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Optimization of Noise Equivalent Count Rate Performance for a Partially Collimated PET Scanner by Varying the Number of Septa

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Abstract

We present a simulation study of the global count-rate performance of a positron emission tomography (PET) scanner with different levels of partial collimation to maximize the noise equivalent count rate for whole-body PET imaging. We achieve partial collimation by removing different numbers of septal rings from the standard 2-D septa set for the GE Advance PET scanner. System behavior is studied with a photon tracking simulation package, which we modify to enable the production of random coincidences. The simulations are validated with measured data taken in 2-D and fully 3-D acquisition mode on a GE Advance system using the National Electrical Manufacturers Association NU-2 count-rate phantom with two sets of annular sleeves to expand the diameter to 27 and 35 cm. For all diameters and in 2-D and fully 3-D mode, there is good agreement between measurements and simulations. All studies use the three phantom diameters to evaluate the effect of patient thickness for each amount of collimation. Optimized system parameters, such as maximum ring difference for single slice rebinning, are determined for the five partially collimated systems considered. The resulting global count rates for true, scattered, and random coincidences, the noise equivalent count (NEC) rates, and the scatter fractions for different levels of collimation are compared along with the results from the conventional 2-D and fully 3-D modes. Improved statistical data quality relative to both 2-D and fully 3-D data is found with the partially collimated systems, particularly when one-half or two-thirds of the septal rings are removed. An increase in NEC rates of as much as 50% is found for clinically relevant activities between 5–10 mCi (184–370 MBq). Scatter fractions for the partially collimated systems are intermediate between the 2-D and fully 3-D numbers. Many factors that affect image quality have not been considered in this paper. However, the significant increase in

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statistical data quality warrants further investigation of the impact of partial collimation on clinical whole-body PET imaging.

Keywords

Biomedical nuclear imaging; collimation; partial collimation; positron emission tomography; sensitivity; simulation

I. INTRODUCTION

THE use of fully 3-D data acquisition in positron emission tomography (PET) has demonstrated significant advantages for brain imaging when compared to 2-D acquisition [1]. The relative advantage of fully 3-D versus 2-D mode for whole-body imaging, however, is less clear and has been the focus of considerable debate [2]–[4]. This debate is especially timely as the number of scanners that only operate in fully 3-D mode is increasing with the advent of dual-modality PET/computed tomography scanners. Fully 3-D imaging (no collimation) yields higher sensitivity to true coincidences than 2-D mode; however, it also yields significantly more scattered and random events [5], particularly when activity directly outside the field-of-view (FOV) is present, such as in whole-body imaging. This leads to elevated scanner dead-time and increased noise in the acquired data. A metric for data quality that takes the relative tradeoffs into account is the noise equivalent count (NEC) rate [6] (essentially the effect of signal to noise ratio of the raw data). It has been used to compare the statistical quality of 2-D and fully 3-D mode sinogram data [7]–[9].

The goal of this paper is to evaluate the relative merit for whole-body imaging of systems with various amounts of partial collimation with respect to 2-D and fully 3-D scanners over a range of activities and patient sizes. This is achieved by simulating the scanner performance with and without removal of 10%–90% of the number of septa from the standard GE Advance 2-D collimator. Simulations are done with the photon tracking Monte Carlo package Simulation System for Emission Tomography (SimSET) [10] that was developed in our laboratory. The results are evaluated in terms of the system characteristic global count rates of true, scattered, and random coincidences and NECs as well as of the scatter fraction.

Optimization of collimators in SPECT imaging is a well-developed field (e.g., Moore *et al.* [11]). For PET image acquisitions, less attention has been paid to the design of the slice-defining septa. Most of the previous work on partial collimation systems concerns hybrid PET systems e.g., [12] and [13], where axial slats were investigated as a means of reducing random coincidences. For full ring PET scanners, Aykac *et al.* [14] evaluated different septa designs in conjunction with a modification of their prototype high-resolution PET scanner, using the NEC metric as a figure of merit. They then followed up with a detectability study for brain lesions [15], finding a definitive increase in NEC rates but questionable improvement in detectability. More recently, Hasegawa *et al.* have proposed, constructed, and evaluated [16]–[18] a long-bore PET scanner with septa located between detector blocks rather than between every ring of detector crystals. Qi *et al.* [19] have used simulations to systematically evaluate both the NEC and the task-based performance of lesion detection for a prostate-specific PET imaging scanner. With these studies they were able to evaluate both the effect on NEC rates and lesion detectability and demonstrated that properly designed sparse septa can improve lesion detection over the traditional 2-D or fully 3-D configurations. In this paper, we focus on NEC rates for different effective patient diameters, as our previous studies [20] have shown that lesion detection is closely related to NEC density, if all other parameters are kept constant.

