Deriving Correction Factors for a Primary Standard for Radiation Dosimetry

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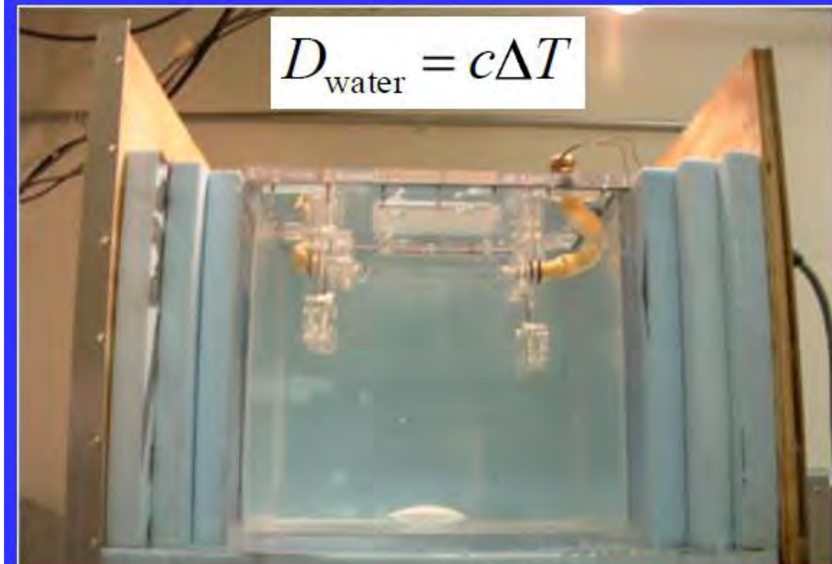
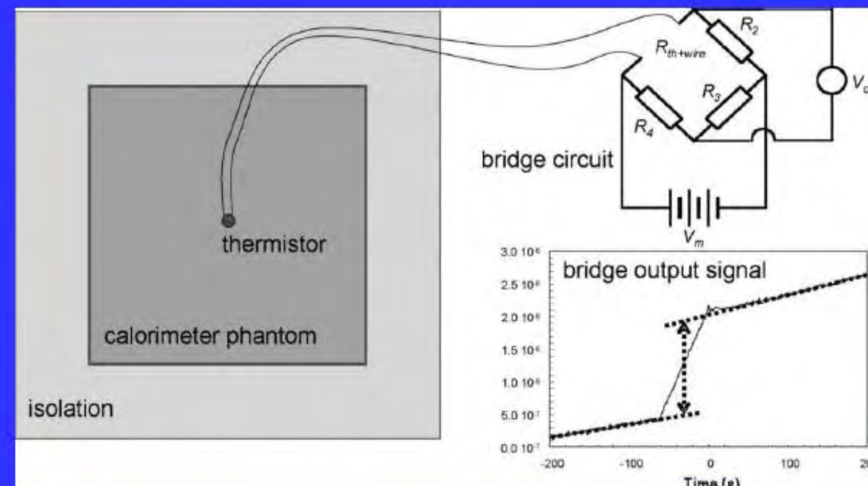
Presented at the 2011 COMSOL Conference
Oct 13, 2011

