# Modeling & Simulation of a Gas Discharge LENR Prototype

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Experimental results from a stainless-steel LENR prototype reactor in a large thermal mass Seebeck calorimeter are modeled to accurately simulate experimental results. The well-known SPICE simulator is used for this work, where thermal properties of the apparatus are converted to lumped electrical circuits for simulation. Lumped electrical analogues for thermal components allow well developed electrical simulation technologies to quickly solve time domain thermal problems. Once the thermal model for a system is extracted, the simulation is accurate enough to detect possible experimental errors and inconsistencies. In addition, the unknown excess heat can be readily de-embedded from the typically long time constant of the calorimeter, enabling better time alignment of the excess heat response to the inputs that may have been the proximate cause for the effect.

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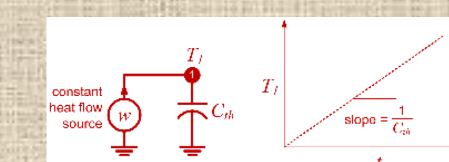
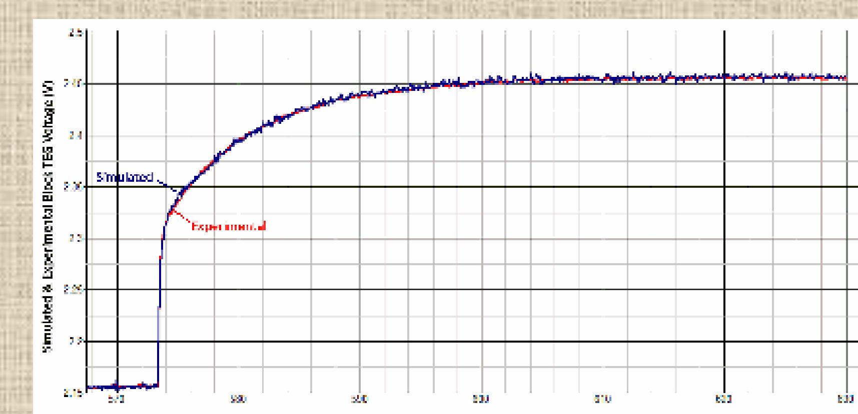
# Outline

- The Letts reactor/calorimeter system

- A common problem in thermal measurements
- Simulation types
- Electrical analogues for thermal modeling
- 1-dimensional thermal circuit modeling

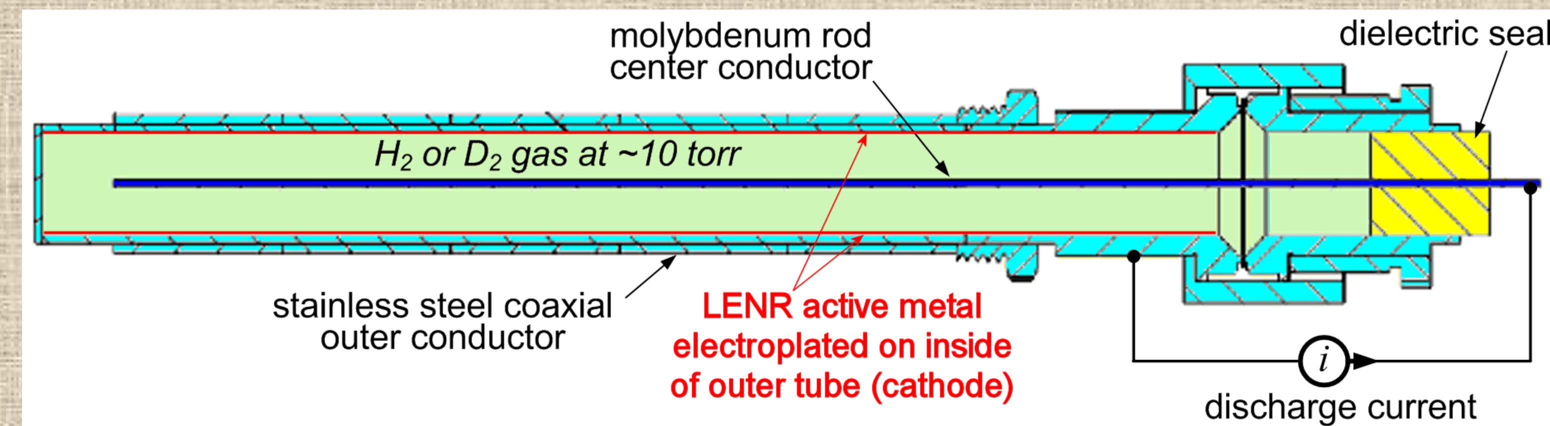



- The SPICE simulator
- Simulation of the Letts system
- Summary & credits



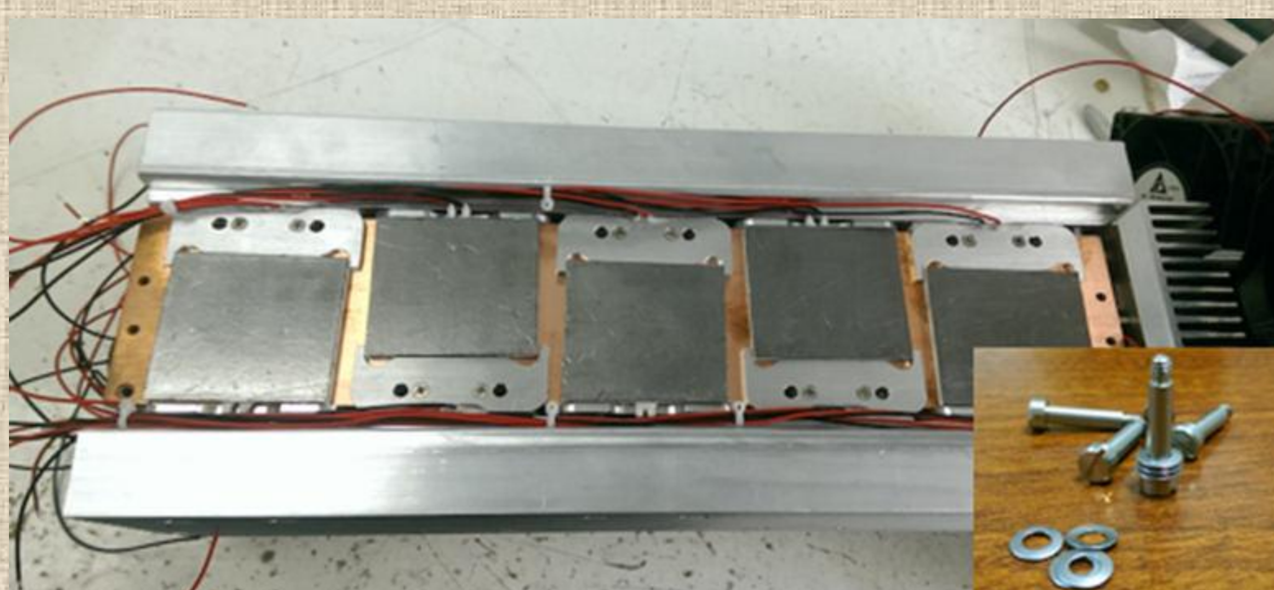
# Letts gas discharge reactor & calorimeter

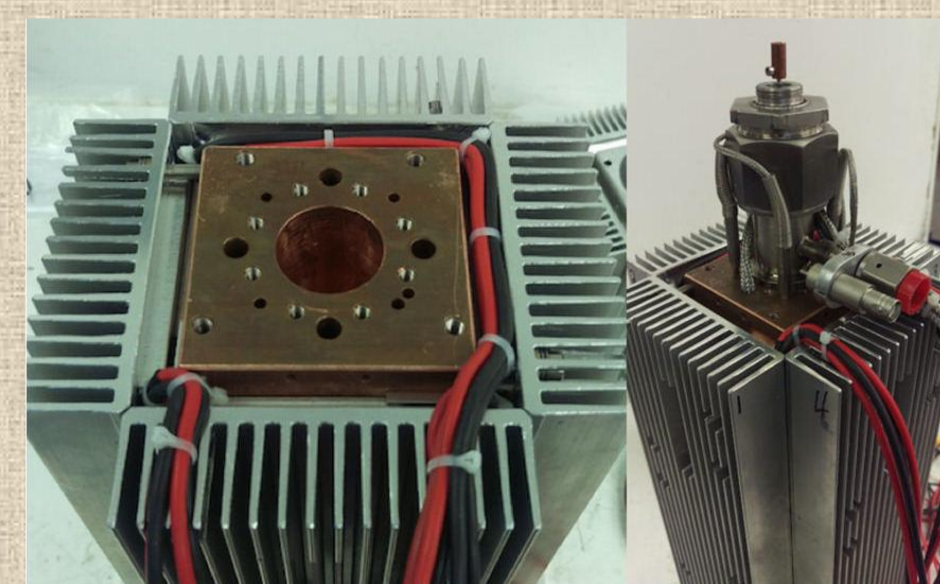
**The system (described Monday) has a coaxial stainless steel gas discharge tube (LT):**




**LENR Tube (LT) inserted in copper block –**

**heat exits via Seebeck (TEG) modules on its sides:**

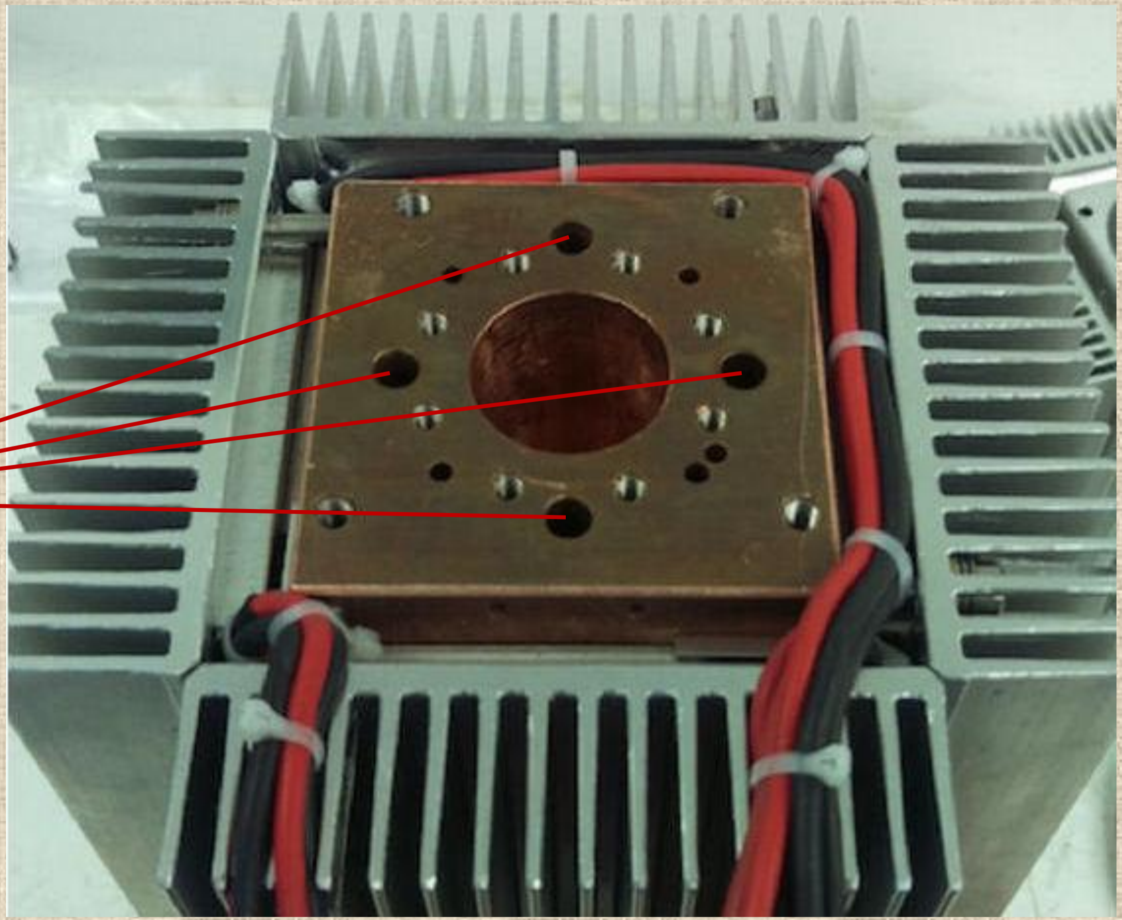




# Reactor & calorimeter (cont)

For higher temperature, 4 cartridge heaters apply heat directly to copper block:

