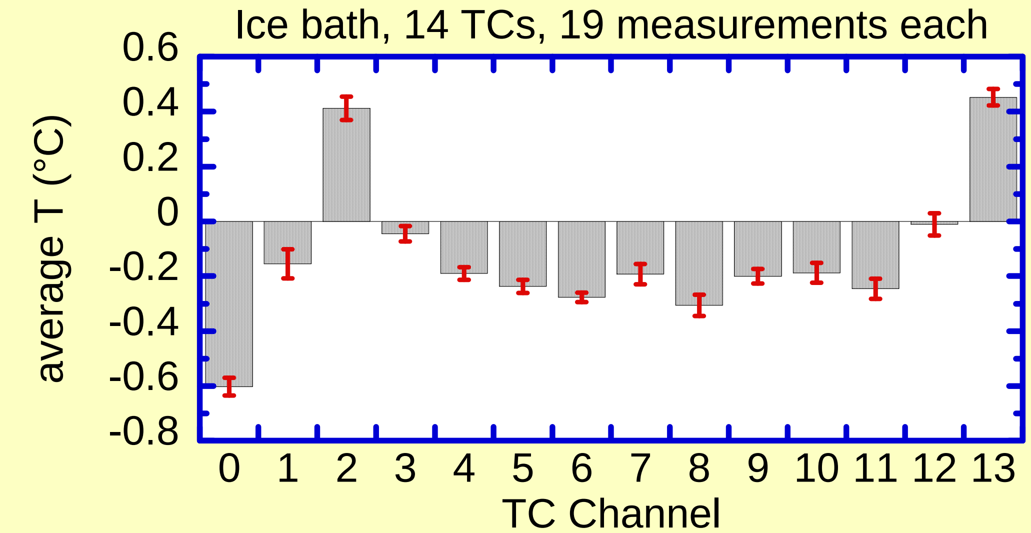
Flow Calibration



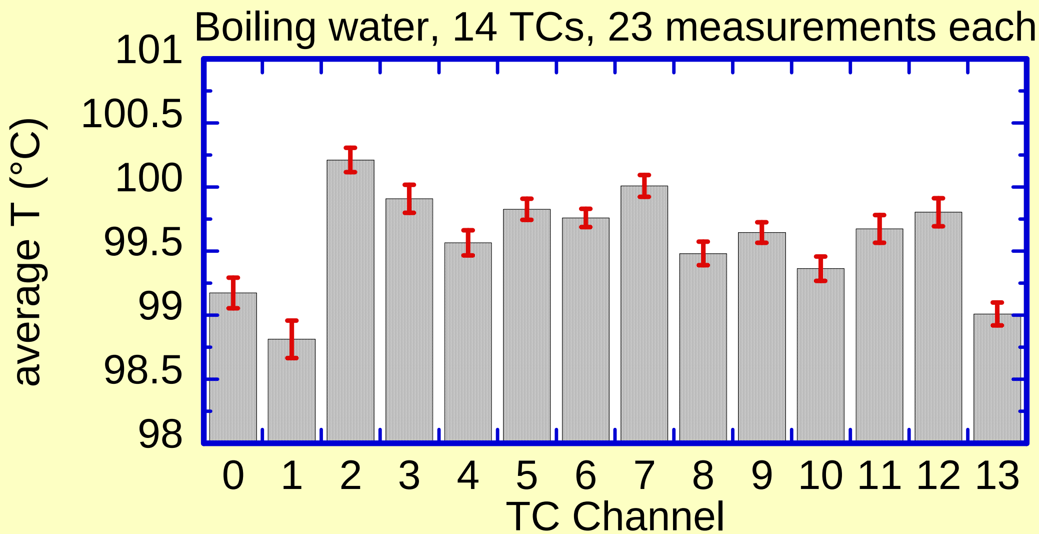
Dig_{in}: 3.478 ± 0.008 (n=8)
Dig_{out}: 3.484 ± 0.013 (n=8)
Bucket: 3.456
Analog: 3.5
Average = 3.48 ± 0.02

