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Use of a Qualification Phantom for PET Brain Imaging in a Multicenter Consortium: A Collaboration Between the Pediatric Brain Tumor Consortium and the SNMMI Clinical Trials Network

Frederic Fahey[1,2], Paul Christian[3], Katherine Zukotynski[4], Briana Sexton-Stallone[1], Christina Kiss[5], Bonnie Clarke[5], Arzu Onar-Thomas[6], Tina Young Poussaint[2,7]

[1]Division of Nuclear Medicine and Molecular Imaging, Department of Radiology, Boston Children's Hospital, Boston, MA, USA
[2]Department of Radiology, Harvard Medical School, Boston, MA, USA
[3]Huntsman Cancer Institute, University of Utah, Salt Lake City, UT, USA
[4] Department of Medicine and Radiology, McMaster University, Hamilton, ON, Canada
[5]Clinical Trials Network, Society of Nuclear Medicine and Molecular Imaging, Reston VA, USA
[6]St Jude Children's Research Hospital, Memphis, TN, USA
[7]Division of Neuroradiology, Department of Radiology, Boston Children's Hospital, Boston, MA, USA

For correspondence or reprints contact:

Frederic H. Fahey
Division of Nuclear Medicine and Molecular Imaging
Boston Children's Hospital
300 Longwood Avenue
Boston, MA 02115

E-Mail: Frederic.Fahey@childrens.harvard.edu
Phone: 617-355-2809
Fax: 617-730-0022

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ABSTRACT

The purpose of this study was to assess image quality and quantitative brain PET across a multi-center consortium. **Methods**: All academic centers and children's hospitals in the Pediatric Brain Tumor Consortium (PBTC) scanned a phantom developed by the Society of Nuclear Medicine and Molecular Imaging Clinical Trials Network (SNMMI CTN) for the validation of brain PET studies associated with clinical trials. The phantom comprises 2 separate, fillable sections: a resolution/uniformity section and a clinical simulation section. The resolution/uniformity section is a cylinder 12.7 cm long, 20 cm diameter; spatial resolution is evaluated subjectively with 2 sets of rods ("hot" and "cold") of varying diameter (4.0, 5.0, 6.25, 7.81, 9.67 and 12.2 mm) and spacing (twice the rod diameter). The clinical simulation section simulates a transverse section of midbrain with ventricles, gray and white matter compartments. If properly filled, hot rods have an 4:1 target-to-background ratio and gray to white matter sections have a 4:1 ratio. Uniformity and image quality were evaluated using the standardized uptake value (SUV) in a small volume of interest as well as subjectively by 2 independent observers using a 4-point scale. **Results**: Eleven PBTC sites scanned the phantom on 13 PET scanners. The phantom's complexity led to suboptimal filling, particularly of the hot rod section, in 5 sites. The SUV in the uniformity section was within 10% of unity on only 5 of 13 scanners, although 12 of 13 were subjectively judged to have very good to excellent uniformity. Four of 6 hot rods were discernable by all 13 scanners while 3 of 6 cold rods were discernable by only 5 scanners. Four of 13 scanners had a gray/white matter ratio between 3.0 and 5.0 (4.0 is truth); however, 11 of 13 scanners were subjectively judged to have very good or excellent image quality. **Conclusion**: Eleven sites were able to image a powerful phantom developed by the SNMMI CTN that evaluated image uniformity, spatial resolution and image quality of brain PET. There was considerable variation in PET data across the PBTC sites possibly resulting from variations in scanning across the sites due to challenges in filling the phantom.

INTRODUCTION

Clinical trials using ^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography computed tomography (PET/CT) can be challenging in the pediatric population since small numbers of eligible patients make it difficult to obtain sufficient data for robust statistical analysis. Multicenter trials help to mitigate this issue. Formed by the National Cancer Institute (NCI) in 1999, the Pediatric Brain Tumor Consortium (PBTC) encompasses a group of 11 North American children's hospitals and academic centers involved in the treatment of primary brain tumors in children (*1*). Imaging data acquired at participating institutions are electronically transferred to the PBTC Operations, Biostatistics and Data Management Core and then to the PBTC Neuroimaging Center for analysis (*2*). In order to compare these images effectively, it is important to understand the variability in PET metrics across multicenter clinical trials.