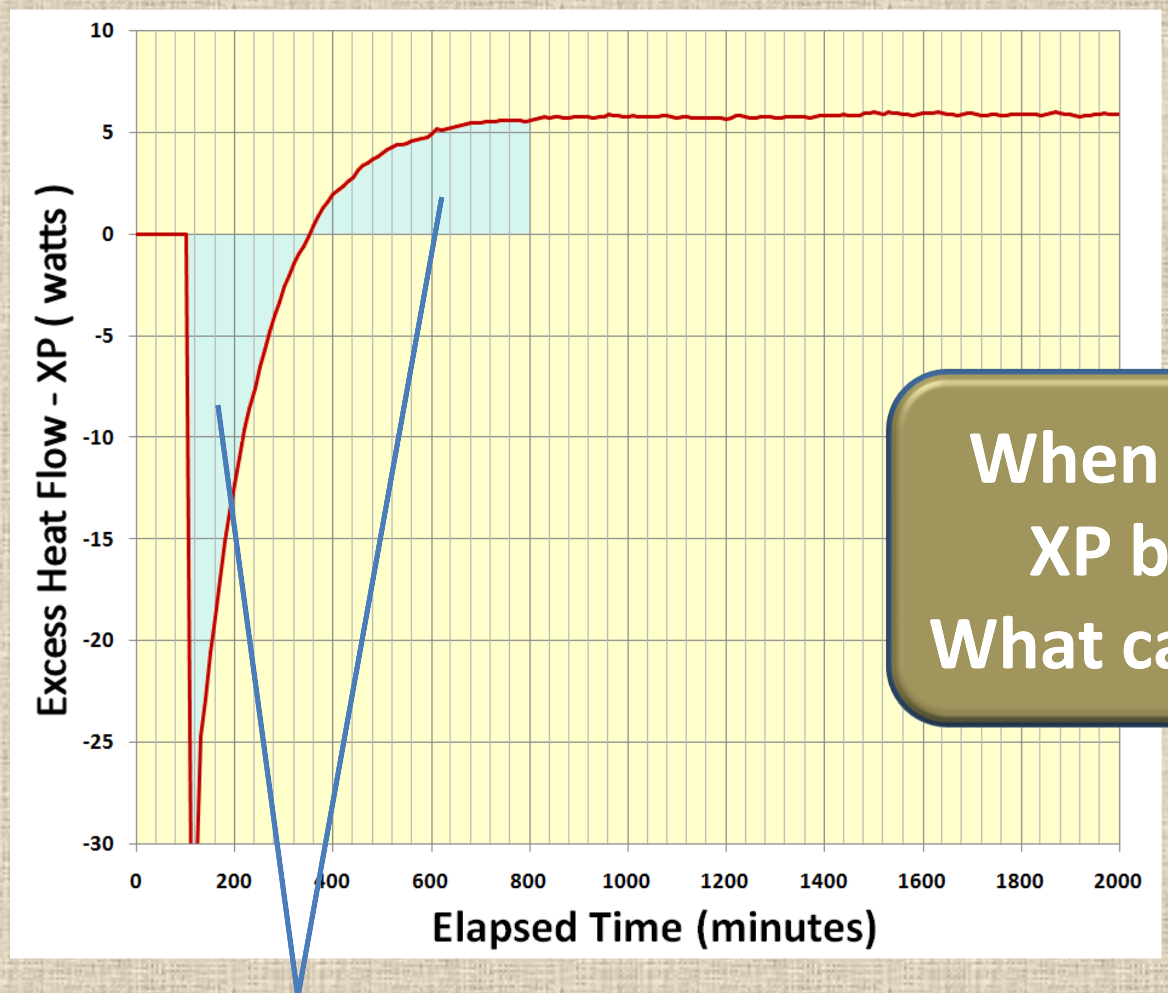
4 cartridge heaters inserted in these holes



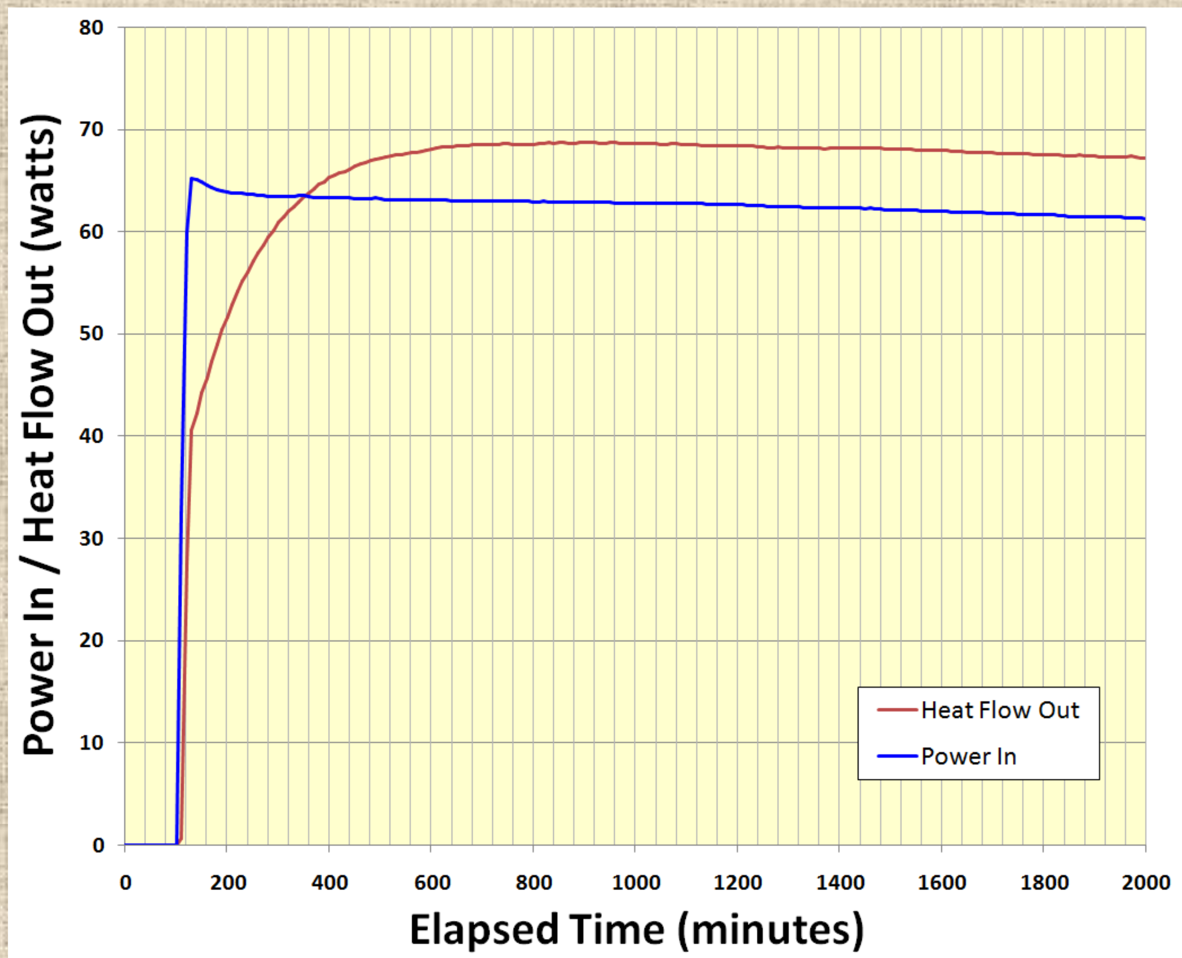
Cartridge heaters + LT discharge + LENR XP (if any) are primary sources of heat in the system.

# Thermal response issue - simple case

**XP is commonly computed as the difference between measured output heat flow and input power:**




When did the XP begin?
What caused it?



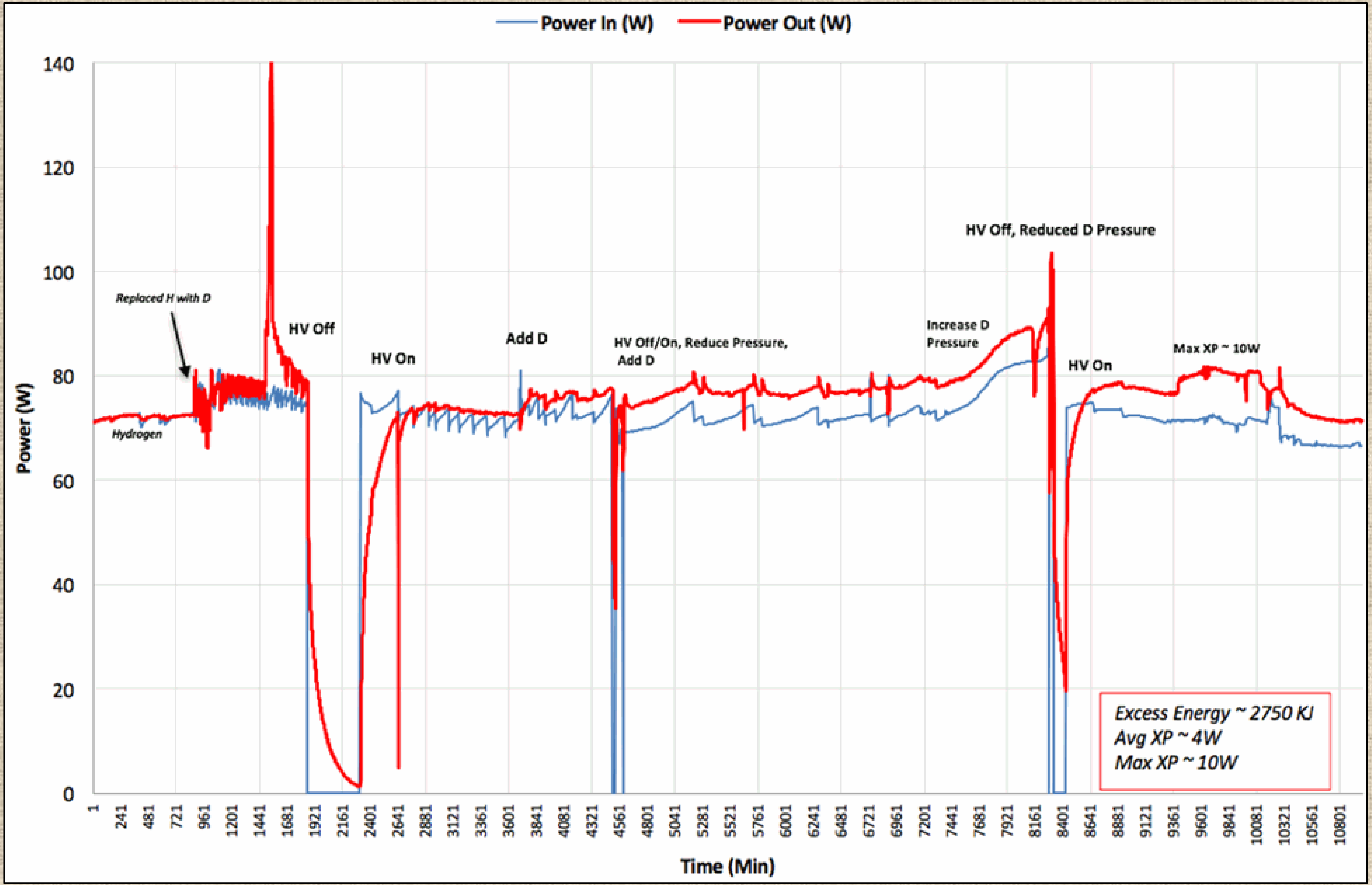

*Invalid report for nearly 12 hours*

***Input power** is a near-instant measurement, but **output heat flow** measure is delayed by long calorimeter time constant*