The NIST Water Calorimeter

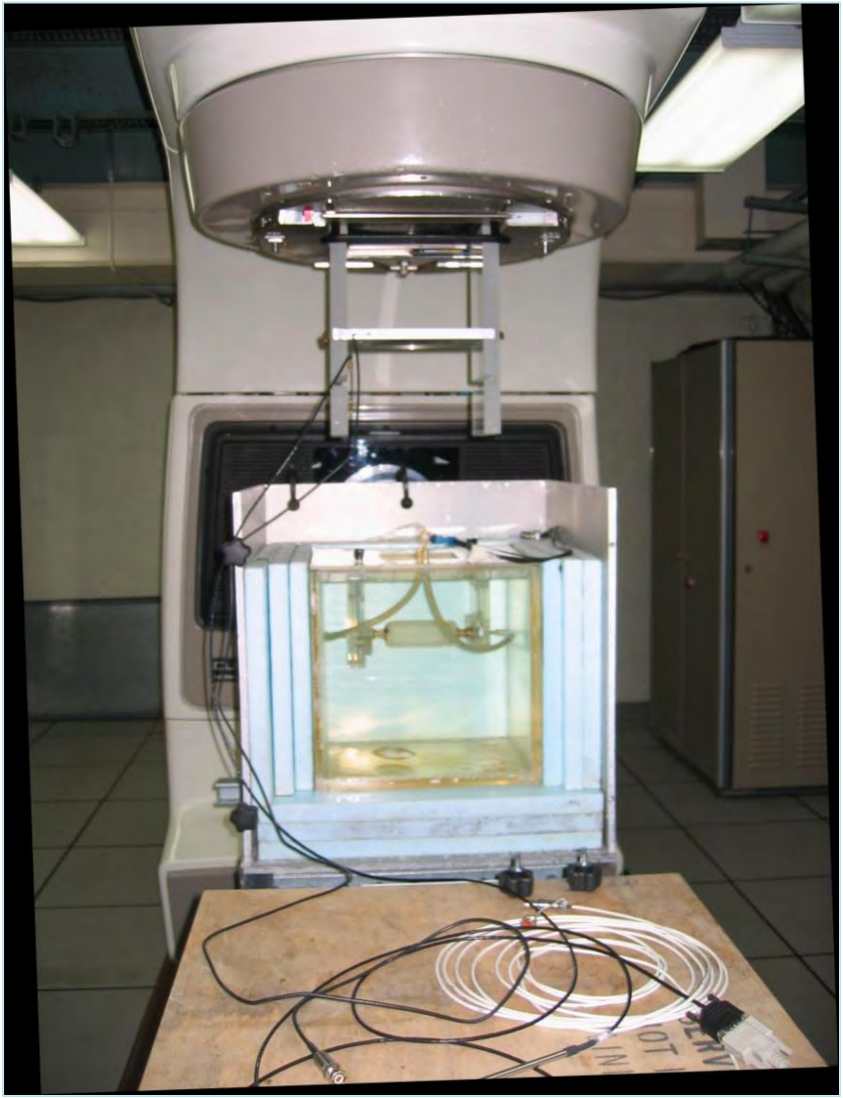


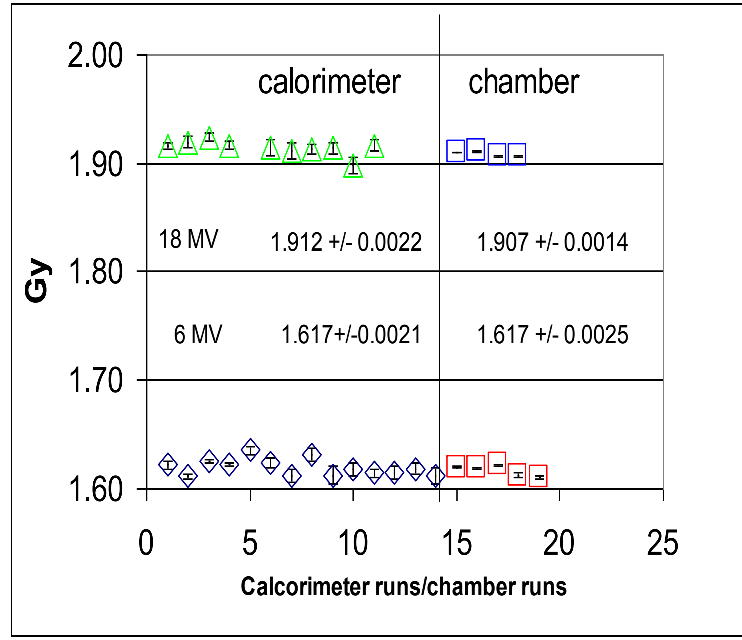


Vessel with thermistors

Vessel with an ion chamber

Application Note: chamber calibration





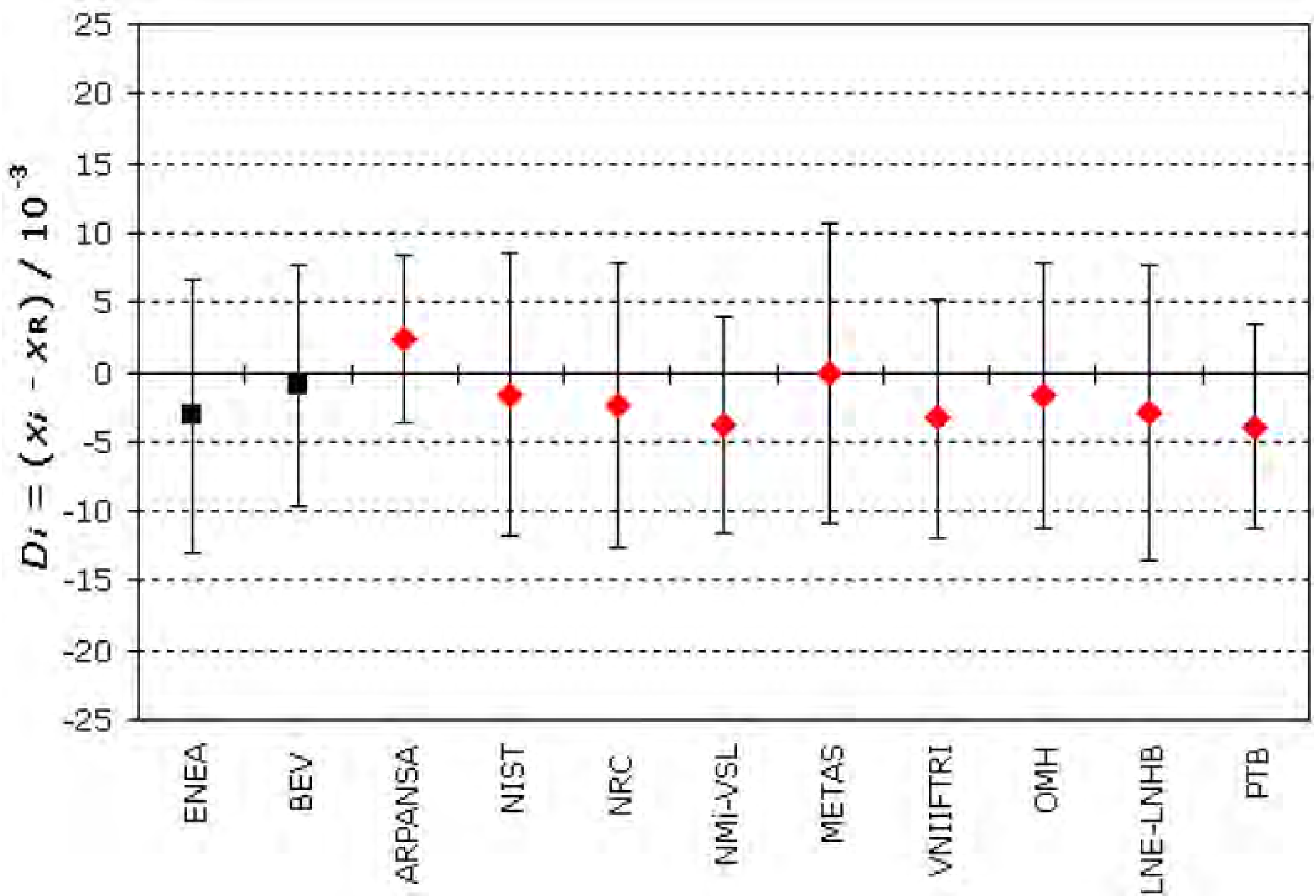
- NIST water calorimeter terminates calibration chain for QA protocols in clinics/hospitals.
- Calibration transferred to reference-quality standards used in secondary calibration labs.

