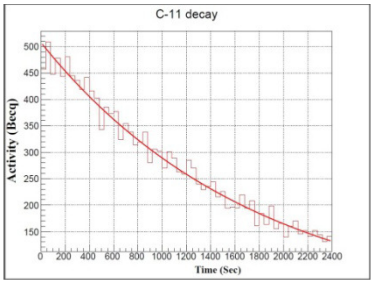
Low Activity Studies of ^{11}C Activation Via GATE Monte Carlo - 4/28/15

Purpose: To investigate the behavior of a Monte Carlo simulation code with low levels of activity (~1,000Bq). Patients prescribed a positron emission tomographic (PET) scan are typically injected with ~20miCi (741 MBq) of flourodeoxyglucose (FDG). Since the detection efficiency of most PET systems may be on the order of ~0.5%, perhaps ~1,000,000 events are typically used in a diagnostic image set[i]. The number of events available from therapeutic proton beam activation may be three orders of magnitude less than this. It is therefore necessary to examine how a low number of events are handled in PET image reconstruction.

Method and Materials: Three different ranges for a therapeutic proton radiation beam were examined in a Monte Carlo simulation code: 13.5, 17.0 and 21.0cm. For each range, the decay of an equivalent length ^{11}C source and additional sources of length plus or minus one cm was studied in a benchmark PET simulation for activities of 1000, 2000 and 3000Bq. The ranges were chosen to coincide with a previous activation study[ii], and the activities were chosen to coincide with the approximate level of isotope creation expected in a phantom or patient irradiated by a therapeutic proton beam.
The GATE 7.0[iii] simulation was completed on a cluster node, running Scientific Linux Carbon 6 (Red Hat©). The resulting Monte Carlo data were investigated with the ROOT analysis tool[iv]. The half-life of ^{11}C was extracted via a histogram fit to the number of PET events vs. time. Figure 1 shows a ROOT screenshot of the ^{11}C decay histogram fit. Figure 2 shows a plot of the ^{11}C half-life deviation vs. initial activity for the 12.5, 13.5 and 14.5cm sources.

Results: The average slope of the deviation of the extracted carbon half life from the expected/nominal value vs. activity showed a generally positive value. This was unexpected, as the deviation should, in principal, decrease with increased activity and lower statistical uncertainty. Table 1 shows the values of the slopes for different lengths of the ^{11}C source.

Conclusion: For activity levels on the order of 1,000Bq, the behavior of a benchmark PET test was somewhat unexpected. It is important to be aware of the limitations of low activity PET image reconstruction and low activity Monte Carlo simulations.



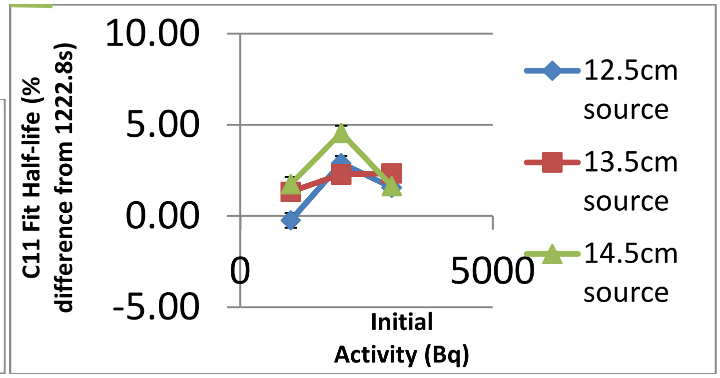


Figure 1: ^{11}C decay histogram. Figure 2: % deviation of ^{11}C ½ life vs. Initial Activity

Table 1: Source Length vs. Slope

Length (cm)	**Slope (%diff./Bq)**	**Length (cm)**	**Slope (%diff./Bq)**
12.5	9.0×10^{-4}	18.0	1.6×10^{-3}
13.5	5.0×10^{-4}	20.0	1.1×10^{-3}
14.5	-5.0×10^{-5}	21.0	-1.0×10^{-4}
16.0	7.0×10^{-4}	22.0	-5.0×10^{-4}
17.0	1.2×10^{-3}		

[i] **Fundamental Limits of Spatial Resolution in PET,** W. Moses, Nucl Instrum Methods Phys Res A. 2011 August 21; 648 Supplement 1: S236–S240.
[ii] Distal Edge Activity Fall Off Of Proton Therapy Beams, A Elmekawy, C Butuceanu, L Zhu and L Ewell, Med. Phys. **41**, 166 (2014).

[iii] See http://www.opengatecollaboration.org/
[iv] See https://root.cern.ch/drupal/