# Thermal response – a "busy" experiment

## Interpreting an actual experiment can be complicated:

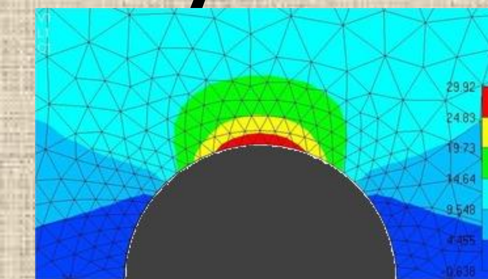
Modeling the system can help understand the response.



# Modeling choices

- Solid model finite element thermal analysis

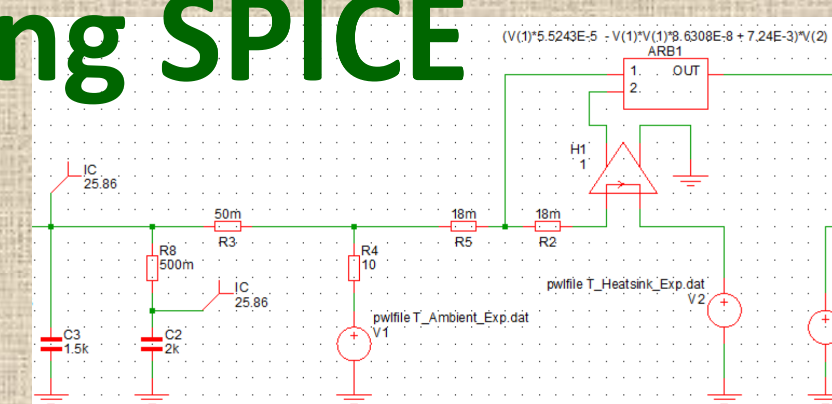
  *For first level design, but will never model fine response features*



- Behavioral modeling - mathematical

  *Measure impulse response and deconvolve. Painful due to the nonlinear nature of the system.  Hard to do "what ifs".*

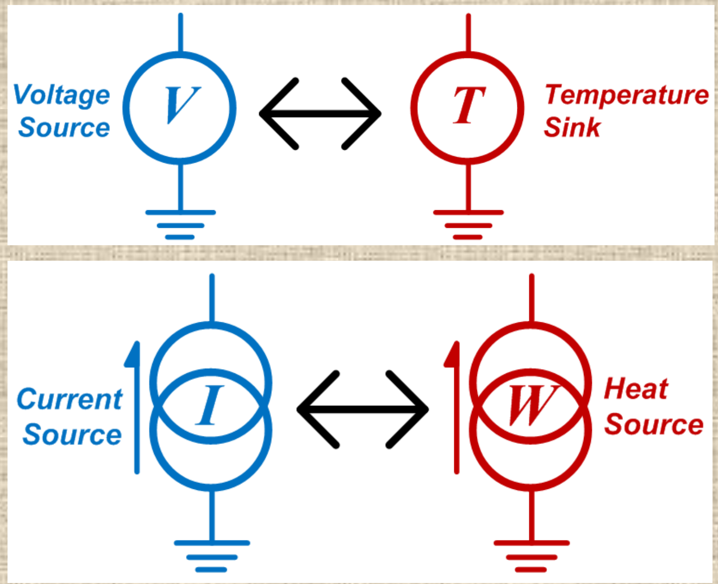
- **Equivalent circuit modeling using SPICE**



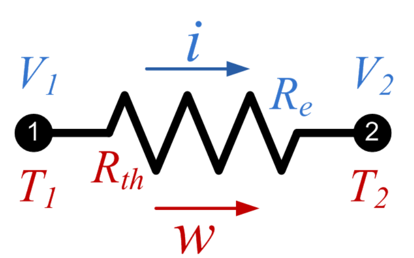

  - *Simple to build & change model*
  - *Compatible with nonlinearities*
  - *Easy to incorporate measured data*
  - *Rich feature set of SPICE simulators – graphics, elements, variables*
  - *Fast simulation – typically <5 seconds on a modern PC*

# Core thermal modeling circuit analogues

- Voltage (V) ⟷ Temperature (°C)
- Charge (coulombs) ⟷ Heat (joules)
- Current (A) ⟷ Heat flow (watts)

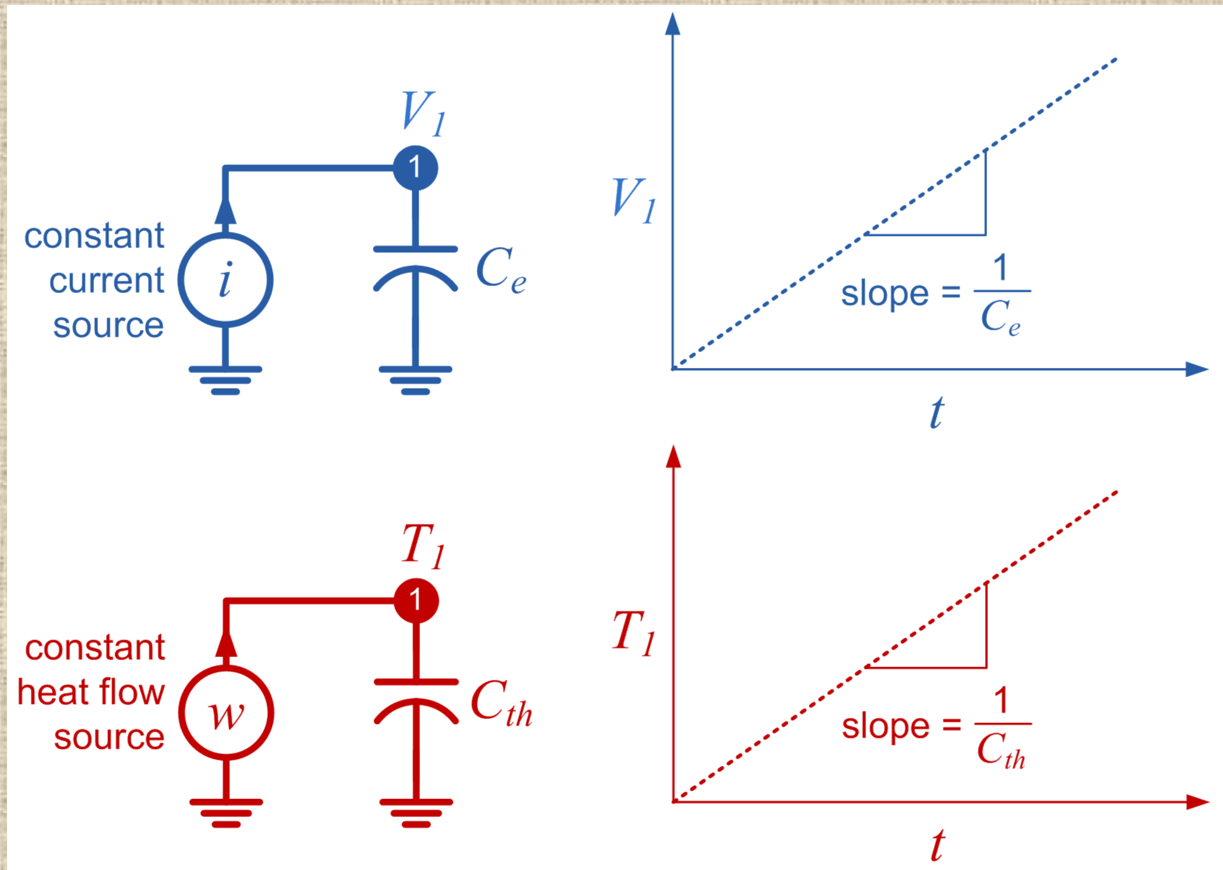



$$R_e = \frac{(V_1 - V_2)}{i} = \frac{Volts}{Amp}$$



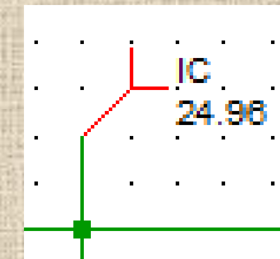

$$R_{th} = \frac{(T_1 - T_2)}{w} = \frac{°C}{watt}$$

Resistors may be nonlinear as needed




Circuit voltage nodes (state variables) become temp. nodes (also state variables)