The "Bureau International des Poids et Mesures" (BIPM)

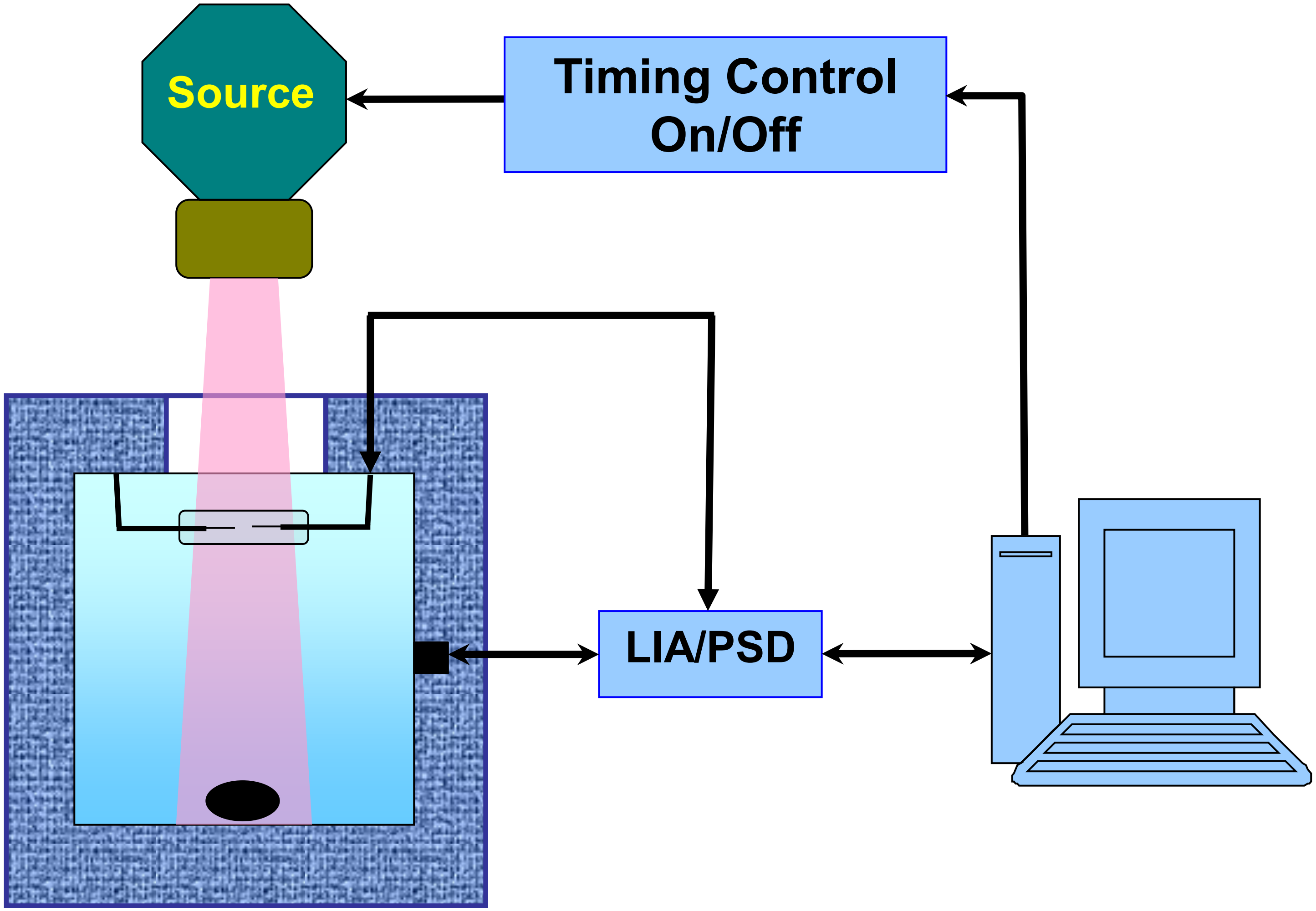
- BIPM = International laboratory created by the metre convention; has an Ionizing Radiation Division
- Role: "The task of the BIPM is to ensure world-wide uniformity of measurements and their traceability to the International System of Units (SI)."
- www.bipm.org