Our work divides into three main parts: first is the expansion of the SimSET code for the production of random coincidences, which is not (yet) possible with the standard SimSET program; second is the validation of the 2-D and fully 3-D simulated single and coincidence count rates with data from the GE Advance scanner; and third is the evaluation of the partial collimation data, including estimation of parameters necessary for partial collimation imaging (e.g., scatter fractions, live time, and minimum energy requirements). For the third part, septa were removed from an otherwise identical configuration of the Advance 2-D collimator.

II. METHODS

We use the photon tracking Monte Carlo package SimSET to simulate the system-characteristic global count rates of true, scattered, and random coincidences for the GE Advance PET scanner [21] in 2-D (full collimation), fully 3-D (no collimation), and five partial collimation modes as described below. The simulation is validated with data taken on a GE Advance scanner in 2-D and fully 3-D mode.

Event rates and the derived NEC rates are determined according to the National Electrical Manufacturers Association (NEMA) NU-2 count-rate protocol [22], using the 70-cm-long NEMA count-rate phantom with a line source of activity offset from the center by 4.5 cm. The standard phantom diameter of 20 cm can be adjusted with optional annular sleeves of the same material to 27 and 35 cm (Fig. 1) in order to more realistically simulate effective patient sizes. This allows for evaluation of the influence of patient size in this paper along with the degree of partial collimation.

Single-slice rebinning (SSRB) is done on all data sets to bring them into the sinogram format used for the subsequent NEMA analysis.

The NEMA NU-2 standard procedure is used to determine the global count rates for true and scattered coincidences as well as the scatter fractions from our measured and simulated data sets. For the scatter fraction calculation, an activity level with less than 1% randoms in measured and simulated prompt coincidence data is used. The NEMA NU-2 protocol prescribes the signal region for the 20 cm phantom to extend 2 cm beyond the exact phantom position in all acquired sinograms. All counts outside this region are deemed to be due to scatter. The number of scattered counts in the signal region is determined from an interpolation between the counts at the edge of the region; the true counts are the remainder. We have applied this same prescription to the larger diameter phantoms, in particular regarding the signal region, extending it 2 cm beyond the exact phantom diameter.

A. SimSET and Its Expansion for Random Coincidences

Random coincidence count rates were estimated by combining the single photon count rates of the contributing detector elements [23], [24]

$$R_{ij}=2\tau S_i S_j. \quad (1)$$

Here R_{ij} is the random coincidence rate between detector elements i and j , S_i and S_j are the single event rates in the same detector elements, and 2τ is the timing window for coincidence counting in the considered system. This requires two steps for the implementation of random coincidences: the production of single photon rates in each detector element using SimSET and their subsequent combination into random coincidences, which is done outside of SimSET. (A new version of SimSET generates random coincidences directly by adding timing information to each photon-detection, enabling

genuine random coincidence counting of unrelated single photons that are detected within the timing window. This version was in validation testing at the time of submission of this manuscript.)

The SimSET code was changed to permit the tracking of single photon events in a cylindrical detector. The single photons are binned by scattering history, energy, axial slice, and detector element within the axial slice. Effectively, this is binning by detector element for single photon detection for use in (1).

This new binning is validated in two ways. First, we ensure that a photon that is manually started in the direction of a particular bin will be found in the expected location. Secondly, we perform solid angle tests, simulating a 511 keV photon point source in a 9 cm radius air cylinder with the source offset from the center of the cylinder by 1 cm in axial direction and a varying distance in radial direction. The photons are detected without collimation and assuming a perfect detector, and binned in 180 angle and four axial bins. The counts per bin in SimSET are then compared to the expectations from geometric solid-angle calculations for this validation test.

Single photon rates for the NEMA simulations are combined into random coincidence rates using (1), and the latter are binned into regular sinograms or projection data format. We consider every combination of single detector elements that yields a valid line of response according to the GE Advance protocol. For consistency, the random coincidence rates in the measured data are also obtained with this method from the measured single photon rates.