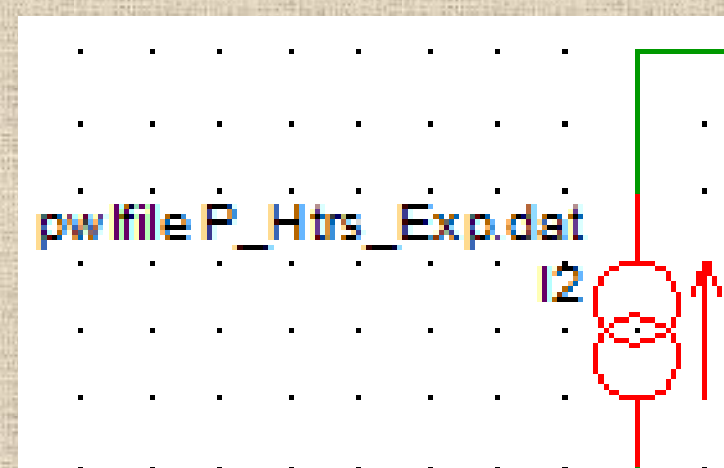
# More thermal circuit elements

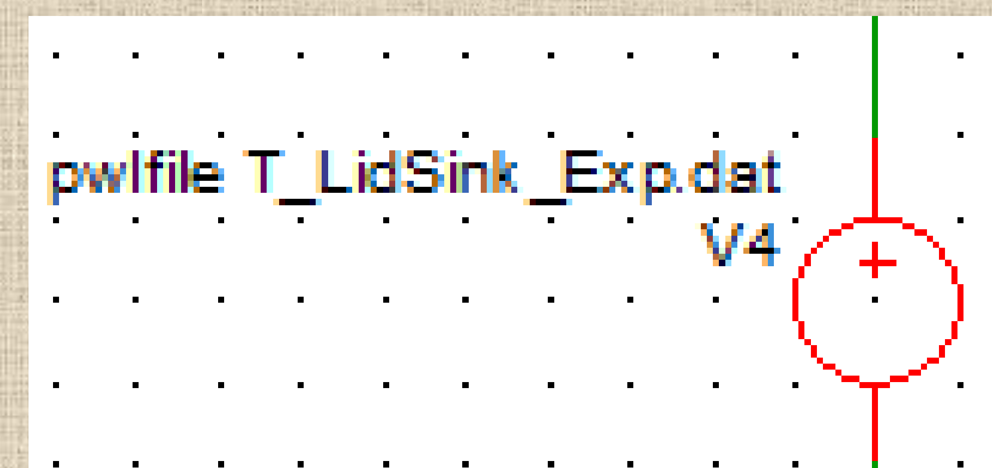
- **Voltage node initialization** 

**Temperature initialization**

- **Piece-Wise-Linear Source – text file driven source – supply [time value] records, simulator interpolates between – use for heat source or temperature source (sink)**

| | |
|---|---|
| 0.0 | 27.95 |
| 60.0 | 27.97 |
| 120.0 | 27.98 |
| 180.0 | 27.97 |
| 240.0 | 28.02 |
| 300.0 | 27.96 |

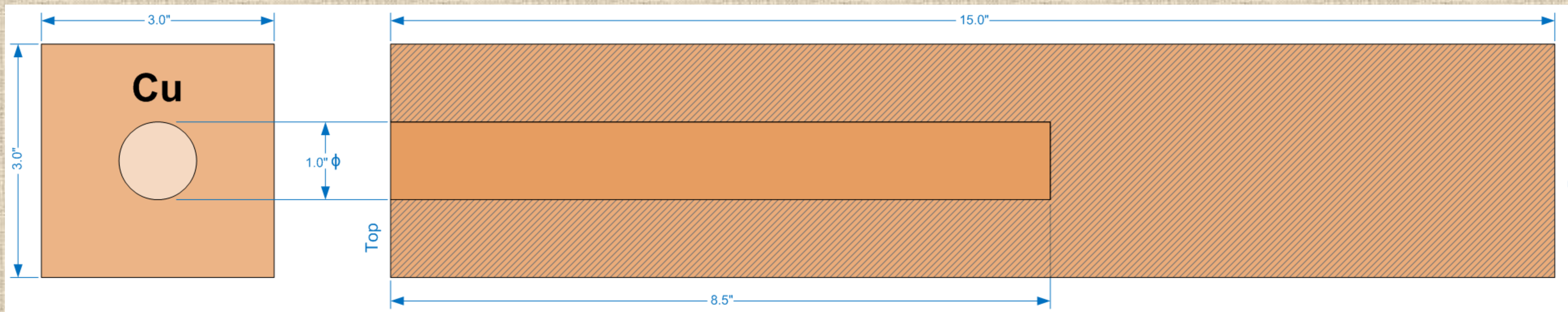



*Put measured data in a file to drive the model:*
*measured heat flow/power input vs. time, or temperature vs. time.*

