Calibration and Operational Data for a Compact Photodiode Detector Useful for Monitoring the Location of Moving Sources of Positron Emitting Radioisotopes

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Abstract. D-Pace has developed a compact cost-effective gamma detector system based on technology licensed from TRIUMF [1]. These photodiode detectors are convenient for detecting the presence of positron emitting radioisotopes, particularly for the case of transport of radioisotopes from a PET cyclotron to hotlab, or from one location to another in an automated radiochemistry processing unit. This paper describes recent calibration experiments undertaken at the Turku PET Centre for stationary and moving sources of F18 and C11 in standard setups. The practical diagnostic utility of using several of these devices to track the transport of radioisotopes from the cyclotron to hotlab is illustrated. For example, such a detector system provides: a semi-quantitative indication of total activity, speed of transport, location of any activity lost en route and effectiveness of follow-up system flushes, a means of identifying bolus break-up, feedback useful for deciding when to change out tubing.

Keywords: Radiation, Photodiode, detector, positron, emission, F18, C11, gamma.

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INTRODUCTION

D-Pace requires its TRIUMF licensed radiation detectors to be calibrated for both stationary and moving sources of radiation so that its customers can effectively use these devices in their own laboratory setups. This paper looks at

^{18}F and ^{11}C sources in both stationary and moving calibrated setups as well as one practical example of usage at the Turku PET Centre.

STATIONARY SOURCE CALIBRATION

This calibration test was performed with 51 GBq of ^{18}F, which decays by positron emission resulting in two gamma rays of 511 keV through annihilation. The setup of the 5 detectors around a *Sep-Pak Accell Plus QMA Carbonate Light Cartridge* containing ^{18}F is shown in Figure 1. Two of the detectors had previous neutron exposure, which caused increased offset voltage and reduced signal response, so those readings will not be evaluated. The ^{18}F source within the cartridge filter is centered on the detectors and can be considered as a disk with diameter 5.0 ± 0.3 mm and height 3 ± 1 mm.

The same test was also performed with 41.1 GBq of ^{11}C in the same setup, this time with five new and undamaged detectors around a *SEP-PAK Light C18 Cartridge* filter and holder.

Figure 2 shows the signal from the detectors in our setup corresponding to the decay of both ^{11}C and ^{18}F.

According to Figure 2, both the ^{11}C and ^{18}F detector output voltage is saturated at 9.9 V. For the dimensions of this setup with positron emitting radioisotopes, the maximum activity for which the detectors give a non-saturated response is just under 19 GBq.

The performance of each of the TRIUMF detectors is quite consistent, as shown by the relatively small standard errors on the average activity corresponding to each signal level in Table 1.

MOVING SOURCE CALIBRATION

For this calibration four detectors were taped directly to the PEEK tubing along the transfer line from target to hotcell at the Turku PET centre, as seen in Figure 3. The tubing has an inner diameter of 1 mm and wall thickness of 0.59 mm. 2 mL of water containing 12 GBq of ^{18}F was run through the line, followed by a flush of 2 mL of water 1 minute later. The radioactive liquid moves through the line as a well-defined bolus, with length 2.25 m.

Figure 4 and Table 2 show the voltage response from each of the detectors as the bolus passes. There is an initial offset voltage on some of the detectors, so Table 2 also takes these into consideration for comparison of the detectors.

It has been noticed that the voltage response of the detectors is proportional to the radioactivity per unit volume. This can be used to estimate the activity as a function of signal voltage and volume. For liquid transport of a positron emitting radioisotope, the equation below can be used to determine activity, in GBq, using volume, in mL, and yields signal voltage in volts, in our setup:

$$Activity = (13.7)\ Signal\ Voltage * Volume \quad (1)$$

TRANSPORT CYCLOTRON TO HOTLAB: A REAL-WORLD EXAMPLE

For this test, five TRIUMF licensed radiation detectors were placed at certain points along the transfer line between the cyclotron and the hotlab, marked in Figure 5. A 2 mL bolus of ^{18}F radioactive liquid with activity 19.2 GBq was pushed through the tubing, which had an inner diameter of 1.0 mm, past all the detectors. The system was flushed twice, with another 1 mL of liquid each time, to pick up any of the radioisotope product that was left in the tubing, first approximately 2 minutes after the initial push and again 1 minute later. Figure 6 shows the detectors' voltage response for the initial run and the two flushes.