BIPM Intercomparison Program:

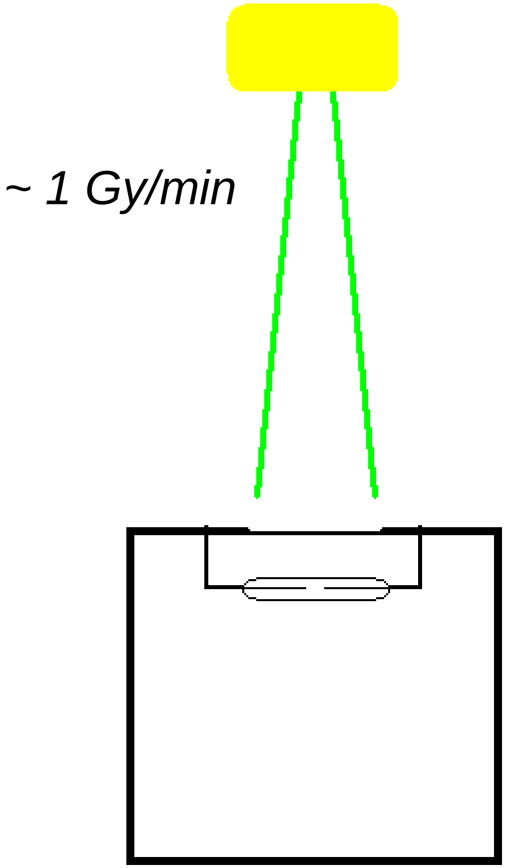
- Enables NMIs (like NIST) to declare calibration and measurement capabilities (CMCs)
- Key comparisons and database (http://kcdb.bipm.org)