PET metrics are sensitive to several technical and patient-related factors (*3,4*). To address this variability, all sites are instructed to follow standardized operating procedures. These protocols provide guidance on patient preparation, ^{18}F-FDG administration, image acquisition and processing parameters, and other considerations depending on the particular goals and design of each, particular study (*5-7*). Consistency of PET data is maintained by adherence to a quality assurance program, which includes daily scans of a uniform radioactive source as well as quarterly normalization, calibration, and preventive maintenance. Within the PBTC, there have been several standardization initiatives beyond routine PET quality control. Initially, a uniformity phantom was used to assure consistent background quantitation. In 2008, the use of an ACR-type PET phantom with ^{68}Ge/^{68}Ga hot features was pioneered, and the results were reported (*8*).

To provide a standardized means of assessing image quality and consistency between sites within multicenter trials, the Clinical Trials Network (CTN) of the Society of Nuclear Medicine introduced a phantom imaging program in 2005. The imaging of standardized phantoms was used, in part, to validate clinical sites for inclusion in multicenter trials utilizing ^{18}F-FDG PET/CT. More recently, a PET brain qualification phantom was developed.

The aim of this study was to evaluate the variability in PET metrics across sites within the PBTC. We performed this evaluation using the SNMMI/CTN brain qualification phantom specifically developed for the validation of clinical sites acquiring brain PET studies associated with clinical trials.

METHODS

Phantom Description

The phantom was comprised of 2 separate, fillable sections: a resolution/uniformity section and a 2D clinical simulation section mimicking a mid-brain transverse section. The resolution/uniformity section was a cylinder (12.7 cm long, 20 cm diameter, Fig 1A). The resolution portion was 6.4 cm long while the remainder provided a uniform portion to evaluate potential artifacts and quantify uniformity as measured by the average standard uptake value (SUV_{ave}) of the background (Fig 1B). Spatial resolution was evaluated subjectively with 2 sets of rods ("hot" and "cold", Fig 1C and D). The pairs of rods had diameters of 4.00, 5.00, 6.25, 7.81, 9.67 and 12.20 mm with center-to-center spacing equal to twice the rod diameter. If properly filled, the hot rods had a 4:1 target-to-background ratio. The smallest hot and cold rod pairs discernable as separate were recorded as a measure of spatial resolution.

The clinical simulation section (Fig 1E) was modeled using a patient MRI scan and consisted of simulated gray matter including the cerebral cortex and central brain, white matter and ventricles. The phantom was designed such that the gray matter appeared 4 times hotter than the white matter with no activity in the ventricles.

The compartments of the phantom were filled with ^{18}F-FDG in concentrations that, at the time of imaging, provided the uniformity and white matter sections of the phantom with 5.18 kBq/cc (0.14 μCi/cc) and the gray matter and hot rod sections of the phantom with four times that concentration 20.72 kBq/cc (0.56 μCi/cc), creating a 4:1 hot rod to background ratio and a 4:1 gray/white matter ratio.

Image Acquisition

One of two identical SNMMI/CTN PET brain qualification phantoms were sent to each PBTC site with PET capability along with a handbook (Supplemental Appendix 1) that described the filling, imaging and emptying of the various parts of the phantom. After filling the phantom with ^{18}F-FDG, the sites obtained two acquisitions: one for 6 minutes, the time used by each site for PBTC brain ^{18}F-FDG PET/CT studies, and a second for 30 minutes. Other than the duration of the scan, the two acquisitions were identical utilizing the CT and PET acquisition parameters routinely used by the site for research ^{18}F-FDG PET/CT brain studies. The sites were instructed to reconstruct the phantom data just as they would a PBTC research ^{18}F-FDG PET/CT brain

study. For the clinical investigations within the PBTC, sites are instructed to acquire, process and reconstruct FDG PET brain scans according to their clinical practice including the application of standard corrections for scatter, random coincidences and count rate losses as recommended by the manufacturer of their specific scanner. Standard quality control of the dose calibrator and cross-calibration to the scanner was confirmed for each site. Upon completion of the study, the sites submitted a scanner equipment questionnaire (Supplemental Appendix 1) describing the scanner and the dose calibrator used for the studies. The sites were also asked to report whether the ^{18}F calibration factor for the dose calibrator had been adjusted. A phantom imaging form was also sent that defined the acquisition concentrations used to fill the phantom as well as the CT and PET acquisition parameters (for both PET acquisitions). The resultant reconstructed images were sent to the PBTC Operations, Biostatistics and Data Management Core and forwarded to the Neuroimaging Center. The phantom was then emptied according as instructed, packaged and shipped to the next PBTC site.

Evaluation of Phantom Data

A central analysis of the objective image parameters was performed. For the uniformity section, this included calculating the SUV_{ave} over a 1-cm^2 area, the coefficient of variation (COV, standard deviation normalized by the mean of the pixel values as a percentage) across 9 slices, and the maximum slice deviation. For the resolution section, this included a measure of the rod contrast. For the clinical simulation section, this included a measure of the SUV_{max} in the gray matter, SUV_{ave} in the white matter and the gray/white ratio. Placement of the regions of interest (ROI) for these assessments is shown in Figure 2.

