Phase-sensitive Microcalorimetry for Study of Low-level Radioactive Sources

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Abstract

Microcalorimetry for standardizing activities of radionuclide samples entails measurements of input power heat flow from the sample cell with the radioactive sample present compared to the reference cell under balanced conditions (Fig. 1 A). A typical run is conducted over a few days, as recovery and stabilization of the instrument after transfer of the radioactive sample requires many hours, and yields measurements with precision of ~0.1% for sources outputting ~100 uW (taken as the product of activity and average decay energy, Fig. 1B). Because the measurement involves the DC response of the instrument, it is susceptible to noise due to drift and 1/f effects which can be discriminated by signal processing in the AC response; thus, a better result might be expected with periodic insertion of the source into the sample chamber and analysis using phase-sensitive methods. The present investigation assesses the prospects for such improvements to the sensitivity of a microcalorimeter that has already beenwas previously used for standardizing activity measurements of radionuclides [1]. Through appropriate choice of absorber, the performance benefits realized might also make the instrument suitable as an absorbed-dose standard for compact x-ray sources and brachytherapy seeds.

The heat source used to simulate the radioactive source heating is by using a function generator and high-precision resistors attached to the lid of the sample holder to provided a periodic, square-wave Joule-heating input with power of 400 nW (100 mV amplitude, 100 mV offset, 100K resistance). This level of heating is substantially below the typical 100 mW of radioactive samples measureable with this instrument, barely discernible above noise with the instrument in DC mode. Frequency of input power to the sample cell varied from 0.2 mHz to 1 mHz, and waveforms acquired over periods ranging from several hours to several days (Fig. 2A) were analyzed both for noise content and attenuation due to intrinsic, instrumental time constants. Fig. 2B summarizes the amplitude of the main signal peak as a function of the modulation period, showing the attenuation at the given frequency due to inefficient coupling of heating resistors to absorber material. This attenuation is stronger for a larger absorber mass. Fig. 2C is a time domain waveform of the 300 nW power stimulation riding on the large thermal drift. Fig. 2D shows a spectrum obtained by FFT of example waveforms acquired from the instrument over 1.3 (black) and 2.7 (red) days. A further reduction of the noise floor at frequencies above 10 mHz suggests that pW-level sensitivity is achievable if attenuation due to instrumental time constants can be overcome.

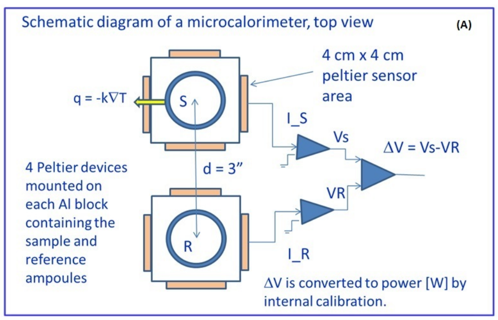
Preliminary modeling of the system was carried out in a simplified 2D model to assess the

system time and frequency domain response to the heat source (Fig. 3). Linear response was obtained which represents an ideal system. The goal is to recreate a system to simulate the experiment and obtain the transfer function from measurement. A 3D model has also been created to further the investigation. Simulations are under way.

Reference

[1] R. Colle, Classical Radionuclidic Calorimetry, Metrologia 44 (2007) S118–S126.

Figures used in the abstract



Estimated heat power per unit activity (μW·GBq-1)

^{3}H / ^{55}Fe	^{103}Pd / ^{125}I	^{32}P	^{90}Sr-^{90}Y	^{226}Ra	
0.9	9	111	181	4338	(B)

Figure 1: (A) Schematic diagram of a isothermal microcalorimeter. (B) Heat power generated by selected radionuclides.