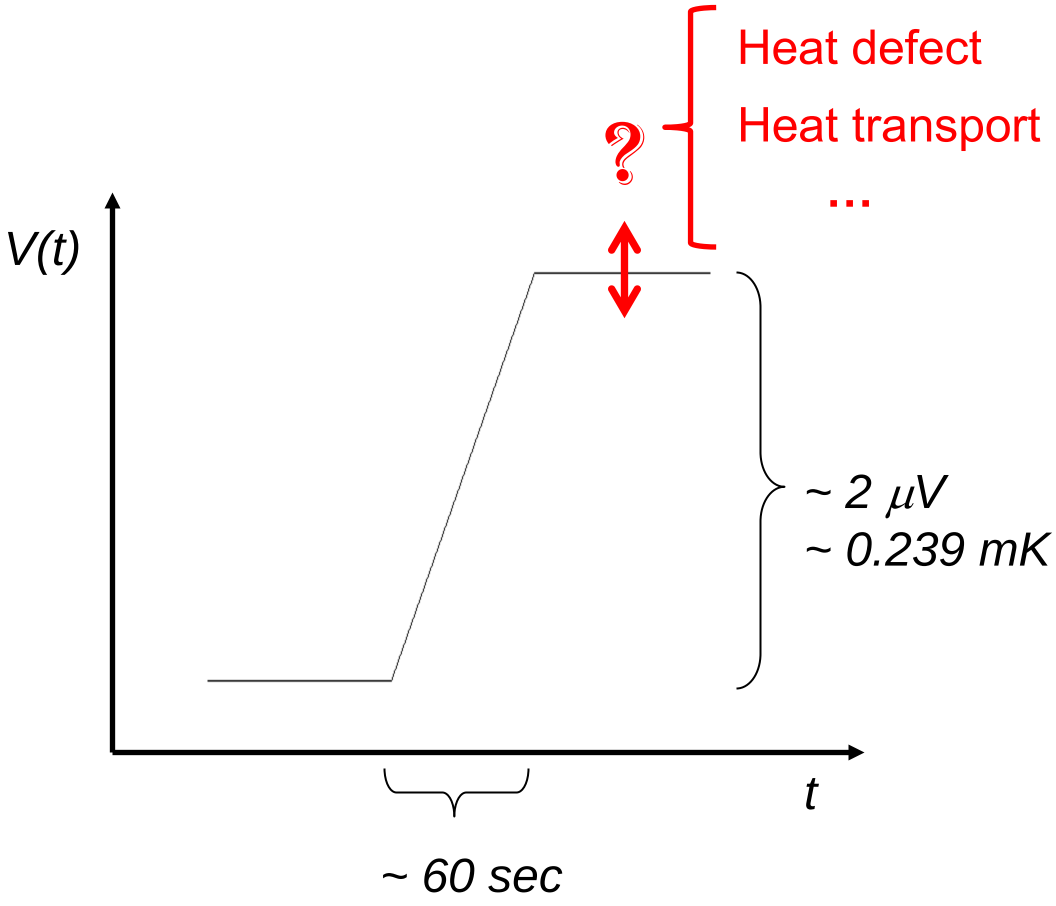


Water Calorimetry at NIST



Experimental corrections

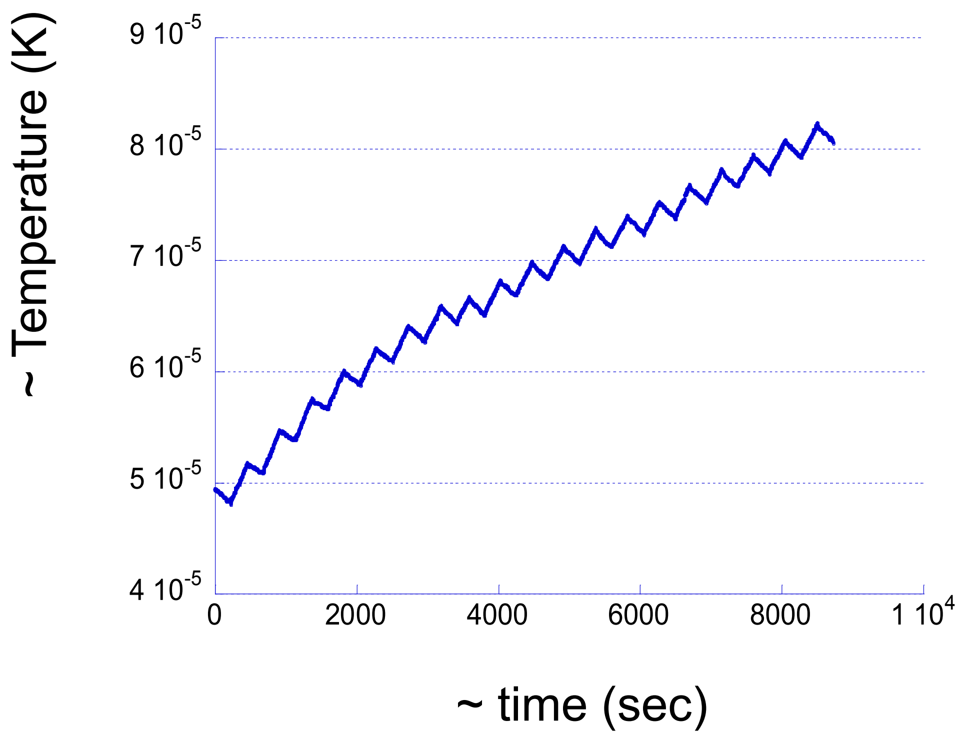


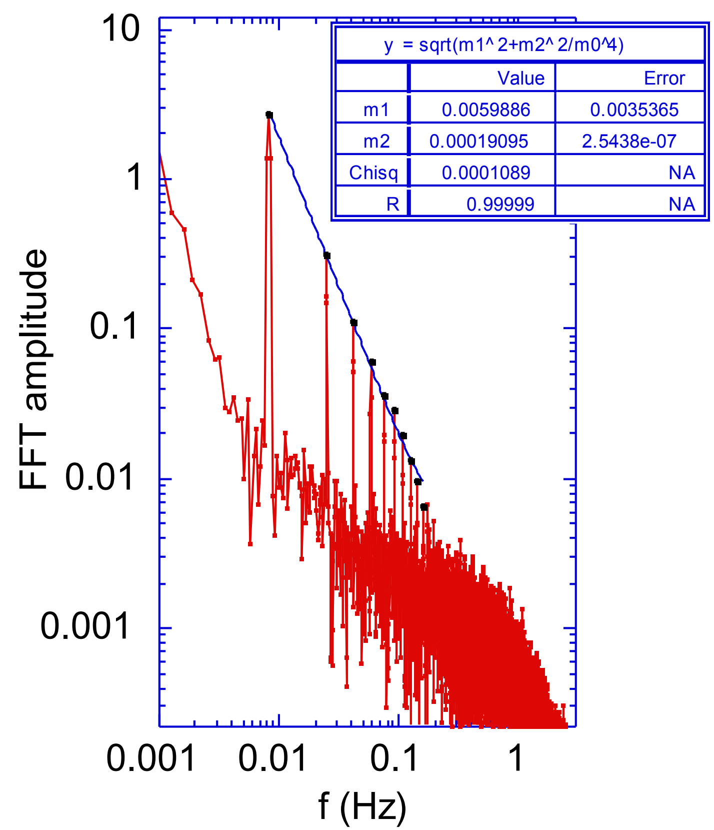


Heat Transport Corrections

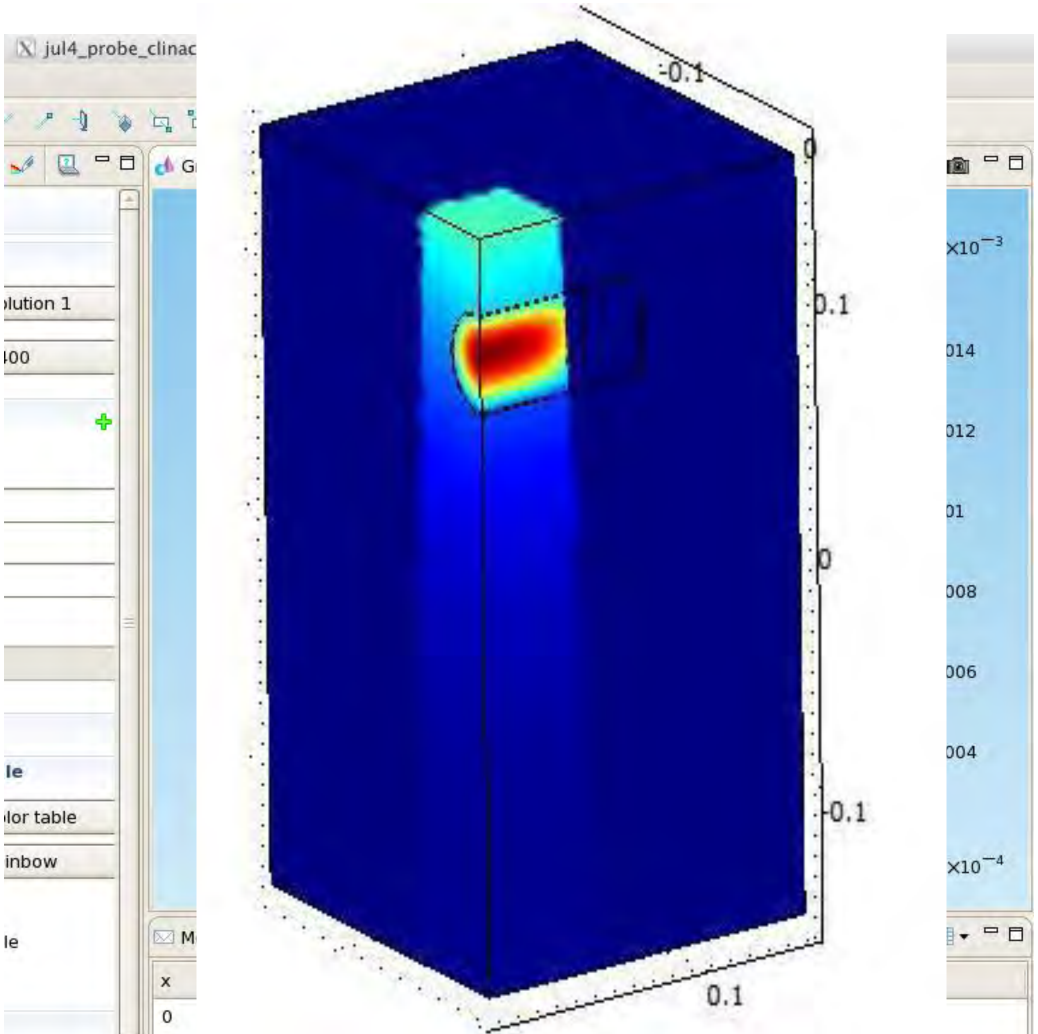
Questions regarding existing remedies:

- Would the system exhibit a stable, steady-state behavior?
  Interruptions to reestablish thermal equilibrium might not be necessary.
- If so, to what extent would convection contribute?
  Possibility to operate at room temperature instead of 3.98 ^oC.