# Circuit model for Letts calorimeter

## Begin with the big copper block heat spreader:



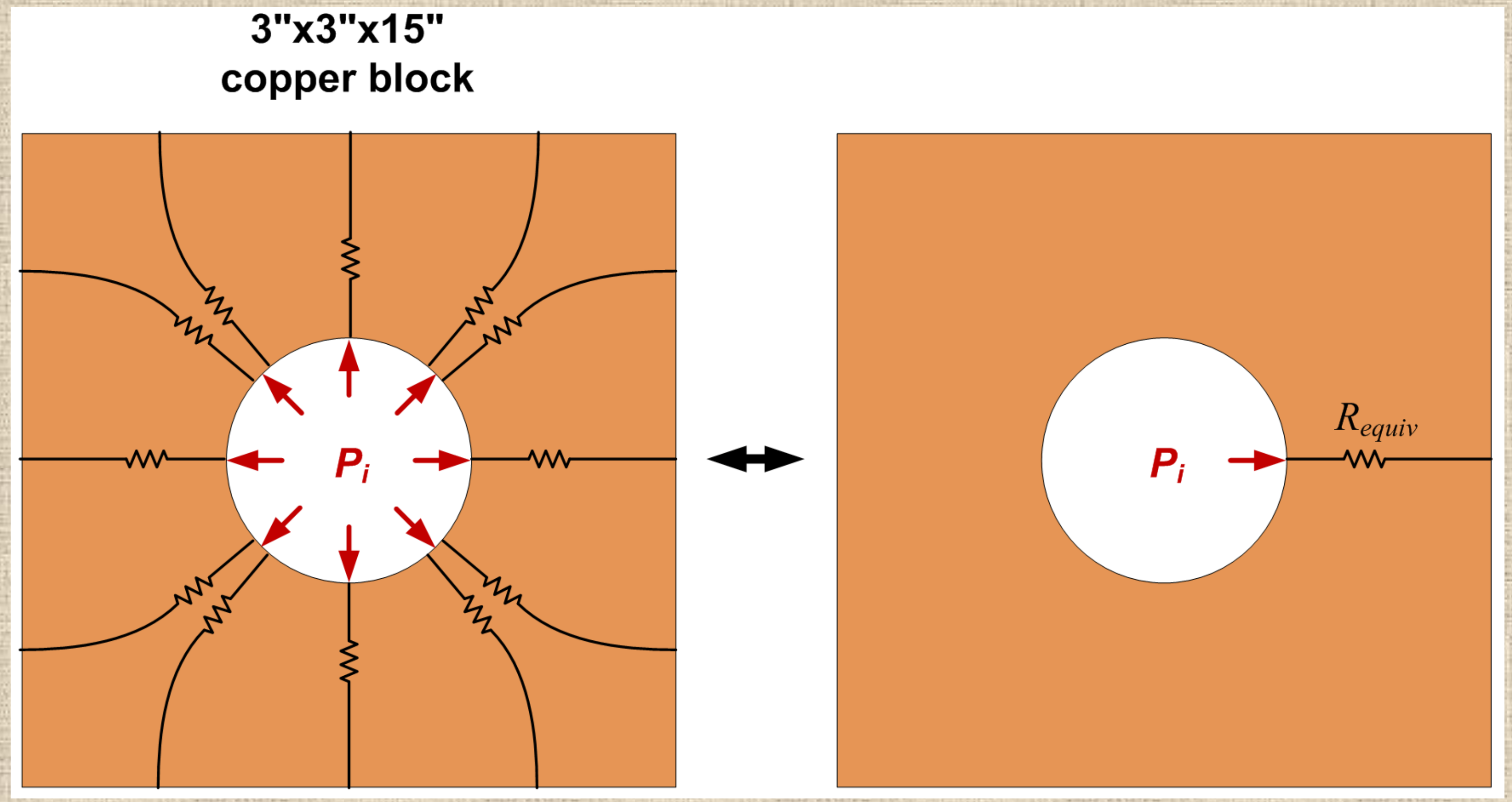

**Volume = 2103 cm$^3$, mass = 18.8 kg**

**Thermal capacity for Cu = 0.385 J/g-°C**

**Thermal capacity of block = 7254 J/°C**

# Reduction to 1-D circuit

**Consider the distributed resistance for the heat flow:**

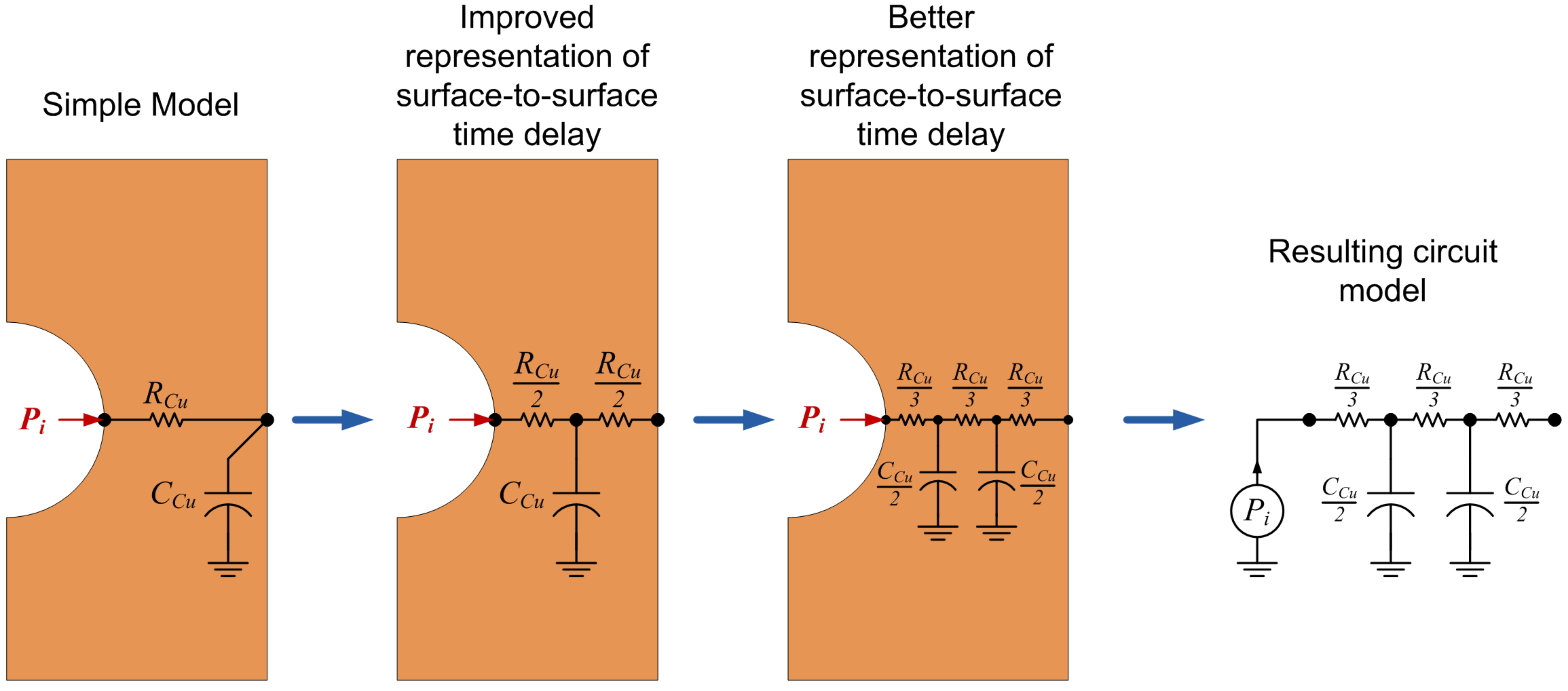



*2-D thinking*

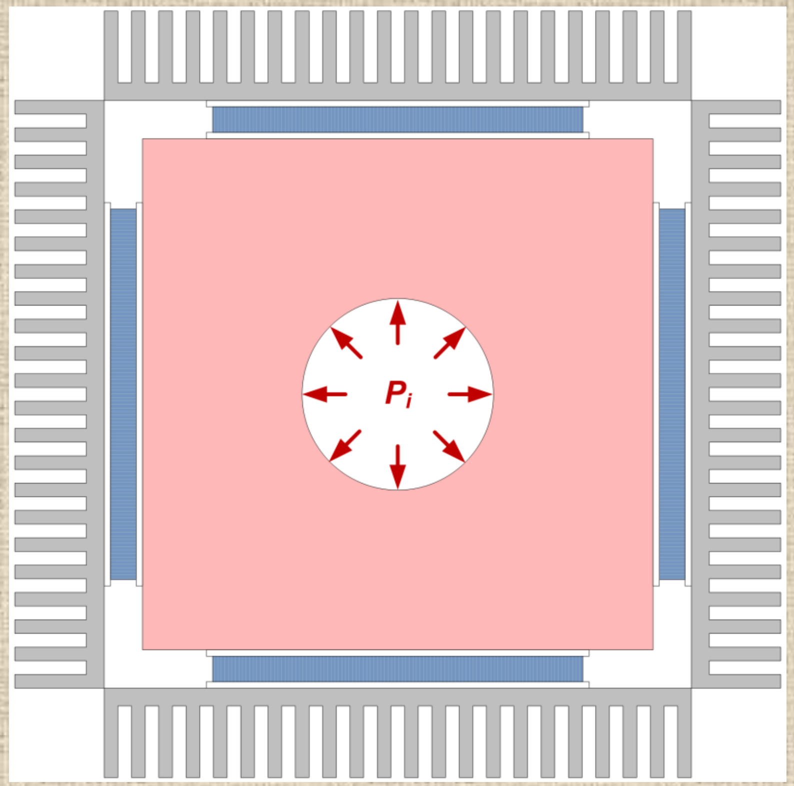
*1-D thinking*

**The distributed resistors end up in parallel …**

# 1st pass modeling of the R-C thermal delay

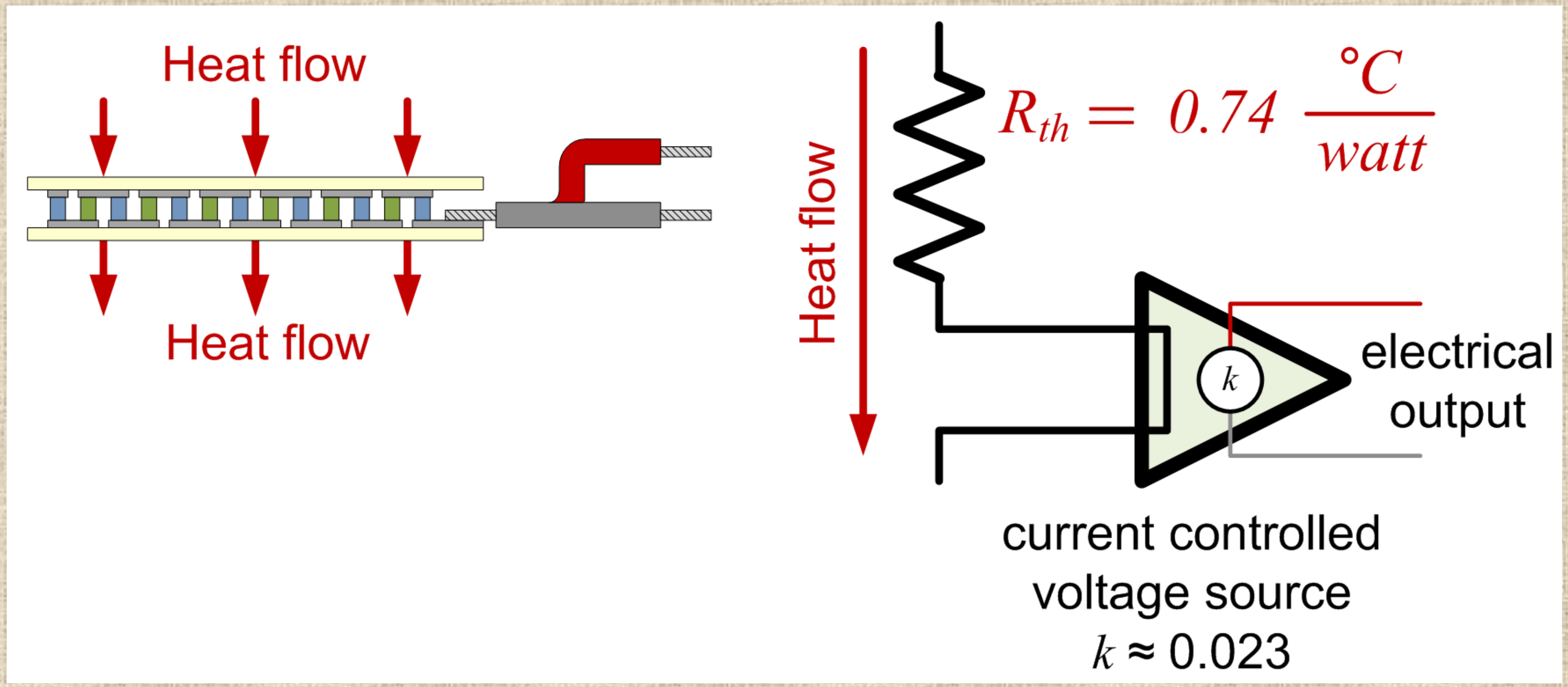