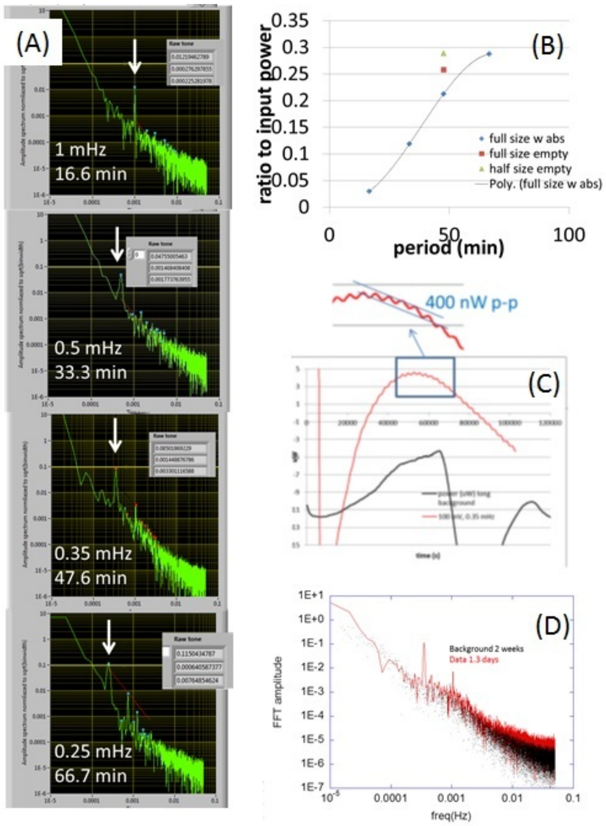


Figure 2: 2A. Frequency response to heat power cycled at 0.25 mHz to 1 mHz; the main signal peak can be seen shifted according to the input modulation frequency. 2B. The amplitude of the signal peak as a function of the modulation period (inverse frequency), effectively a transfer function for the system. 2C. Time domain waveform of the 300 nW power stimulation riding on the large thermal drift. 2D. Frequency spectrum showing the signal peak clearly above the noise background.

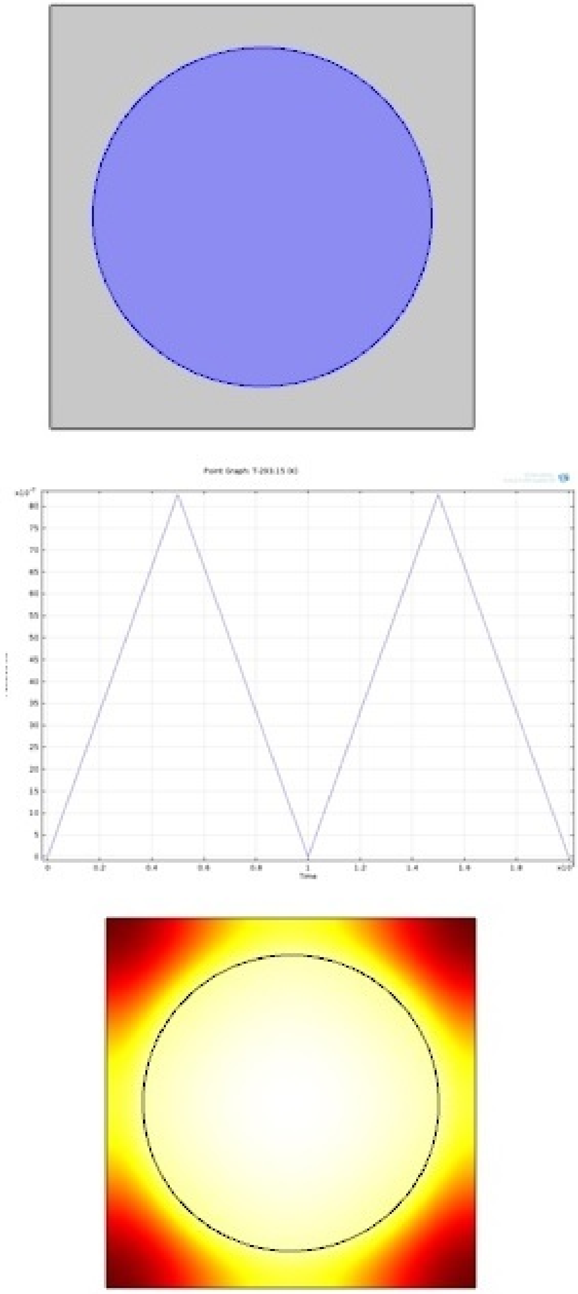


Figure 3: 1 uW heat source distributed uniformly throughout graphite sample volume housed in aluminum block, turned on/off at 5e+04 seconds – to test linearity of time-domain response over many hours of operation. Linearity of time-domain response suggests that the thermal transfer function of the system is flat over wide frequency range, which would indicate very slow roll off of attenuation with frequency.