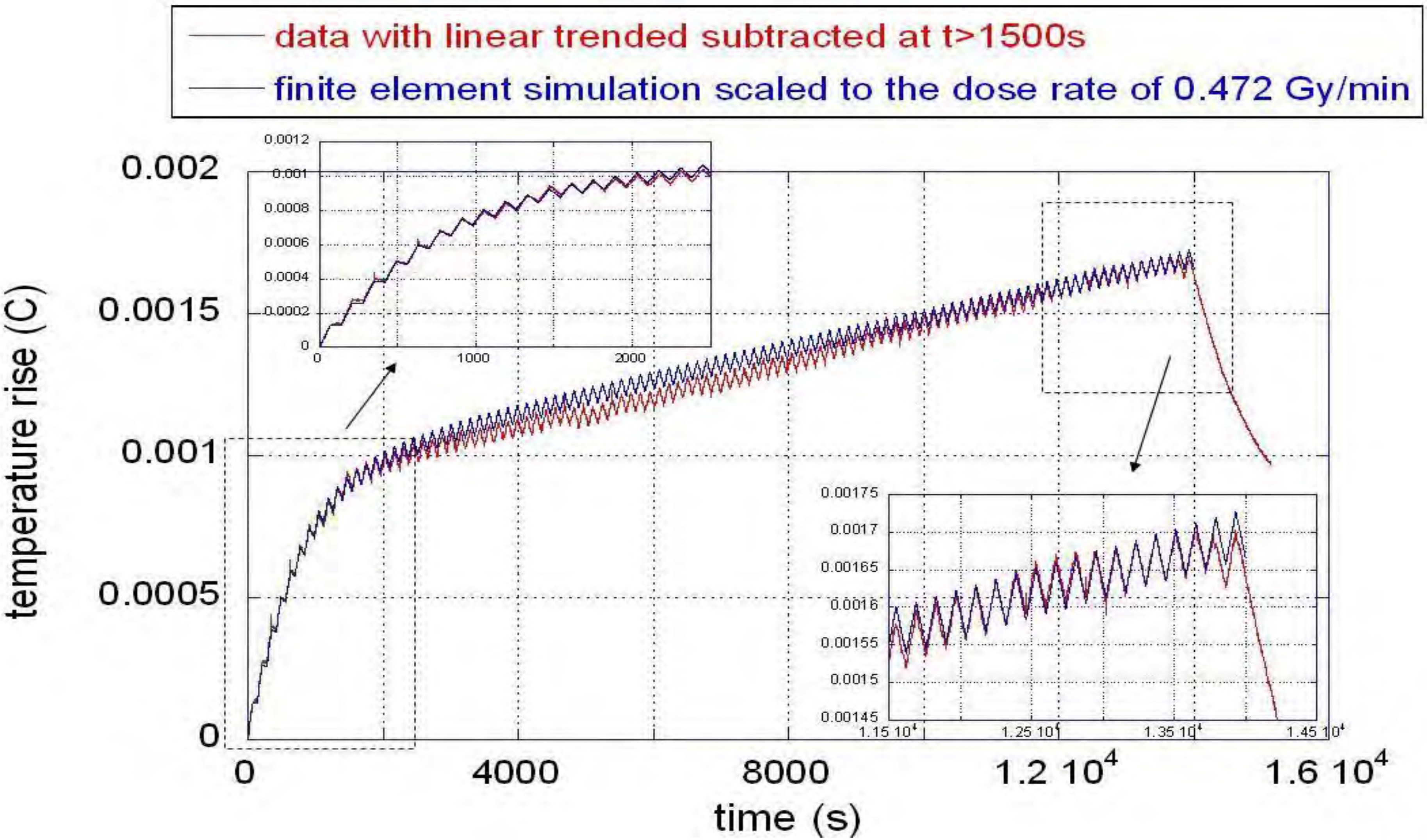


Heat Transport

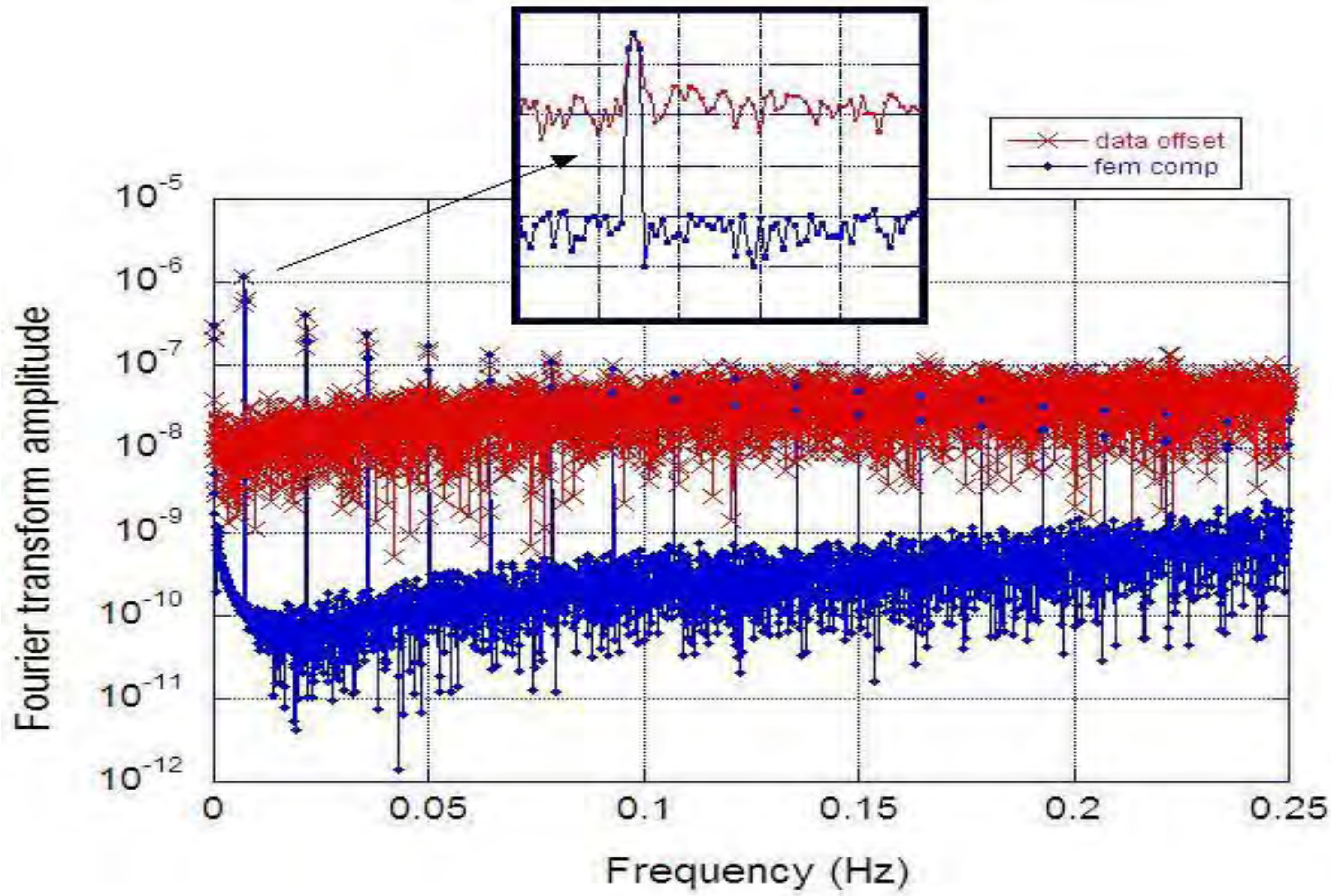


- **Beam:** distributed heat source with semi-empirical depth and transverse dose gradients.
- **Ext stirring:** simulated by elevated thermal conductivity in unstirred water.
- **Heat transport:** conduction only; no convection.