B. Validation of Count Rate Simulations With Measured GE Advance Data

For the validation of the count rate simulations from SimSET, phantom measurements are taken at varying activity levels on a GE Advance scanner in 2-D and fully 3-D acquisition mode for all three diameters of the modified NEMA NU-2 count rate phantom. Prompt coincidences and single photon events are acquired separately. Subsequently, prompt coincidences and single photon rates are simulated with the expanded SimSET program and compared to the measured rates.

The GE Advance scanner uses a maximum ring difference of three in 2-D mode and of 11 for fully 3-D acquisitions. The same is applied to the corresponding simulated data.

For the SimSET simulations, a solid, nonsegmented cylindrical detector is assumed, whereas the GE Advance scanner uses block detectors. Therefore, all simulated data are corrected for the packing fraction (PF), which is the ratio of the combined crystal volume in the Advance and the volume of the solid cylinder in SimSET ($PF = 0.844$). In addition, all simulations are adjusted for the livetime observed in the measured data at each activity point. The measured livetime is determined from a linear fit to the lowest activity part of the data separately for single photon rates and coincidence count rates, for each phantom diameter, and for 2-D and fully 3-D mode.

C. Simulations of Partial Collimation Systems

For the simulation of partial collimation, we introduce five new hypothetical collimator geometries with septa identical to the Advance 2-D case but with different numbers of septa removed symmetrically from the standard 2-D collimator set of the GE Advance scanner, which has 17 septa (shown in Fig. 2). These in-between 2-D and fully 3-D systems are named 2. D, with depending on the degree of collimation: For 2.1-D, we remove only the two septa that are in between the three axial detector blocks in the GE Advance PET scanner; for 2.3-D, in addition, the septa in the middle of each axial detector block are removed; for 2.5-D every other septum and for 2.7-D two out of three septa are removed;

the 2.9-D system has all septa removed except for the two that are in between the axial detector blocks. The parameters for all considered collimator systems are summarized in Table I, and the partial collimation systems are visually represented in Fig. 3.

For single-slice-rebinning of the partial collimation data, the optimal maximum ring difference has to be determined for each level of collimation. We use an estimate of the resulting NEC rate to compare different values at an activity level of 10 mCi for all phantom diameters. This is shown for some systems representatively in Fig. 9.

For cross-compatibility amongst the partial collimation studies, the acceptance range for the energy of the produced photons is set as 375–650 keV (as in the Advance fully 3-D case) for the initial comparison of all considered collimation options, including 2-D, even though the standard energy window for clinical 2-D studies on the Advance is 300–600 keV. A second set of comparisons is done where the lower energy threshold is varied to confirm the optimal setting.

All other simulation and binning parameters are kept constant for the partial collimation simulations.

For the partial collimation cases, since we do not simulate the actual scintillation and detection nor the downstream electronics chain, no single or coincidence lifetime characteristics can be assumed. Instead, we derive a lifetime model based on single photon event rates above a nominal energy threshold of 100 keV (referred to as “trigger singles”). Measured lifetime data from 2-D and 3-D decay series is used to assess the validity of the model and determine its parameters.

III. RESULTS

A. Validation of the New Single Photon Binning in SimSET

There is good agreement in both tests of the validity of the new singles binning in PET simulations with SimSET. All ten photons that were manually started in the direction of a particular bin are detected and binned in the expected location (no data shown). Secondly, Fig. 4 shows the observed agreement between solid angle calculations and simulations for the axial slice containing a point source at three radial offsets in a 9 cm radius detector ring.

B. Validation of Count-Rate Simulations

Fig. 5 shows the lifetime observed in the measured data on the example of the 27 cm phantom for coincidences in 2-D and fully 3-D mode.

The NEMA NU-2 global count-rate curves versus total activity for all three phantom diameters in 2-D and fully 3-D mode are compared in Figs. 6 and 7 for measured counts obtained from the GE Advance scanner (symbols) and simulated counts from the expanded SimSET program (lines). Fig. 8 depicts the derived global NEC rates, in the comparison between measured and simulated data (again, symbols and lines, respectively). No adjustments, such as global scale factors, are applied to the simulation results to fit the simulation to the measured data.

Note that to convert the clinically relevant total activity in the phantom as used on our plots (in units of mCi) into SI units of activity concentration (kBq/cm³), phantom-size dependent scale factors are necessary, which are given in Table II.