Dig_{in}: 1.810 ± 0.008 (n=6)
Dig_{out}: 1.823 ± 0.010 (n=6)
Bucket: 1.761
Analog: 1.8
Average = 1.80 ± 0.03

TC calibration

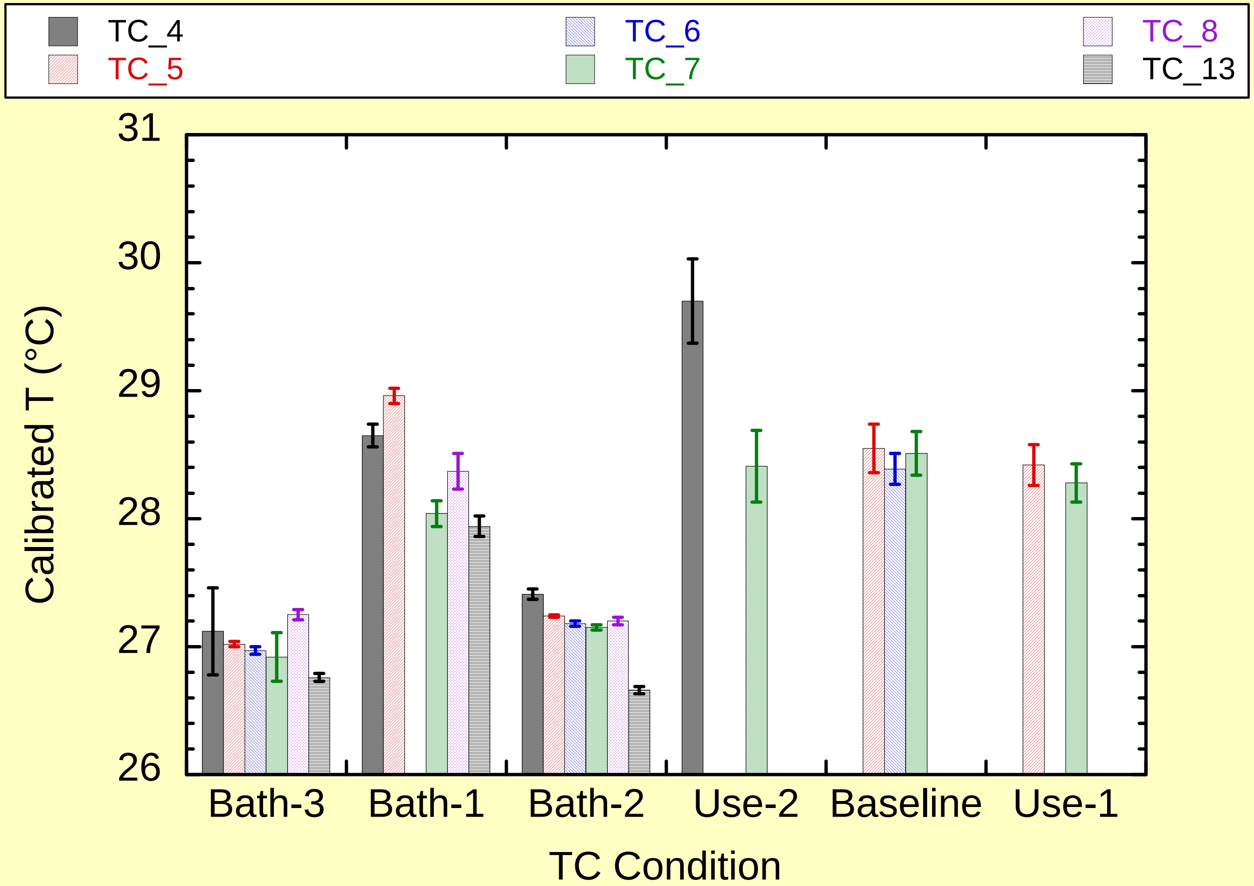


Ave stdev each TC = 0.033
Ave T = -0.1 ± 0.3



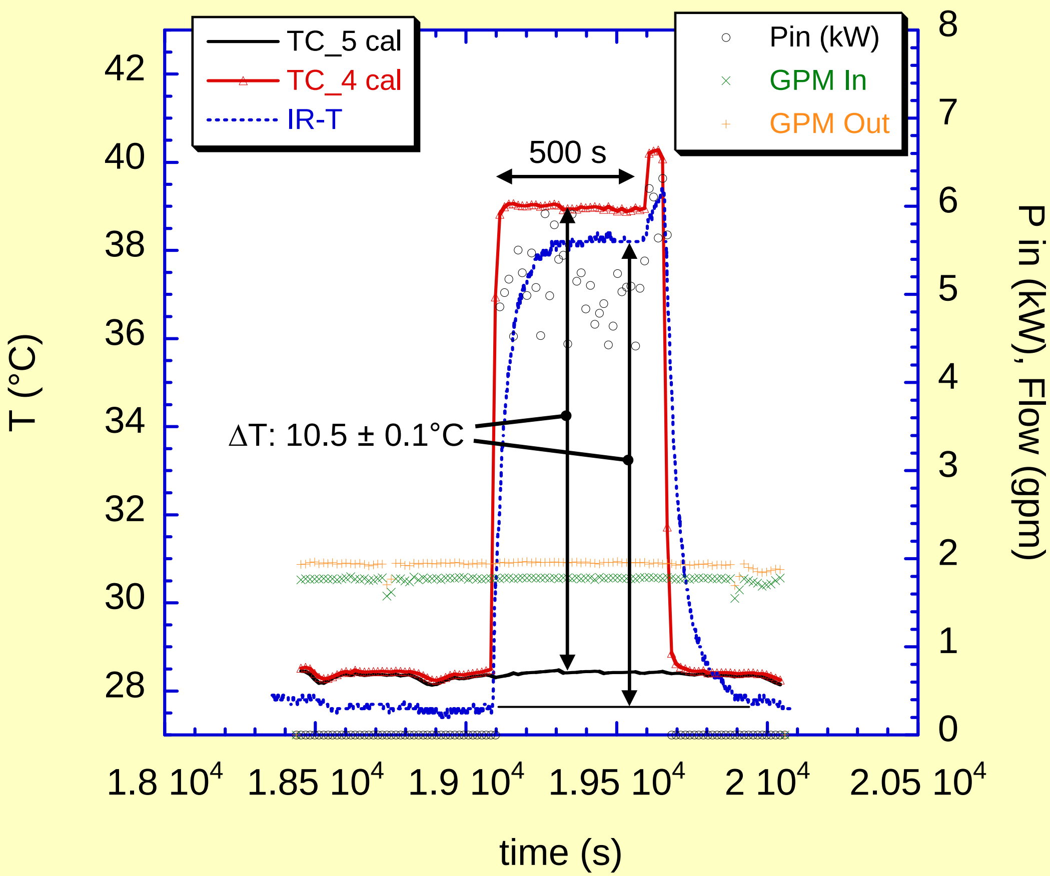
Ave stdev each TC = 0.099
Ave T = 99.6 ± 0.4

Calibrated Thermocouple Stability



Even after calibration, TCs in like environment show variability of ~1K during use. Use of matched pairs can help.

Mass Flow Measurement of Water Heater Power



P_{in} undersampled with power meter, as heater operates in “switching” mode, causing scatter in data.
Average Pin =5.07 ± 0.40 kW (± 8%)

Average **flow** while Pin ~5 kW:
input = 1.780±0.006 gpm
output = 1.958±0.006 (10% high?)
analog meter = 1.77

ΔT = 10.5 ± 0.1°C, based on averages of calibrated TC_4_{out} and TC_5_{in}. Output IR sensor also has ΔT = 10.5 °C, after ~200 s.

Since output flow seems discrepant, use estimate of 1.775 gpm from input flow and analog meter. This provides a conservative measure of power.