# Modeling the Seebeck TEG "heat detector"

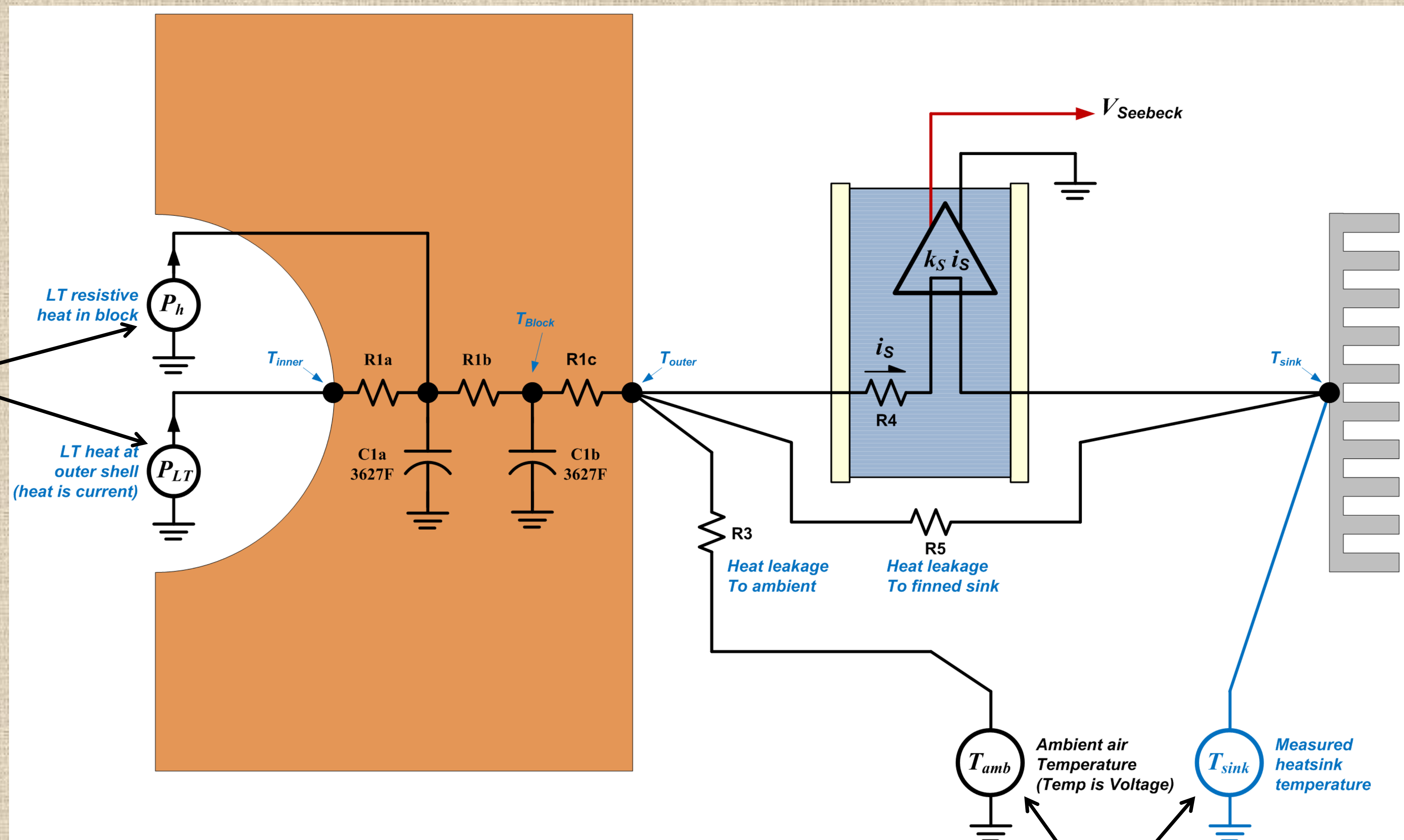



**Heat escapes to the environment via low thermal resistance Seebeck TEG modules**

**Heat flow through Seebeck TEG modules produces voltage output proportional (*k*) to heat flow**



# A first model circuit



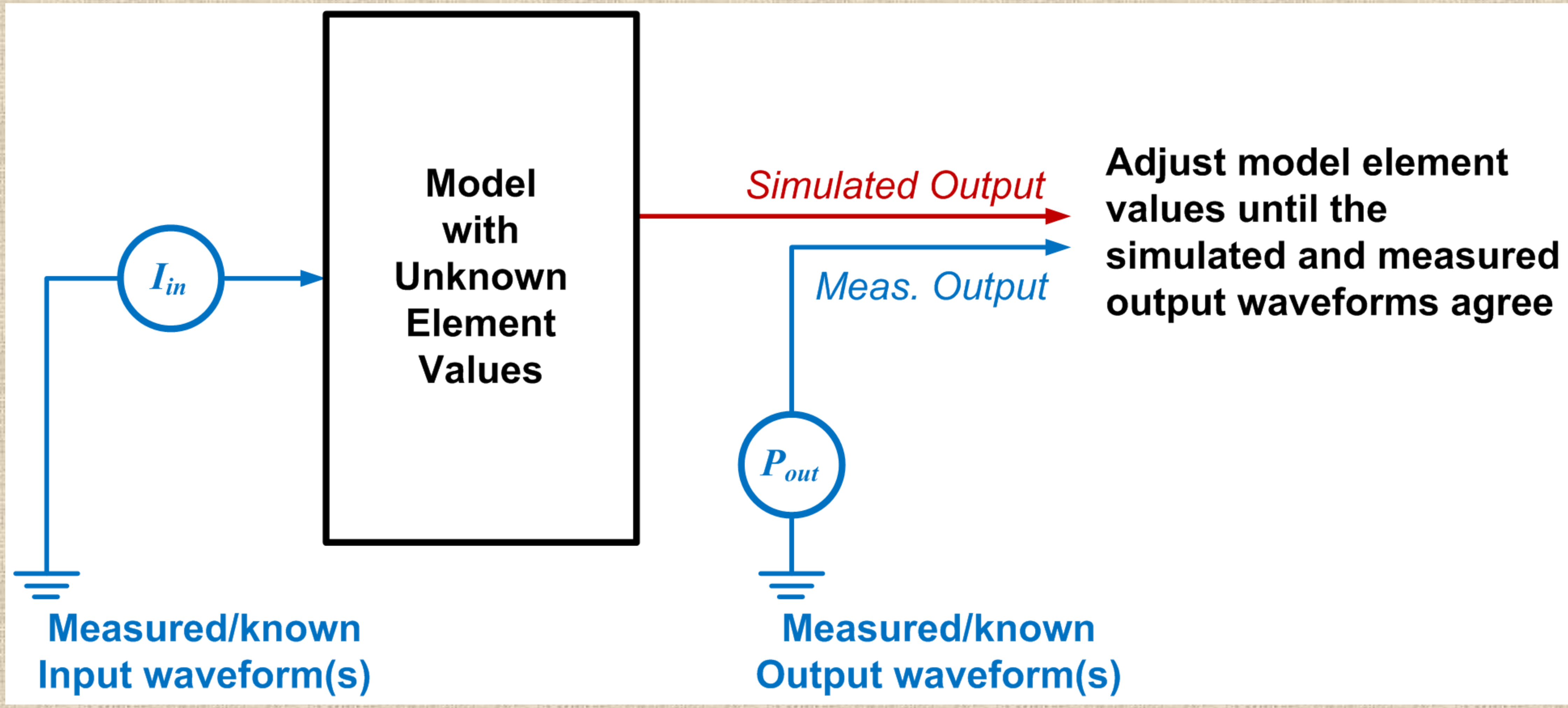

Measured – use data in PWL sources

Measured – use data in PWL sources

# Determining unknown model parameters

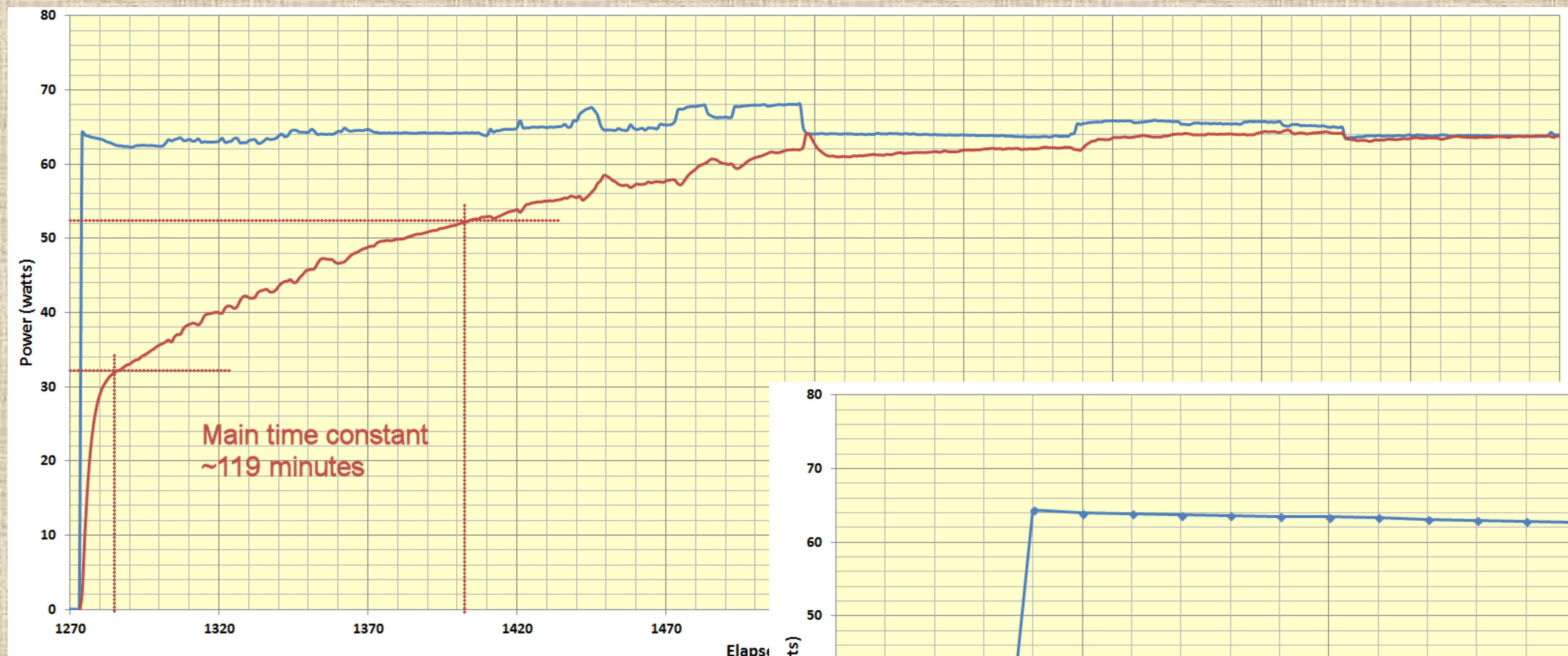
**Iteratively adjust parameters to cause the simulated output to match the measured output.**