Response to chopped ^{60}Co beam -time domain

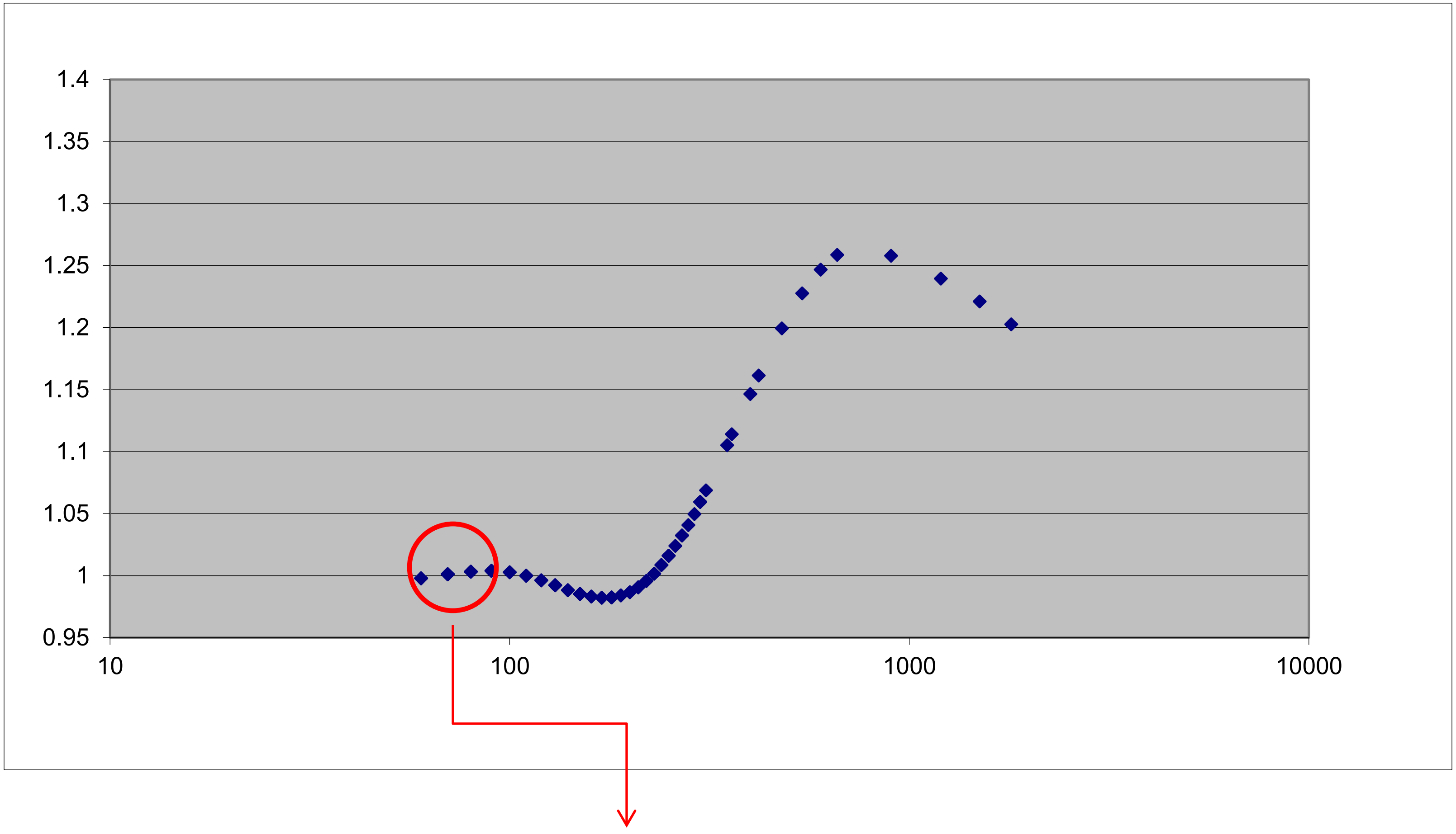


Response to chopped ^{60}Co beam -frequency domain



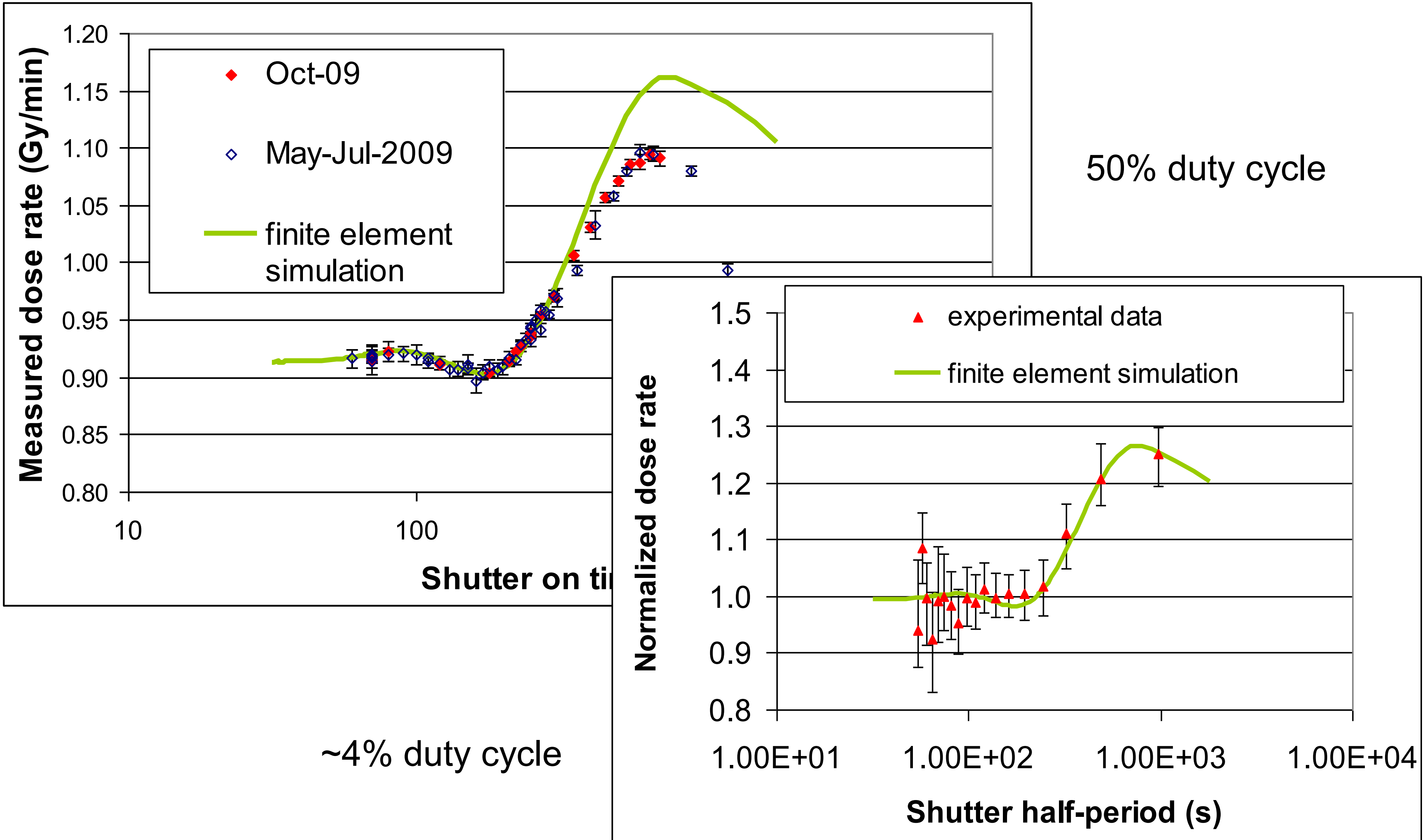
k_{ht} vs. shutter time (sec)

- derived from simulation



k_{ht} (70 sec) = 1.0009

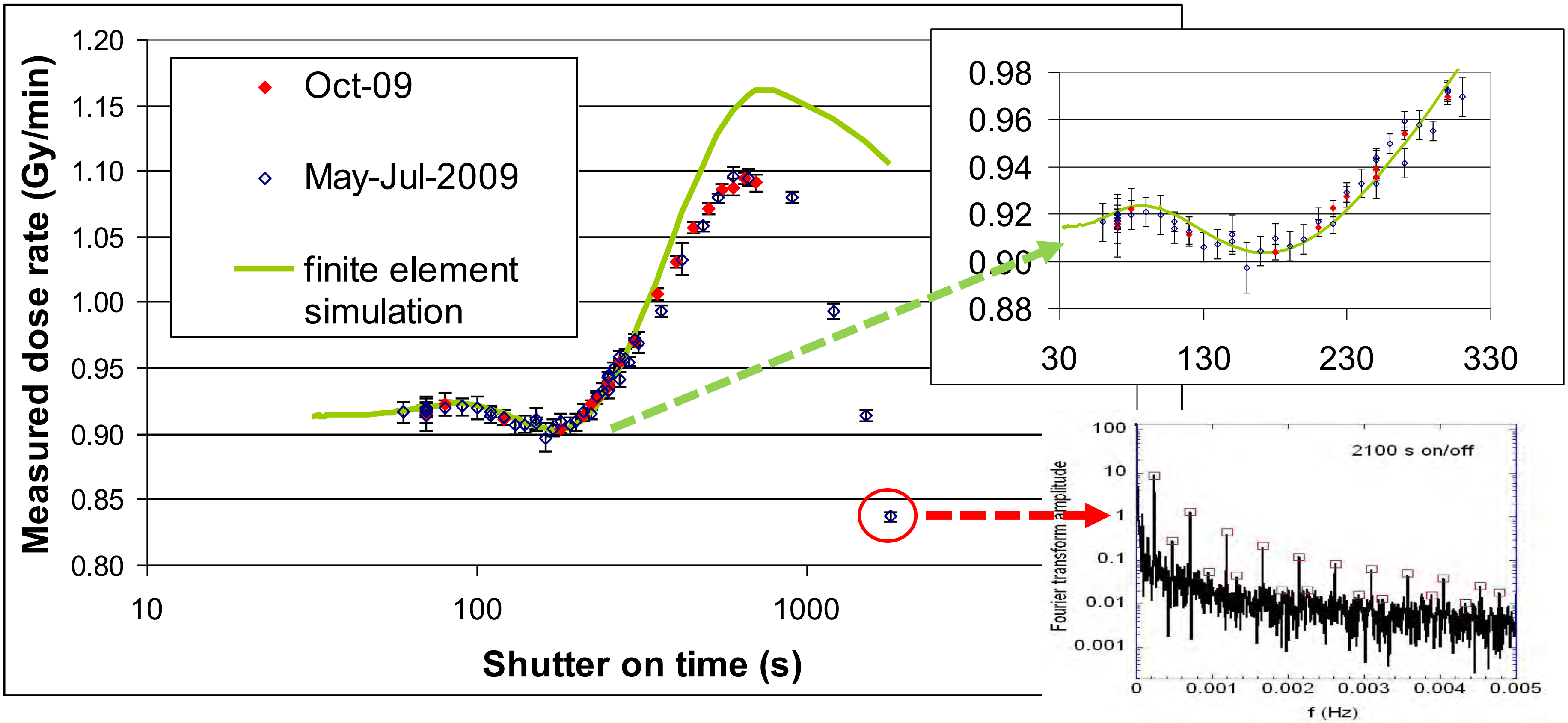
Conduction-like behavior obtained at low duty cycle (70s on, 1940 s off)



Heat Transport cont'd

Variation of "apparent" dose rate with shutter freq/period demonstrates agreement with heat equation (i.e. conduction only) *except* at higher shutter periods.

→ steady-state operation at room temperature appears feasible at shorter exposure periods.



Heat Defect

Table 1. Model IIIR: reactions and rate constants (4 °C)