Therefore, **P_{out}** = 4.91 ±0.05 kW, and
Efficiency = 97 ± 8%

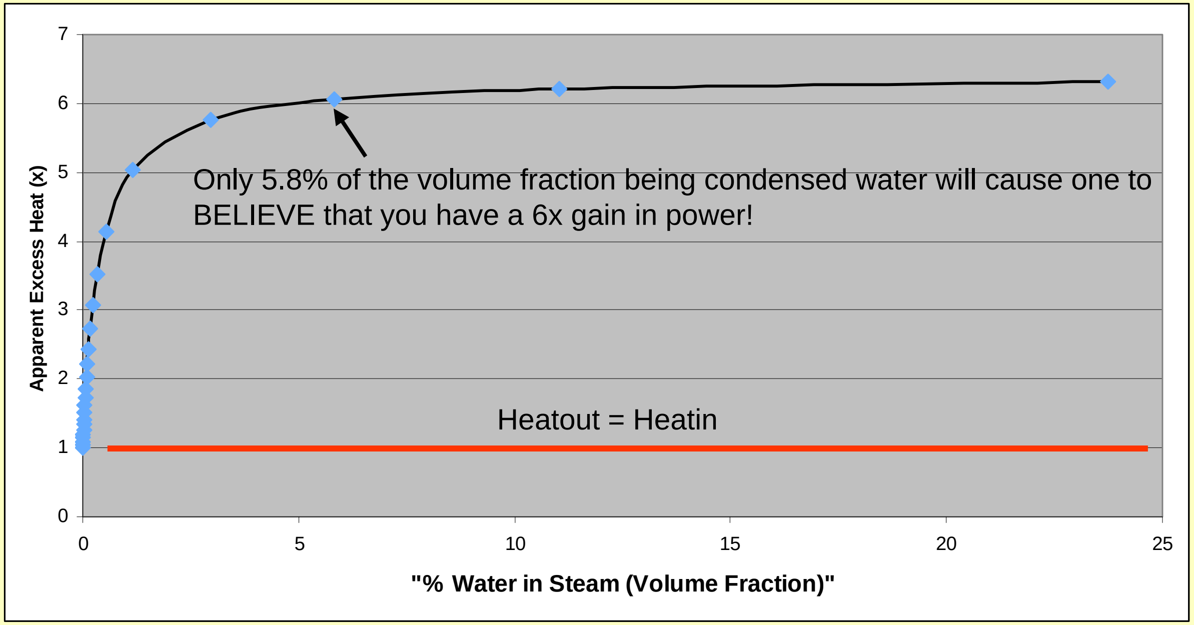
(Limited precision from high quality power meter)

5 kW easily measured

Challenge of Calorimetry with Steam:
Must Measure Steam Quality Accurately and Precisely

Extra care must be taken during phase changes

Apparent Excess Heat vs. Dryness of Steam



Summary

- NRL's existing water input and output manifolds can measure a large heat input with high efficiency (97%)
- Requires care in use of sensors, including use of redundant, calibrated, and tested devices.
- Digital data collection provides means to rigorously validate performance of claimed LENR energy generators.

Recommendations

- Design, conduct and analyze tests thoroughly, to withstand all anticipated questions and criticisms.
- Persons experienced in the types of measurements and instrumentation employed should participate in all phases of the tests.
- Redundant calibrated sensors and systems should be employed to measure all streams of energy and matter entering and departing the device under test.
- Signal-to-noise ratios of ten or more are required for all measurements to exclude the possibility of cumulative errors leading to a wrong conclusion.
- The test should be conducted for a sufficient continuous period to strongly exclude the possibility of stored chemicals generating the observed energy output.
- A thorough statistical data analysis should be conducted to determine the error associated with each measurement, and to compute an overall uncertainty in the energy gain.
- A separate “red team” of persons experienced in related laboratory measurements should critique the design and execution of the test, and the analysis of the results.