Agreement in count rates between measured data and simulations is close, but not perfect. Some of the discrepancy can be attributed to the fact that the measured data include the

effects of the patient table, which was not modeled in the simulations. We expect the effect of the bed on global count rates to yield a less than 5% relative decrease in trues and scatter rates in the measured versus simulated data.

Overall, trends and structure in count rates and the derived NEC rates are predicted very well.

The peak NEC rates and the activities they occur at for measured data and simulations are listed in Table III for the different phantom diameters and acquisition modes. The predicted peak rates are only rough estimates of the measured values, but the corresponding peak activities (locations) are predicted very well by SimSET, as are all trends in the measured data.

The corresponding NEMA NU-2 scatter fraction comparison from measurements and simulations for the three phantom diameters in 2-D and 3-D acquisition mode is presented in Table IV. SimSET predicts the trend of increasing scatter fraction with growing phantom diameter correctly. The simulation results are, however, somewhat lower than the measured values. This is expected to be due, in part, to the missing patient table in the simulation. From other studies that simulate the GE Advance scanner [25], the missing bed is expected to decrease the scatter fraction by 3%–5%.

C. Partial Collimation Simulations

The optimization curves for the maximum ring difference in single-slice rebinning are shown in Fig. 9 for some of the partial collimation systems representatively. The optimal values are listed in Table V as system-specific parameters.

The livetime curves that are applied to the simulated partial collimation results are shown in Fig. 10 (measured livetime as a function of simulated trigger singles). They exhibit independence of the collimation settings with 2-D and fully 3-D curves falling together. The slight spread observed is due to the influence of attenuation at different phantom diameters. For a common livetime description to be used for all collimation systems and all phantom diameters, the average of all livetime curves is fit with a third-order polynomial as a function of trigger singles rate (wider dashed curves in Fig. 10).

The global count rates of true, scattered, and random coincidences and NECs versus a range of activities from all five partial collimation geometries as well as from 2-D and 3-D mode are compared in Fig. 11 for all three phantom diameters. Over this large range of activities, the partial collimation data clearly show the progression of each count rate curve from full collimation to the collimation-free case.

The peak NEC rates and the activity values at the peak are summarized in Table VI in a comparison of all partial collimation systems and phantom diameters. As expected, the peak NEC values decrease with increasing phantom diameter. However, it is notable that the peak locations, where the NEC curves turn over, are approximately invariant with respect to varying phantom diameters. The partial collimation results demonstrate again the progression from 2-D to fully 3-D in terms of both the peak NEC values and their locations. Both shift to higher and higher values for more collimation.

Table VII presents a summary of explicit simulated NEC values for three activity points in the clinically important region. Only the two most promising partial collimation configurations (2.5-D and 2.7-D mode) are compared to the conventional 2-D and fully 3-D cases. The comparison includes all phantom diameters. Compared to 2-D or 3-D, the partial

collimation modes yield a 20%–50% increase in statistical data quality. This is graphically represented in Fig. 12.

The complete NEC curves are presented in Fig. 13. This is the summary result for the experiment. For all degrees of partial collimation, the curves demonstrate improved performance compared to both 2-D and 3-D over varying intermediate activity ranges. Significant improvement is reached in the 2.5-D and 2.7-D cases of one-half and one-third collimation, respectively. In the range of total activity starting at about 3 mCi for the 20 cm phantom and somewhat lower for the larger diameter phantoms, these two systems outperform both 2-D and fully 3-D acquisitions by a large margin.

To investigate whether the chosen lower energy threshold of 375 keV is the optimal setting, we also studied count-rate behavior as a function of this parameter. Fig. 14 gives an impression of the observed variation on the example of the 20 cm phantom in 2.5-D and 2.7-D collimation, finding 375 keV as used above as the best setting.

IV. DISCUSSION AND CONCLUSION

We have expanded the photon tracking package SimSET to enable random coincidence simulations and validated the new results.

Two-dimensional and fully 3-D acquisition mode data sets for the GE Advance scanner were simulated and validated with measured data, giving adequate agreement over a range of activities and with three considered phantom diameters.

Trends and structure in count rates and the derived NEC rates are well predicted, which allows us to predict relative changes in count rates with a good level of confidence. Since in this paper we strive to show trends in count rates when different collimator geometries are introduced, it is sufficient for the validation of our simulation to confirm that these overall trends are predicted well. It is worth noting that no arbitrary scale factors were used. It would have been possible to introduce a global scale factor to produce a better match between measured and simulated NEC rates for the 2-D and fully 3-D scans, but we would have less confidence in the partially collimated studies, which have to rely solely on simulations.