	Reactions[a]			Rate constants[b]
1	$e^-_{aq} + e^-_{aq}$	$\rightarrow$	$H_2 + OH^- + OH^-$	3.48×10^9
2	$e^-_{aq} + H$	$\rightarrow$	$H_2 + OH^-$	1.73×10^{10}
3	$e^-_{aq} + OH$	$\rightarrow$	OH^-	2.38×10^{10}
4	$e^-_{aq} + H_2O_2$	$\rightarrow$	$OH^- + OH$	8.84×10^9
5	$e^-_{aq} + O_2$	$\rightarrow$	O_2^-	1.16×10^{10}
6	$e^-_{aq} + O_2^-$	$\rightarrow$	$HO_2^- + OH^-$	8.48×10^9
7	$e^-_{aq} + HO_2$	$\rightarrow$	HO_2^-	8.48×10^9
8	$H + H$	$\rightarrow$	H_2	3.44×10^9
9	$H + OH$	$\rightarrow$	H_2O	1.21×10^{10}
10	$H + H_2O_2$	$\rightarrow$	$OH + H_2O$	3.18×10^7
11	$H + O_2$	$\rightarrow$	HO_2	9.58×10^9
12	$H + HO_2$	$\rightarrow$	H_2O_2	7.24×10^9
13	$H + O_2^-$	$\rightarrow$	HO_2^-	7.24×10^9
14	$OH + OH$	$\rightarrow$	H_2O_2	3.76×10^9
15	$OH + H_2$	$\rightarrow$	$H + H_2O$	2.40×10^7
16	$OH + H_2O_2$	$\rightarrow$	$H_2O + H_2O$	1.79×10^7
17	$OH + HO_2$	$\rightarrow$	$H_2O + O_2$	9.08×10^9
18	$OH + O_2^-$	$\rightarrow$	$OH^- + O_2$	7.89×10^9
19	$HO_2 + HO_2$	$\rightarrow$	$H_2O_2 + O_2$	3.72×10^5
20	$HO_2 + O_2^-$	$\rightarrow$	$H_2O_2 + O_2 + OH^-$	5.84×10^7
21	H_2O	$\rightarrow$	$H^+ + OH^-$	2.22×10^{-6}
22	$H^+ + OH^-$	$\rightarrow$	H_2O	7.23×10^{10}
23	H_2O_2	$\rightarrow$	$H^+ + HO_2^-$	1.34×10^{-2}
24	$H^+ + HO_2^-$	$\rightarrow$	H_2O_2	3.13×10^{10}
25	$H_2O_2 + OH^-$	$\rightarrow$	$HO_2^- + H_2O$	7.56×10^9
26	$HO_2^- + H_2O$	$\rightarrow$	$H_2O_2 + OH^-$	5.45×10^5
27	H	$\rightarrow$	$e^-_{aq} + H^+$	8.83×10^{-1}
28	$e^-_{aq} + H^+$	$\rightarrow$	H	1.88×10^{10}
29	$e^-_{aq} + H_2O$	$\rightarrow$	$H + OH^-$	5.08×10^0
30	$H + OH^-$	$\rightarrow$	$e^-_{aq} + H_2O$	7.77×10^6
31	OH	$\rightarrow$	$H^+ + O^-$	1.34×10^{-2}
32	$H^+ + O^-$	$\rightarrow$	OH	3.13×10^{10}
33	$OH + OH^-$	$\rightarrow$	$O^- + H_2O$	7.56×10^9
34	$O^- + H_2O$	$\rightarrow$	$OH^- + OH$	5.45×10^5
35	HO_2	$\rightarrow$	$O_2^- + H^+$	4.21×10^5
36	$O_2^- + H^+$	$\rightarrow$	HO_2	3.13×10^{10}
37	$HO_2 + OH^-$	$\rightarrow$	$O_2^- + H_2O$	7.91×10^9
38	$O_2^- + H_2O$	$\rightarrow$	$HO_2 + OH^-$	1.94×10^{-2}
39	$O^- + H_2$	$\rightarrow$	$H + OH^-$	7.95×10^7
40	$O^- + H_2O_2$	$\rightarrow$	$O_2^- + H_2O$	3.44×10^8
41	$OH + HO_2^-$	$\rightarrow$	$OH^- + HO_2$	5.17×10^9
42	$OH + O^-$	$\rightarrow$	HO_2^-	6.02×10^9
43	$e^-_{aq} + HO_2^-$	$\rightarrow$	$O^- + OH^-$	2.19×10^9
44	$e^-_{aq} + O^-$	$\rightarrow$	$OH^- + OH^-$	1.82×10^{10}
45	$O^- + O_2$	$\rightarrow$	O_3^-	2.63×10^9
46	O_3^-	$\rightarrow$	$O_2 + O^-$	6.70×10^2
47	$O^- + HO_2^-$	$\rightarrow$	$O_2^- + OH^-$	2.84×10^8
48	$O^- + O_2^-$	$\rightarrow$	$OH^- + OH^- + O_2$	4.26×10^8
49	$HO_2 + H_2O_2$	$\rightarrow$	$OH + H_2O + O_2$	2.90×10^{-1}
50	$O_2^- + H_2O_2$	$\rightarrow$	$OH^- + OH + O_2$	9.30×10^{-2}

N.V. Klassen and Carl K. Ross, J. Res. Natl. Inst. Stand. Techol. **107**, 171-178 (2002).

Causes:

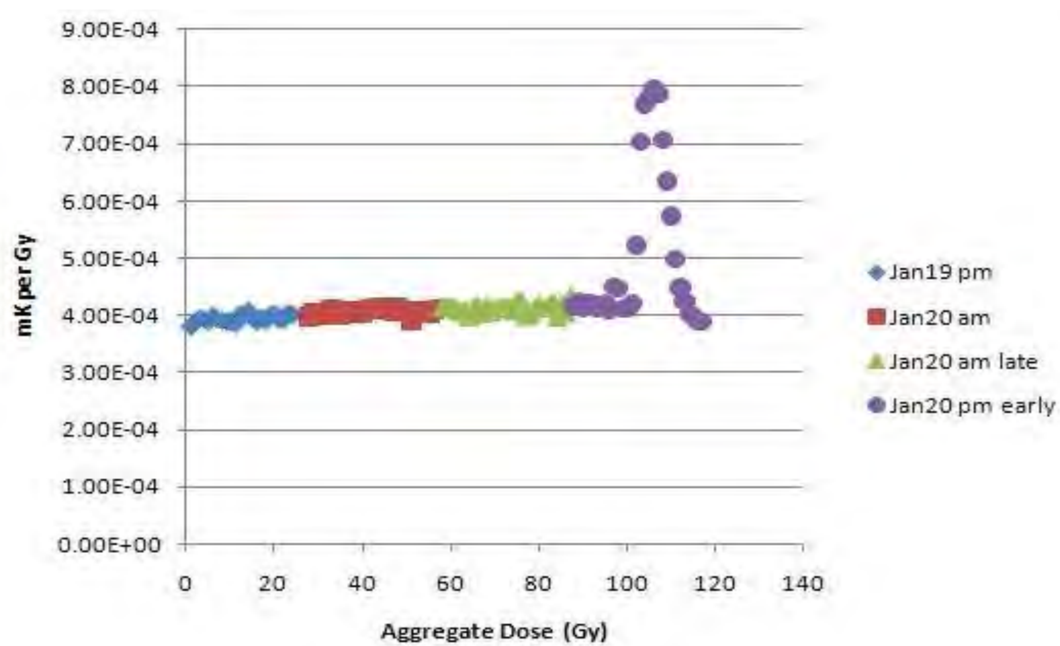
- Chemical reactions involving products of incident radiation and various dissolved species within the water

Effect on signals:

- Transient – can be huge (~100%).
- Steady state – depends on dissolved species (0 to few %).

Remedy:

- H_2 – saturated, high-purity water in a sealed glass vessel.



Summary

We convert from temperature rise to absorbed dose as follows:

$$D_w = \Delta T_w \cdot c_w \cdot k_{ht} \cdot k_p \cdot k_{dd} \cdot \frac{1}{1-k_{HD}}$$