The image quality of the phantom was judged subjectively by 2 independent observers using a 4-point scale (1-excellent to 4-unacceptable), and the results were then averaged. This included grading of the uniformity for the 30-min acquisition, the numbers of cold and hot rods discerned as separate, and the subjective image quality of the clinical simulation section for both the 6-min and 30-min acquisitions.

RESULTS

The phantom was imaged under controlled conditions on 13 PET scanners at 11 PBTC sites (Table 1). The vendors and models of the scanners are listed in Table 2. Since this project

involved phantom rather than patient imaging, it did not require Internal Review Board (IRB) approval at any of the sites. The phantom was relatively complex in design and challenging to fill correctly given it had 4 filling ports filled with 3 different activity concentrations. For the resolution/uniformity section there was one filling port for hot rods and one for background. Several sites had difficulty filling the hot rods appropriately leading to only a portion of the rods having activity. For the clinical simulation section there was one filling port for gray matter and one for white matter. This complexity led to suboptimal filling in 5 of the 11 sites. The fact that a number of sites had difficulty led us to believe that the complexity of the phantom contributed to the high percentage of cases of suboptimal filling.

Uniformity Section

The uniformity section was judged both objectively and subjectively (Table 3). The SUV_{ave} across 9 slices in the uniformity section ranged from 0.75 to 1.84 with a mean of 1.14. This value should be unity. Only 5 of the 13 scanners had an SUV_{ave} within 10% of unity. However, 12 of the 13 scanners were subjectively judged to demonstrate very good or excellent uniformity. The COV across 9 slices ranged from 3.38 to 7.32% with a mean of 5.3%. All 13 scanners had a COV value below 10%, and 5 of 13 were below 5%. Eleven of the 13 scanners demonstrated a maximum slice deviation less than 5%. Figure 3 shows a uniform slice from two scanners, one judged to have “excellent” uniformity and the other judged to be “good.”

Resolution Section

The suboptimal filling described above was most notable in the resolution section where only a portion of the hot rod section was filled in several instances (Figure 4). The subjective grading of the resolution section is presented in Table 4. In all 13 scanners, at least one of the two observers could discern 4 of the 6 hot rods while in only 5 scanners could 5 of the 6 hot rods be seen. Four of the 13 scanners could discern at least 3 of the 6 cold rods. The rod contrast could not be calculated in one case due to suboptimal filling. In 10 of the remaining 12 scanners, the rod contrast was measured to be greater than 2.5.

Clinical Simulation Section

The objective and subjective rankings of the clinical simulation section are shown in Table 5. The SUV_{max} of the gray matter had a range from 3.06 to 8.25 with a mean of 4.50. This value should be 4.00. All 13 scanners had a gray matter SUV_{max} greater than 3.00. The SUV_{ave} in the white matter had a range of 0.28 to 2.57 with a mean of 1.13 (should be unity). Only 1 of the scanners demonstrated a white matter value between 0.90 and 1.10 with all other values being outside this range. There was considerable variability between scanners regarding the gray/white ratio with a range of 1.75 to 15.39 with a mean of 5.60 (should be 4.00). The coefficient of variation (COV) for the gray matter SUV_{max}, white matter SUV_{ave} and the gray/white ratio are 28.8, 60.4 and 68.0%, respectively. Thus, the bulk of the variation in the gray/white ratio results from variability of the white matter activity.

The subjective image quality was rated separately for the 6-min and 30-min acquisitions. For both the 6-min and 30-min image quality, images from 11 of 13 scanners were deemed to be very good or excellent by at least one of the observers. For the 6-min images, one of the observers judged the images to be "good" in 6 cases and unacceptable in one case. For the 30-minute images, 11 of 13 were judged to be very good to excellent, one was judged to be good and one deemed unacceptable. Example 30-min images are presented in Figure 5.

DISCUSSION

^{18}F-FDG PET/CT studies are often evaluated both subjectively by visual inspection and objectively using quantitative parameters. Images that are interpreted visually may require less stringent reconstruction standardization across institutions than what is required when quantitative PET analyses are performed. Ultimately, different levels of standardization are needed depending on the intended analyses.