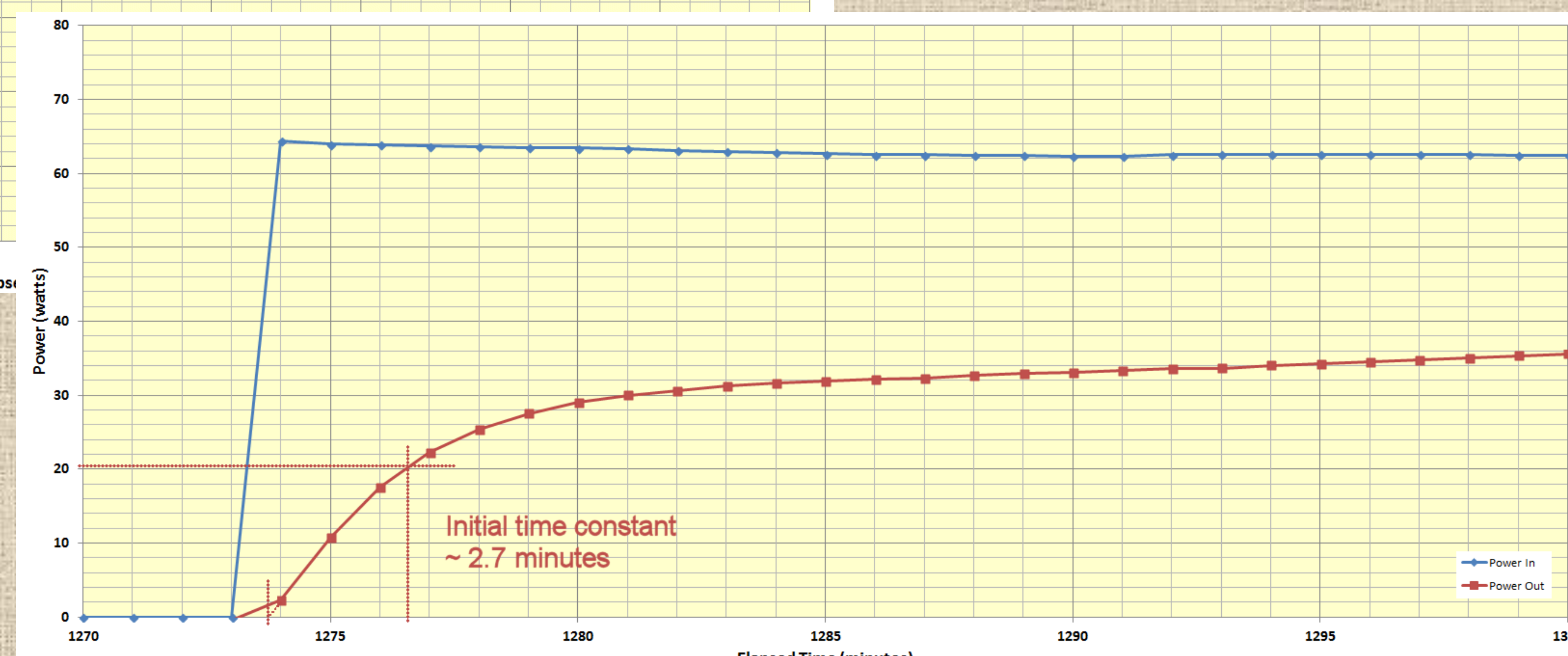
***This is parameter "extraction".***



# Measure the system with canonic inputs

## First choice is a step in power input to a null reactor …

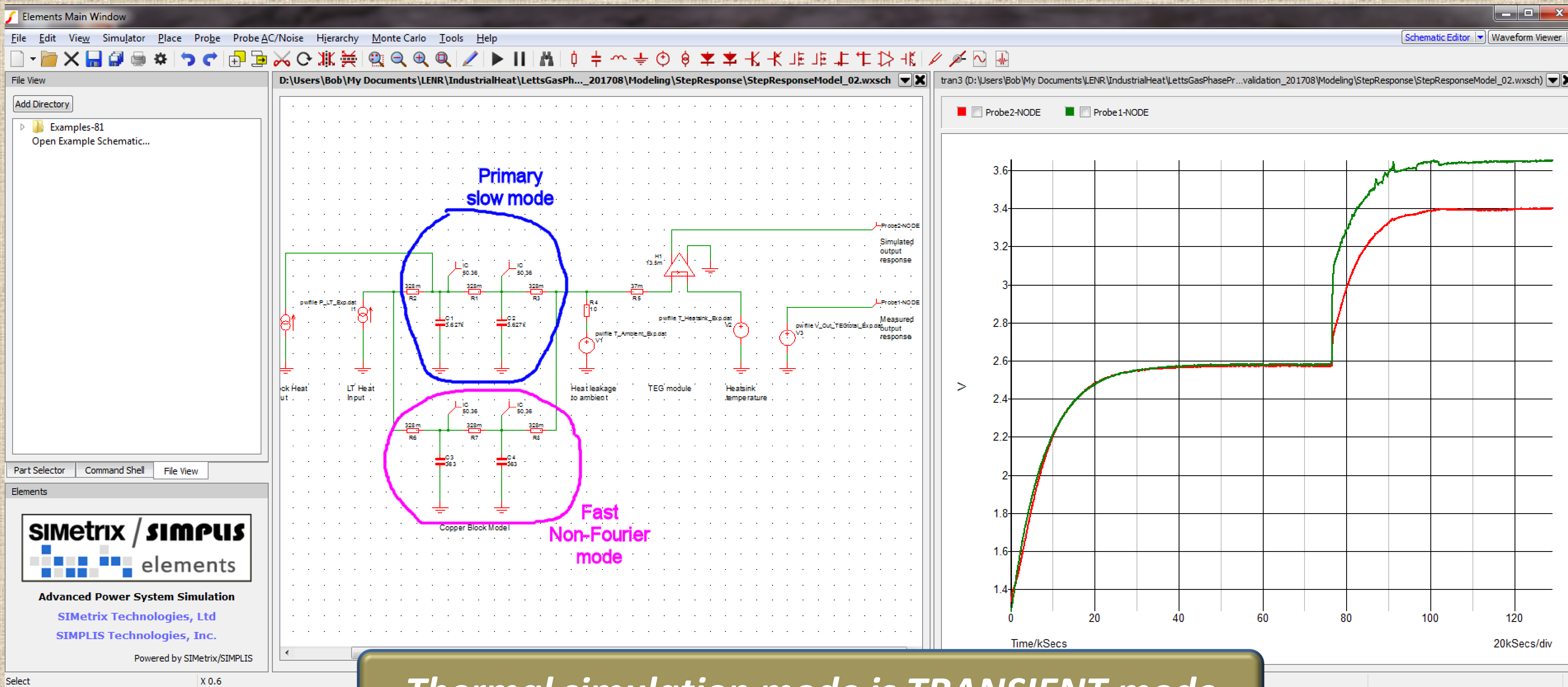



*** SURPRISE ***
Two heat propagation modes are present …
non-Fourier heat transfer!

# Simulating with SPICE – I use Simetrix

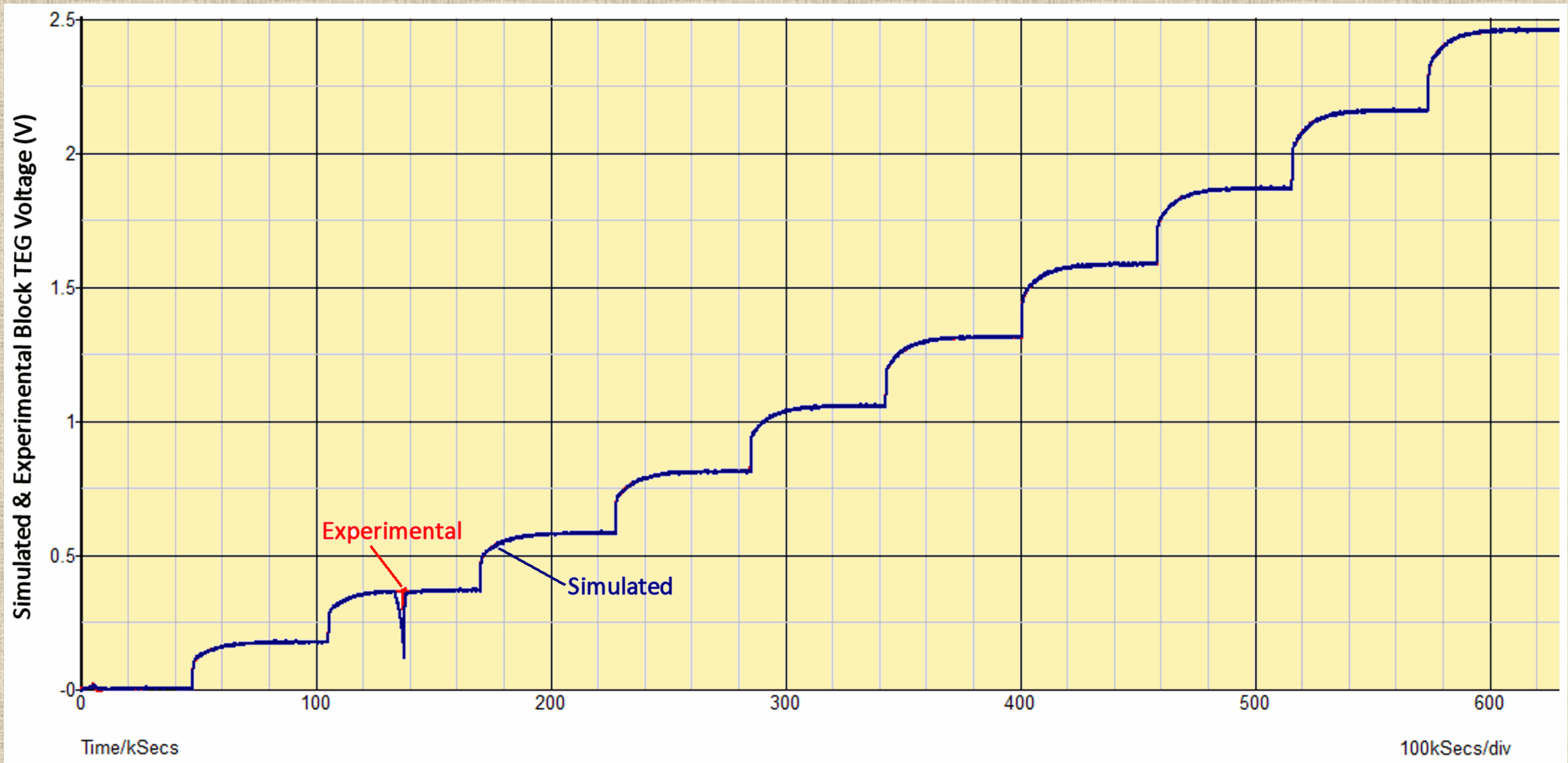
## Simetrix Elements is a FREE SPICE simulation environment*:




***Thermal simulation mode is TRANSIENT mode***

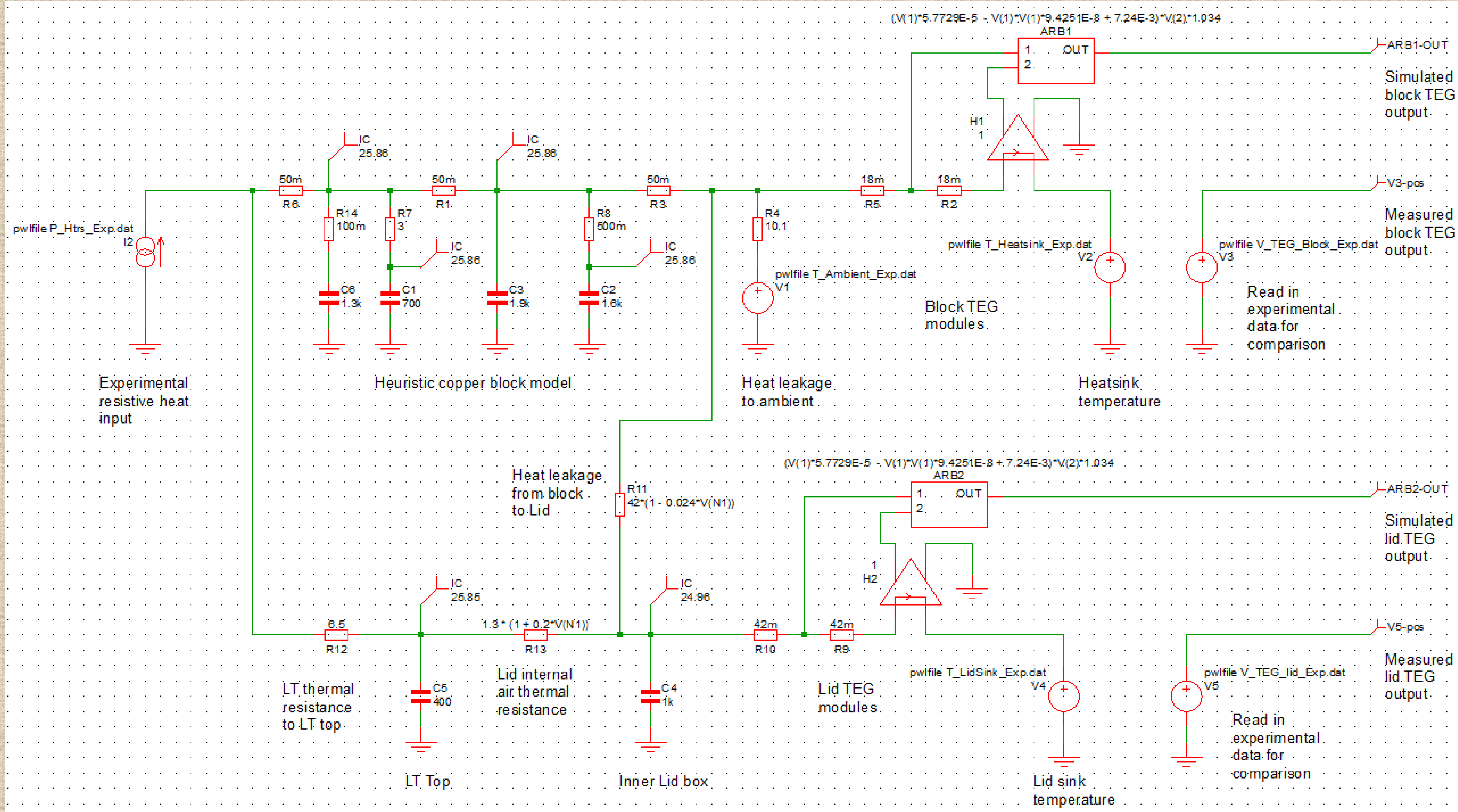
* Simetrix simulator for Windows PC: https://www.simetrix.co.uk/downloads/download.php?file=elements

# Stairstep confirms dual mode heat transfer



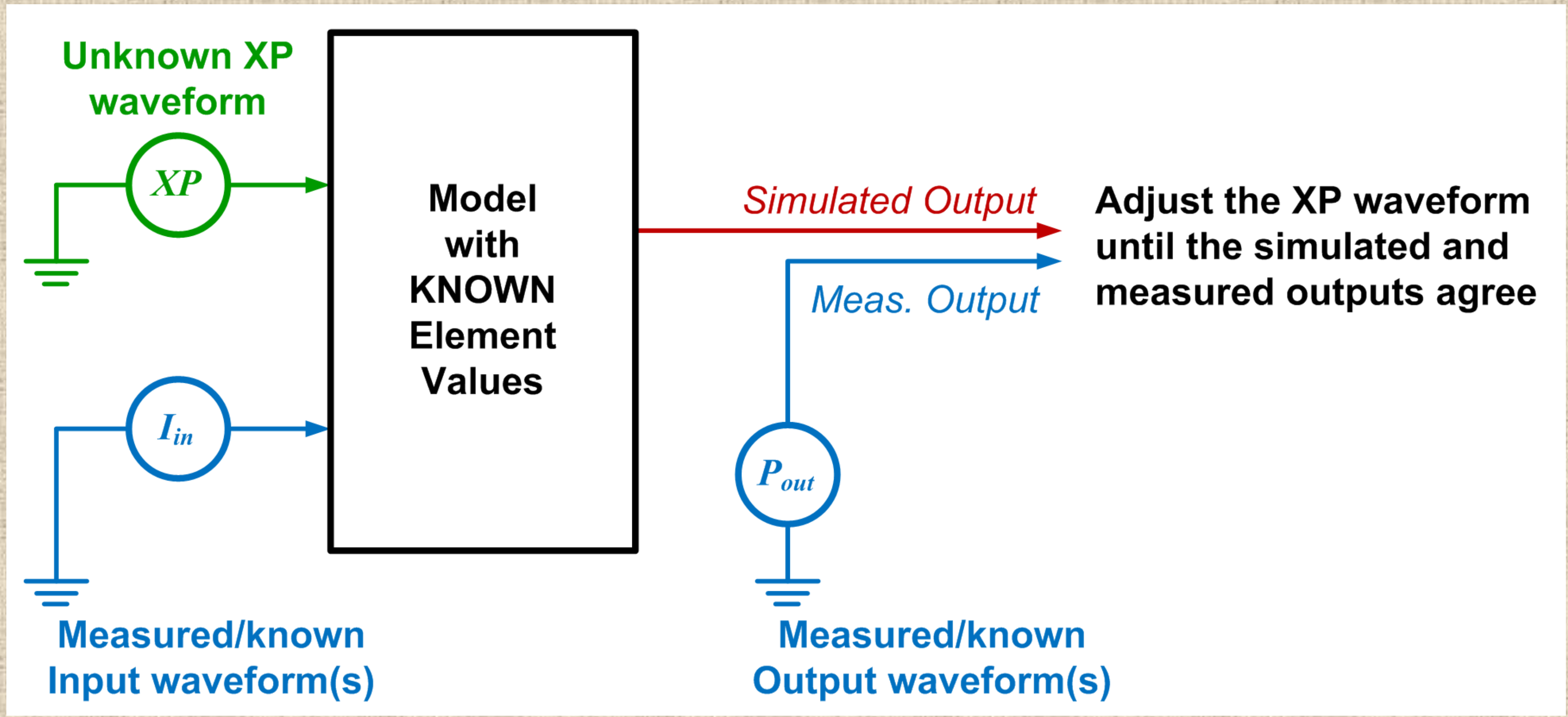

***Fast rise exists on each of the stairsteps. This means that two modes are present, not a TEG nonlinearity as suggested by the TEG mfgr.***