The offset voltage that can be seen in Figure 6, that sets each detector's voltage response to a different initial level, was artificially added to the program to make the voltage response of the detectors easier to read. All of the voltage response values used for calculations and analysis have the offset removed, so these artificial offsets do not affect the results.

The strength of the signal varies greatly between the detectors, as it depends on their proximity to the PEEK transfer tube and the rate which the bolus passes by the detector. In an actual PET lab it is not always possible to place a detector directly against the tubing.

For this specific setup an equation can be determined for each detector to estimate activity as a function of signal voltage and volume of initial ^{18}F bolus. For example, for detector 2 the following equation can be used to estimate activity, in GBq, for the case of signal voltage in V and volume in mL:

$$Activity = (50.5)\ Signal\ Voltage * Volume. \quad (2)$$

Notice the peak on detector 4 is wider than the others. This is caused by the extra time that the bolus is at this location while the pump builds up pressure to lift the water 3 m vertically upwards.

Bolus breakup did not occur in this test, but, in the event that it does occur, it would be observed as two or more voltage response peaks at a detector for a single push, indicating that the activity is not passing as a single, well defined bolus.

The time between the first and second detectors is 51 seconds. An increase in this time, with all other conditions the same, to about 75 seconds for example, could be used as an indication of dirty or deteriorating tubing and would be a useful flag denoting when tubing should be replaced. Another useful indicator is when the voltage response signal does not return to the initial offset level after the first bolus passes the detector. This is an indication of residual activity being left in the lines and illustrates tubing areas where transport problems are occurring. This is useful to technical staff who can act to rectify the problem.

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REFERENCES

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TABLE 1. Activity of ^{18}F and ^{11}C corresponding to voltage response of the detector at 10.78 mm from the source.

Signal [V]	Activity of ^{18}F [GBq]	Activity of ^{11}C [GBq]
9.9	18.6 ± 0.2	18.7 ± 0.5
8	14.2 ± 0.2	14.7 ± 0.4
6	10.6 ± 0.1	11.0 ± 0.3
4	7.0 ± 0.1	7.4 ± 0.2
2	3.5 ± 0.1	3.7 ± 0.1

TABLE 2. Offset voltage, maximum signal and average change in voltage response of 4 TRIUMF licensed radiation detectors in our setup.

	Initial Offset [V]	Maximum Signal [V]	Signal response (ΔV) [V]
Detector 1	-0.003	0.437	0.439
Detector 2	0.002	0.387	0.385
Detector 3	0.017	0.516	0.498
Detector 4	0.040	0.492	0.451
Average	—	—	0.44
Std. Dev.	—	—	0.04
Std. Error	—	—	0.02

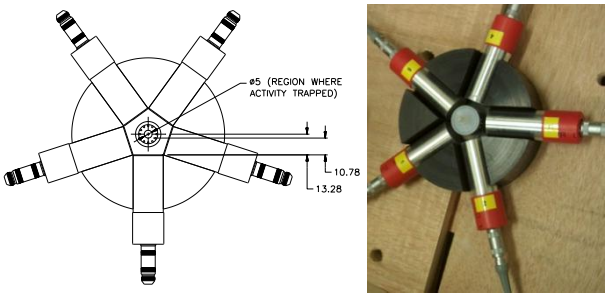

FIGURE 1. Setup of five TRIUMF licensed radiation detectors around radioisotope source. Dimensions in millimeters. Each detector is approximately 57.5 mm long by 19 mm. The detectors are 10.78 mm from the source disk, which is diameter 5.0 ± 0.3 mm by 3 ± 1 mm in height.