Five hypothetical systems with varying degrees of collimation were simulated and evaluated in terms of their global count rates, scatter fraction, and NEC performance for whole-body imaging. Note that our analysis compares NEC values at clinically useful activities and uses them as a figure of merit. While peak NEC values and locations yield important general information about the considered collimation systems, the NEC peaks should not be used as a figure of merit. While the peak NEC rate increases with increasing collimation, it is important to recognize the dramatic increase in the activity required to realize that peak. Clinically this becomes increasingly infeasible, at least for F-18 imaging. Instead, the NEC performance over a clinically useful activity range must be used to determine the relative merit of a system.

We observe significant improvement in statistical data quality of partial collimation systems as compared to 2-D or fully 3-D mode in clinically relevant activity ranges above about 2–3 mCi. These findings hold for all considered phantom diameters and may prove especially useful for larger patients. Particularly encouraging for further work are the partial collimation cases with one-half or two-thirds of septa removed from the Advance 2-D collimator set, yielding increases in NEC values of 47% and 54% at 7 mCi for the 27 cm diameter phantom.

A smaller part of our study looked at different lower thresholds of the photon energy, with values between the established GE Advance scanner 2-D and fully 3-D settings of 300–375 keV for two partial collimation systems. Within each collimation scheme, the highest NEC rates are achieved with a photon minimum energy of 375 keV. It is possible that tightening this threshold might result in even better performance. However, this paper concerns itself only with improvements from partial collimation; hence all system comparisons were done with the above GE Advance scanner—informed value.

Future work has to determine correction and reconstruction schemes tailored to the characteristic properties of the partial collimation data. They are required in order to turn this statistical advantage into improved PET image quality.

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Fig. 1.
Sketch of the NEMA NU-2 count rate phantom with the additional optional sleeves for increased attenuation.

Fig. 2. Schematic axial drawings of the GE Advance PET scanner and axial details of the fully collimated 2-D system as modeled in our simulations. Dashed lines in the BGO crystal volume indicate the axial boundaries of the detector blocks.

Fig. 3. Schematic axial drawings of (a)—(e) the collimator locations for the considered partial collimation schemes and (f) for the fully 3-D mode without any collimation. Note that the collimator arrangement for (e) 2.9-D with septa only between axial detector blocks corresponds to that used in [17]. Dimensions for these systems are given in Table I. (a) 2.1-D. (b) 2.3-D. (c) 2.5-D. (d) 2.7-D. (e) 2.9-D. (f) 3-D.

Fig. 4. Singles counts per azimuthal angle for a point source at (x,y,z) locations (0,6,1), (0,4,1), and (0,0,1) in centimeters from (lines) SimSET simulations and (symbols) solid angle calculations.

Fig. 5. (Circles) Measured live time derivation as the fraction of (triangles) measured delay-subtracted prompt coincidences and the extrapolation value of a linear fit to the lowest activity part of the data on the example of the 27 cm phantom in (A) 2-D and (B) fully 3-D mode.

Fig. 6.
Global count rates versus activity from (lines) simulation and (symbols) Advance data in 2-D for the three phantom diameters (A) 20 cm, (B) 27 cm, and (C) 35 cm.

Fig. 7.
Global count rates versus activity from (lines) simulation and (symbols) Advance data in 3-D for the three phantom diameters (A) 20 cm, (B) 27 cm, and (C) 35 cm.

Fig. 8. NEC rates derived from (lines) simulated and (symbols) measured count rates in (A) 2-D and (B) 3-D for all three phantom diameters.

Fig. 9.
Estimated NEC values at 10 mCi activity at varying maximum ring differences used in SSRB. The (A) 2.1-D, (B) 2.5-D, and (C) 2.9-D data sets are shown representatively.

Fig. 10.

Measured live time for (A) singles and (B) coincidences as a function of simulated trigger singles rate for each phantom diameter in 2-D and fully 3-D.

Fig. 11.

Simulated global count rates for increasing phantom diameter (left to right). (a)–(c) 20 cm, (d)–(f) 27 cm, and (g)–(i) 35 cm from left to right. From top to bottom: (a), (d), and (g) true, (b), (e), and (h) scattered, and (c), (f), and (i) random coincidences.