# Final extracted model



# With model, extract unknown XP waveform

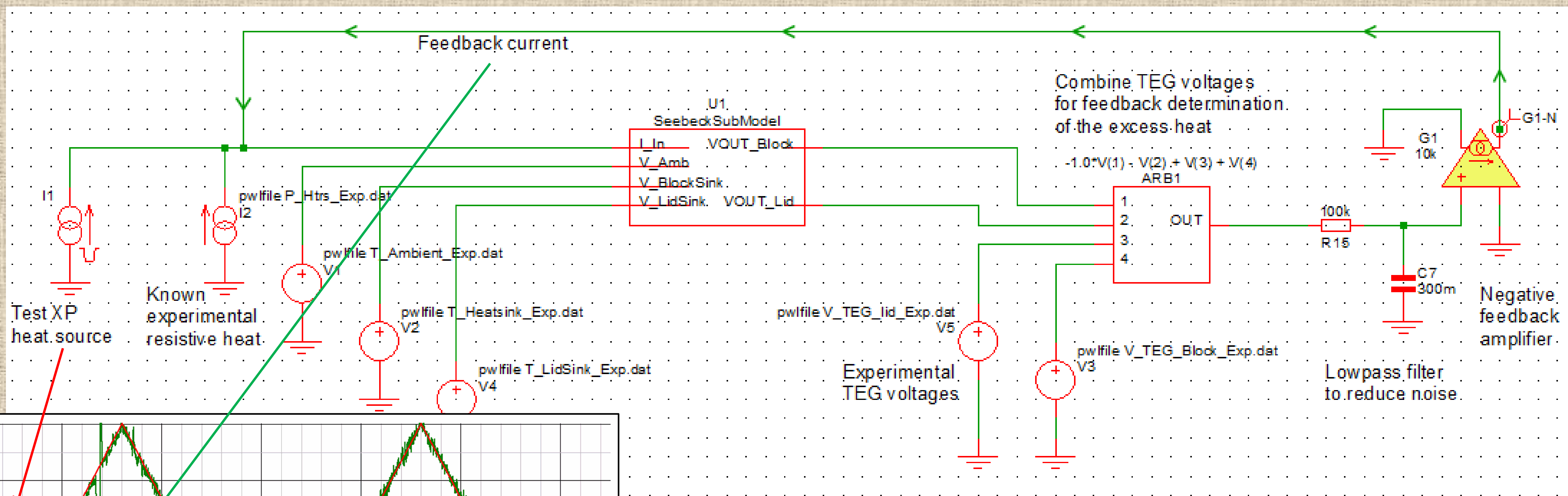
**With the model extracted, the only unknown in an active experiment should be the XP waveform:**

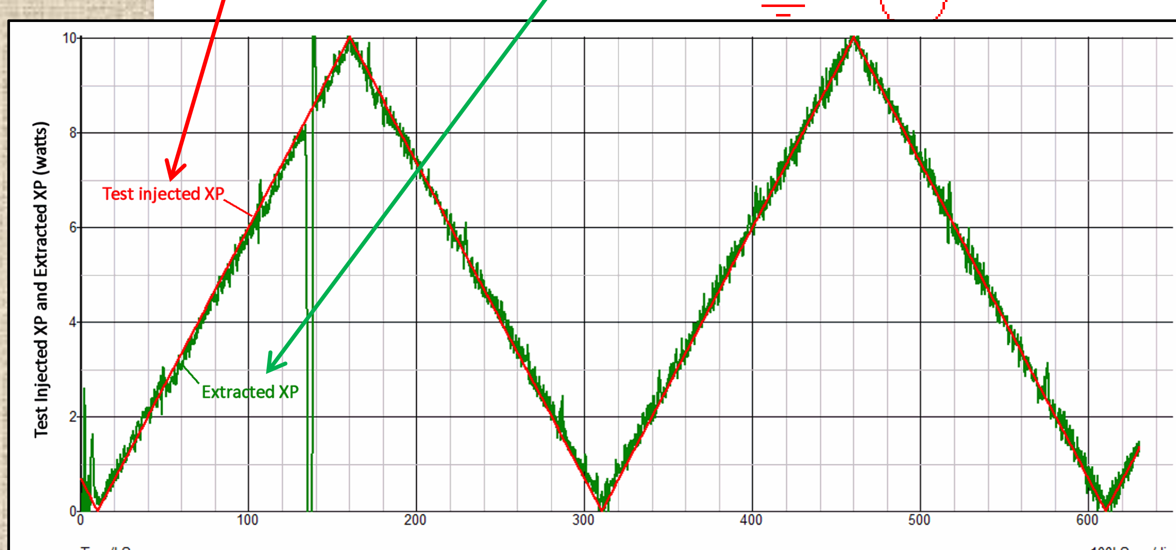



**XP waveform extraction is deconvolution – an ill-conditioned problem due to noise.**

# Use feedback in simulation to find XP

## Apply negative feedback to force simulated output to match measured output:




**Inserted triangle waveform (mock XP) is well recovered by the negative feedback method**

# Modeling tips

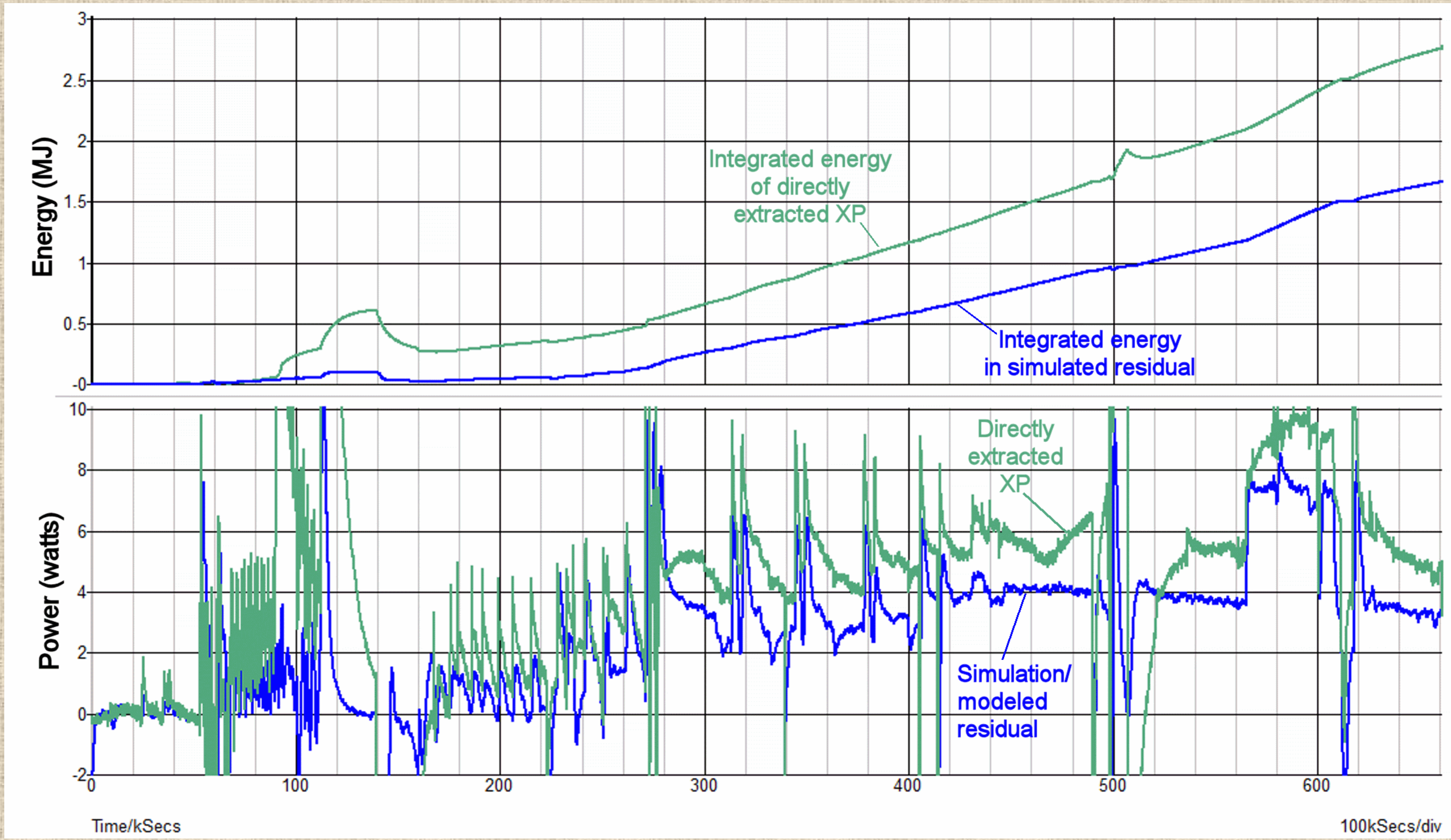
- ***Model only what you don't measure***
  *(use PWL sources to set nodes where data was acquired)*
- ***Sample 10x faster than shortest time constant***
- ***Thermal capacitors & metallic conduction R's are linear***
- ***Model convection/radiation heat flow with nonlinear R's***
- ***True endothermic regions in XP are exceedingly rare***
  *(usually an indication of inadequate modeling)*

# Modeling notes

- **Modeling *DID* turn up error sources**
  - *heater lead wire dissipation - heat was not deposited in the calorimeter*
- **Found new sources of heat flow & storage**
  - *Gas admitted to the evacuated LT caused Joule-Thompson cooling, notable even at 10 torr*
  - *Energy stored to heat the plasma was released when the discharge was turned OFF*

# Sample modeling results

## *XP & XH from modeling vs. differential curve fit calibration:*



# Conclusions

- ***Modeling increases understanding***
- ***Modeling improves S/N in extracted XP***
- ***XP waveform extraction helps identify its stimulus***
- ***Free SPICE simulators are valuable thermal modeling tools***

# Thank you for listening

*This modeling was sponsored by* INDUSTRIAL HEAT *as due diligence evaluation of the Letts experiments in progress. But …*

**The IH standard for official confirmation of any excess heat claims requires verification by a major independent lab with recognized, credible, and skeptical researchers.**

*Slides file and paper pre-print are available at:*

**https://goo.gl/Zq77ar**