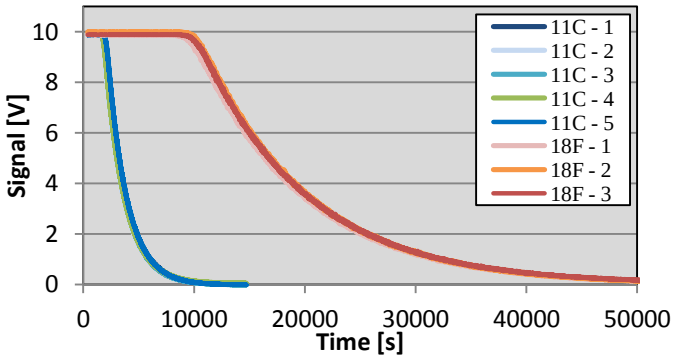

FIGURE 2. Voltage response of the radiation detector as a function of time for the decay of 41 GBq (1.1 Ci) of ^{11}C and 51 GBq (1.4 Ci) of ^{18}F, in our setup.

FIGURE 3. Standard setup of four radiation detectors with PEEK tubing attached directly to ends for calibration active liquid transport measurement.

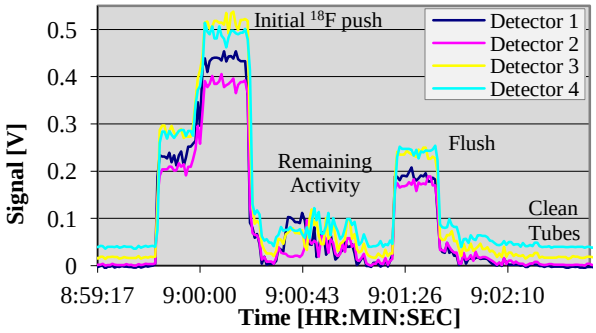

FIGURE 4. 2 mL of 12 GBq (0.32 Ci) ^{18}F radioactive liquid transport with a 2 mL flush, in our setup.

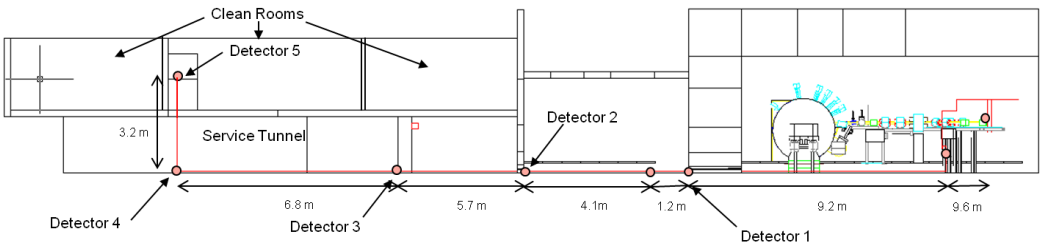

FIGURE 5. Positioning of 5 TRIUMF licensed radiation detectors along transfer line from target to hotcell. All detectors are outside the cyclotron vault.

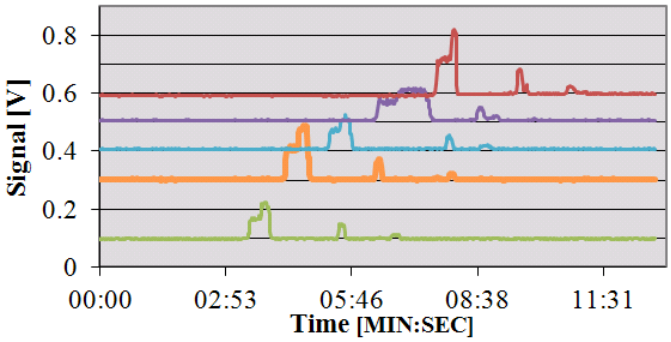

FIGURE 6. Voltage response of 5 TRIUMF licensed detectors, along transfer line from cyclotron, to 19.2 GBq (0.51 Ci) of ^{18}F liquid transfer. Detectors in numerical order from lowest to highest.