PET quantification of non-pure positron emitting radioisotopes: $^{90}$Y case study

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Introduction

- Most clinical settings do not have methods for validating the activity of Yttrium-90
- $^{90}$Y is commonly labeled to microspheres for selective internal radiation therapy (SIRT)
- $^{90}$Y exhibits a small internal pair production branching ratio of $31.86\pm0.47 \times 10^{-6}$ (Selwyn et al, 2007)
- This project investigated whether a PET scanner could be calibrated for accurate assay validation
Coincidence Spectrum of $^{90}$Y

- Spectrum was obtained using coincident NaI-HPGe detectors (Nickles et al, 2004)
Methods

- PET scans performed on a GE Discovery LS CT/PET scanner
- Each $^{90}\text{Y}$ sample vial was assayed using a single HPGe detector
- Each vial was then placed in a plastic sleeve to absorb emitted electrons & positrons
- Sinogram data was collected with and without each reconstruction correction
- 2D and 3D scans were compared
# Sinogram Correction Detail

<table>
<thead>
<tr>
<th>Sinogram Correction</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random</td>
<td>Corrects for random coincidences detected within the coincidence resolving time</td>
</tr>
<tr>
<td>Well</td>
<td>Corrects for axial sensitivity variation within the field of view</td>
</tr>
<tr>
<td>Geometric</td>
<td>Corrects for sensitivity variation caused by gaps in the detector configuration</td>
</tr>
<tr>
<td>Decay</td>
<td>Corrects for isotope decay during the scan</td>
</tr>
<tr>
<td>Dead time</td>
<td>Corrects for electronic dead time losses</td>
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<tr>
<td>Normalization</td>
<td>Corrects for variations in detector pair gains</td>
</tr>
<tr>
<td>Attenuation &amp; Scatter</td>
<td>Corrects for sensitivity variation caused by photon attenuation and scatter within the scan object</td>
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</tbody>
</table>
2D vs 3D Acquisition
Sensitivity Linearity Results

- Twelve 2D PET scans were taken over a period of several months.
- Poisson 2σ uncertainty associated with the uncorrected sinogram count rate was less than 0.9% for each measurement.
## Sinogram Correction Results

<table>
<thead>
<tr>
<th>Type of Sinogram</th>
<th>Sensitivity (2σ uncert.)</th>
<th>Adjusted R-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrected</td>
<td>4.000 cps/mCi ± 1.754%</td>
<td>99.91%</td>
</tr>
<tr>
<td>Random Corrected</td>
<td>4.003 cps/mCi ± 1.756%</td>
<td>99.91%</td>
</tr>
<tr>
<td>Well Corrected</td>
<td>3.510 cps/mCi ± 1.174%</td>
<td>99.96%</td>
</tr>
<tr>
<td>Geometric Corrected</td>
<td>4.440 cps/mCi ± 1.700%</td>
<td>99.91%</td>
</tr>
<tr>
<td>Decay Corrected</td>
<td>4.006 cps/mCi ± 1.752%</td>
<td>99.91%</td>
</tr>
<tr>
<td>Dead time Corrected</td>
<td>4.137 cps/mCi ± 2.448%</td>
<td>99.82%</td>
</tr>
<tr>
<td>Normalization Corrected</td>
<td>3.826 cps/mCi ± 1.604%</td>
<td>99.92%</td>
</tr>
<tr>
<td>All Corrections Applied</td>
<td>8.227 cps/mCi ± 1.012%</td>
<td>99.97%</td>
</tr>
</tbody>
</table>
Discussion

- All sinogram count rates correlated strongly with $^{90}$Y activity ($R^2 > 98\%, P < 0.001$)
- Random and decay corrections do not significantly change the observed sensitivity ($P = 0.821$ and $P = 0.682$)
- Well and normalization corrections improve correlation ($P < 0.001$)
- Dead time correction degrades the sensitivity correlation ($P < 0.001$), suggesting that the dead time model may be inadequate
- The two highest count rates contain more than 75% of the total absolute residual when the dead time correction is applied
Discussion

- The count rate for the 2D scan was higher than the 3D scan for $^{90}$Y activities greater than 100 mCi ($P < 0.001$)
- The increased sensitivity of the 3D modality is offset by the increased number of third-gamma coincidences associated with the bremsstrahlung spectrum from the dominant beta-minus decay of $^{90}$Y
- This comparison is consistent with the results of other research on 2D and 3D PET modalities (Schueller, 2003; Lubberink, 1999)
Conclusions

- The provided PET scanner responds well under conditions of high photon background with a sensitivity 2σ uncertainty of 1.75%
- Most of the built in sinogram corrections of the GE Discovery LS improve performance, reducing the uncertainty to 1.01%
- Adequate results can be obtained in several minutes
- PET is a quick and accurate method for assay validation can be created for $^{90}$Y and used to perform quality assurance on SIRT treatments
Monte Carlo model was developed to simulate the PET scanner response using MCNP5 ($9 \times 10^7$ source decays)

1. Read in parameters, initialize storage arrays
2. Import and combine MCNP5 data
3. Advance time to next source emission
4. Combine electron collisions into event pulses
5. Apply energy discrimination
6. Check block dead time
7. Convolve pulse with energy resolution
8. Determine event location within detector
9. Apply module electronic dead time
10. Trigger coincidence window
11. Reject multiple coincidences
12. Process & store coincidence in sinogram
13. Export results to Excel
14. Apply efficiency corrections
15. Bin event separation time
16. Bin coincident event energy resolution
Simulation Results

- Simulations fit measured PET scanner sensitivity to 3.6%
- Applying new dead time model reduces sensitivity 2σ uncertainty from 1.01% to 0.92%
- \(^{90}\)Y activities greater than 100 mCi should use a separate dead time model
Acknowledgements

- The research group would like to recognize Dr. Robert J. Nickles and Dr. Robert Pyzalski at the University of Wisconsin for their ideas regarding $^{90}\text{Y}$ PET imaging and expertise in positron emission tomography and coincidence detection systems.
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References