A SIMPLE LOW-COST PHOTODIODE RADIATION DETECTOR FOR MONITORING IN PROCESS PET RADIOCHEMISTRY

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Introduction

We have found that placing radiation detectors throughout our radiochemistry synthesis rigs is advantageous for determining the progress of radioisotopes through the system, delineating thresholds and triggering steps in a sequence, monitoring radiochromatographic separations, providing process feedback and adjustment, and determining maintenance needs, in addition to troubleshooting. In our carbon-11 synthesis module we monitor no less than 10% of the activity produced. This is amplified and converted into an output signal of about 8 µA. Maximum signal of 20 mA is thus reached for about 2 Ci (74 GBq) at this distance.

Noise Analysis: By observing the decay of a sample of carbon-11 over time, it was possible to measure the noise level as a function of detector signal. The Signal-to-Noise Ratio (SNR) was found to be proportional to the square root of the signal, consistent with the main noise source being due to the statistics of the interacting gamma rays. The measured SNR/√(Signal) was about 16 pA/µA⁻¹/₂. For 1 pA this is the level of noise that would be produced by a rate of interacting photons of 16=256 over the integration time of the detector (which is effectively 1 second). This indicates that the average photon interacting with the detector produces 1 pA/256 = 0.004 pA as 24k electron-hole pairs. In silicon each electron-hole pair requires 3.64 eV of energy, indicating an energy deposition of about 90 keV. Using the 0.004 pA per gamma estimate from above, and the measured detector signal for a known source and distance, it is possible to estimate the fraction of each 511 keV gamma ray that interacts in the active volume of the detector. This is about 1.1%.

Electronic noise is at an output level of 0.25 µA (0.1 pA in the detector) and thus is dominated by the statistical photon noise described above.

Temperature Effects: We observed fluctuations in the “zero” baseline over periods of tens of minutes. When the temperature was held constant at 20.5±1°C, these fluctuations were less than 1 µA, but temperature variations from 25 to 45°C produced shifts of from 5-50 µA depending on the source and distance. When the temperature was held constant at 25°C, the shifts were less than 10%. If the detectors can be temperature controlled, the sensitivity could be increased by this factor. When the temperature was held constant at 20.5±1°C, these fluctuations were less than 1 µA, but temperature variations from 25 to 45°C produced shifts of from 5-50 µA depending on the source and distance. When the temperature was held constant at 25°C, the shifts were less than 10%. If the detectors can be temperature controlled, the sensitivity could be increased by this factor.

Sensitivity: The measurement sensitivity of the detectors depends on their use. We define sensitivity as the level at which measurement uncertainty is 10%. If the detectors can be “zeroed” (i.e. have their baseline readings measured at zero radioactivity) near the time of the measurement, so that baseline fluctuations are minimal, then sensitivity of better than 1 mCi at 45 mm can be achieved. Overa longer period between zeroing and the measurement, with typical temperature variations in a hotcell, sensitivity might be more like 5 mCi at 45 mm. And near sources of significant temperature variation (heaters or liquid nitrogen) the sensitivity could be 10 mCi at 45 mm or worse.

Results

Our compact, low-noise, design is based on off-the-self amplifier and two-wire 4-20 mA transmitter chips and can easily be connected to standard analog input electronics with only a single twisted pair of wires. The photodiode and all electronics fit into a small epoxy-sealed package shaped as a 12.5 mm x 40 mm cylinder that is 40 mm long, allowing the detector to be placed within a few centimeters of the radiation source.

Conclusion, References, & Acknowledgements

The radiation detectors described herein are low-cost, easy to construct, and reliable. We are able to incorporate a large number into our radioisynthetic processes due to these favorable properties.