Fig. 12. Explicit NEC rates for 2-D, 2.5-D, 2.7-D, and 3-D for all three phantom diameters at (A) 5.5, (B) 7.0, and (C) 10.1 mCi. The values are listed explicitly in Table VII.

Fig. 13.

Noise-equivalent count-rate comparison for all considered collimation systems for each phantom diameter (A) 20 cm, (B) 27 cm, (C) 35 cm. NEC count rates are derived from the global count rates shown in Fig. 11. Note the change in vertical scale.

Fig. 14.
NEC rates from the 20 cm phantom at 2.5-D and 2.7-D collimation with energy thresholds varied from 375 to 337.5 and 300 keV.

TABLE I

Parameters and Labels for Partially Collimated Systems Drawings for these Systems are Shown in Fig. 3

Label:	2D	'2.1D'	'2.3D'	'2.5D'	'2.7D'	'2.9D'	3D
# septa removed	0	2	5	9	12	15	17
# septa in collimator	17	15	12	8	5	2	0
septal gap* [mm]	7.5	7.5/ 16**	7.5/ 16**	16	24.5	50	152

* The septal gap describes the air space in between opposing septa or septa and end shields.

** No even septa spacing

TABLE IIConversion Factors from Total Activity (mCi) to Activity Concentration (SI Units of kBq/cm³)

mCi	20 cm diam kBq/cm ³	27 cm diam kBq/cm ³	35 cm diam kBq/cm ³
1	1.63	0.97	0.56

TABLE III

Peak NEC Rates in Simulation and Measurement

Mode	20cm	27cm	35cm
2D	Advance 138 keps @ 44 mCi	67 keps @ 36 mCi	27 keps @ 38 mCi
	SimSET 179 keps @ 44 mCi	82 keps @ 36 mCi	34 keps @ 38 mCi
3D	Advance 35 keps @ 6.6 mCi	15 keps @ 5.6 mCi	6 keps @ 6.2 mCi
	SimSET 54 keps @ 6.6 mCi	23 keps @ 5.6 mCi	8 keps @ 6.2 mCi

TABLE IV

NEMA Scatter Fractions in Measured Data and Simulations

		20cm	27cm	35cm
2D	Measured	11.0%	17.2%	21.6%
	Simulated	9.4%	13.4%	20.8%
3D	Measured	43.1%	55.0%	66.0%
	Simulated	35.2%	48.1%	60.5%

TABLE V

Optimal Maximum Difference Values for Partially Collimated Systems. The System Geometry for these Cases is Shown in Fig. 3, Examples of the Optimization of Expected Rate Versus Maximum Ring Difference are Given in Fig. 9

Label:	2D	'2.1D'	'2.3D'	'2.5D'	'2.7D'	'2.9D'	3D
Max. ring difference	3	7	7	7	11	11	11

TABLE VI

Peak NEC Rates in KCPS at the Peak Activity in mCi for all Degrees of Collimation

Mode:	2D	2.1D	2.3D	2.5D	2.7D	2.9D	3D
20cm	203 @60 *	164 @50	145 @40	123 @25	102 @17	72 @10	52 @6
27cm	107 @60 *	81 @50	71 @40	60 @25	47 @17	32 @10	24 @6
35cm	45 @60 *	36 @50	28 @40	23 @25	18 @17	12 @10	9 @6

* this was the highest activity simulated, but still below the peak

Simulated NEC Rates in KCPS at 10.1, 7.0, and 5.5 mCi for the 2.5-D and 2.7-D Partial Collimation Modes in Comparison to 2-D and 3-D Rates for all Phantom Diametes. Also See Fig. 12 for Graphic Representations

TABLE VII

<div>↓ Collimation → Description</div>	10.1 mCi				7.0 mCi				5.5 mCi			
	20 cm	27 cm	35 cm	20 cm	27 cm	35 cm	20 cm	27 cm	35 cm	20 cm	27 cm	35 cm
2D	61.9	32.9	14.4	44.4	23.7	10.4	35.5	18.9	8.3			
2.5D	89.0	40.1	17.5	69.9	34.9	14.0	58.4	29.3	11.8			
2.7D	92.8	43.0	16.4	78.5	36.6	14.2	68.1	31.9	12.4			
3D	47.7	22.2	8.3	51.5	23.8	8.7	51.5	23.6	8.6			