Quantitative PET analyses, commonly performed in clinical studies today, are based on the SUV, a metric of ^{18}F-FDG uptake within a tumor normalized by the radiotracer administered activity and patient body weight after a certain uptake time. The SUV is significantly affected by many factors, both physiologic and technical, including scan acquisition, image reconstruction, and uptake time (*3*). Some of these factors may be mitigated by using a relative SUV or ratio of uptake between different ROIs. However, in cases where an absolute SUV is desired, these factors can become significant. For example, image reconstruction parameters alone have been

shown to have an effect of up to 30% on the SUV (*9-13*). The need for standardization in PET has been recognized as key in this situation particularly regarding image acquisition, reconstruction and QC of the instrumentation (*5-7*). Takashi *et al*. showed that standardized protocols reduced the variation in the SUV between different scanners from 47% to 23% (*14*), while Boellard *et al*. observed this could be reduced as low as 10% (*15*). Our earlier work within the PBTC indicated that a central analysis of the SUV data reduced the variable range by at least a factor of 2 (from 29.9%–42.8% to 7.7%–23.2%) (*8*). Several more recent studies have confirmed variability in quantitative parameters on the order of 10-15% (*16-18*).

Differences in scanner performance and the reconstruction algorithms between sites are difficult to eliminate as these are often specific to the scanner hardware and software that is available. Recently, insight into these technical limitations was provided using the NEMA NU-2 Image Quality (IQ) phantom and the 3D Hoffman anthropomorphic brain phantom (*19*). In multicenter clinical trials it is important for image resolution to be matched as closely as possible across sites since it is difficult to correct for these differences after the fact. Fortunately, harmonization across different PET scanners has been well studied (*20-23*). To this end, the make and model of scanners in multicenter clinical trials needs to be recorded (*24-26*). Daily QC routines and cross calibration of the PET scanner with the dose calibrator is also necessary. Further, all scanners in the trial should undergo a qualification process by the same mechanism prior to scanning the first patient and throughout the trial. Therefore, standardized phantom experiments are needed so that differences between scanners can be ascertained and corrected for (*27-29*).

We found variation in precision of quantitative PET metrics across the PBTC sites. The phantom we used was unique. With one acquisition, spatial resolution, quantitative accuracy, uniformity and clinical image quality could be evaluated. However, as discussed in the RESULTS, the phantom was also relatively complex in design and filling instructions than the conventional ACR PET phantom or even the 3D Hoffman brain phantom. In our phantom, 4 ports needed to be filled with three different activity concentrations. This complexity led to the phantom being sub-optimally filled in several instances and likely contributed, at least in part, to the variability in results. Indeed, there was considerable variability in quantitation, both in the background region uniformity and with respect to the gray and white matter contrast and gray/white ratio. Since a number of sites had filling difficulties, we concluded that the phantom's

complexity contributed to the suboptimal filling. In the context of standardization for a clinical investigation, it is essential that the phantom be prepared in a consistent manner which was not the case with this phantom. We considered resending the phantom to those sites with suboptimal filling. However, it took nearly a year to circulate the phantom through the 11 sites and there was concern that further delay would compromise the comparability of the results.

Less than 40% of the scanners had an SUV_{ave} within 10% of unity. The SUV_{max} of the gray matter had a range from 3.06 to 8.25, almost a 3-fold variation across 13 scanners. Less than 10% of scanners demonstrated a white matter SUV_{ave} within 10% of the expected value and the COV for the gray matter SUV_{max}, white matter SUV_{ave} and gray/white ratio was 28.8, 60.4 and 68.0%, respectively. However, 12 of the 13 scanners were subjectively judged to demonstrate very good or excellent uniformity. Further, the overall visual inspection of image quality of the clinical simulation section was very good to excellent, although there were several examples of lower image quality. As might be expected, standardization can be more relaxed with subjective visual assessment compared to absolute quantitation.

A limitation of our study is that we could not distinguish variability quantitation resulting from suboptimal phantom filling, inadequate scanner calibration, or improper data acquisition/processing. A simpler phantom may have made these differences easier to discern but may have required the acquisition of multiple phantoms to attain the same data. The use of multiple phantoms is certainly challenging within the context of a multicenter trial. Variations in performance within multicenter clinical trials can be substantial. The use of phantoms can help to highlight the extent of the differences between sites and potentially allow for compensation for these differences. If a more complex phantom is to be used, considerable training regarding correct phantom preparation is essential.

CONCLUSION

In summary, this was a powerful phantom that could evaluate uniformity, resolution quantitative accuracy and clinical image quality with a single acquisition. However, the phantom was complex in design and filling instructions leading to suboptimal filling in several instances. There was considerable variability in quantitation in several aspects of the phantom, and it was difficult to determine if this variability resulted from suboptimal filling, inadequate scanner calibration or poor image quality.

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DISCLOSURE

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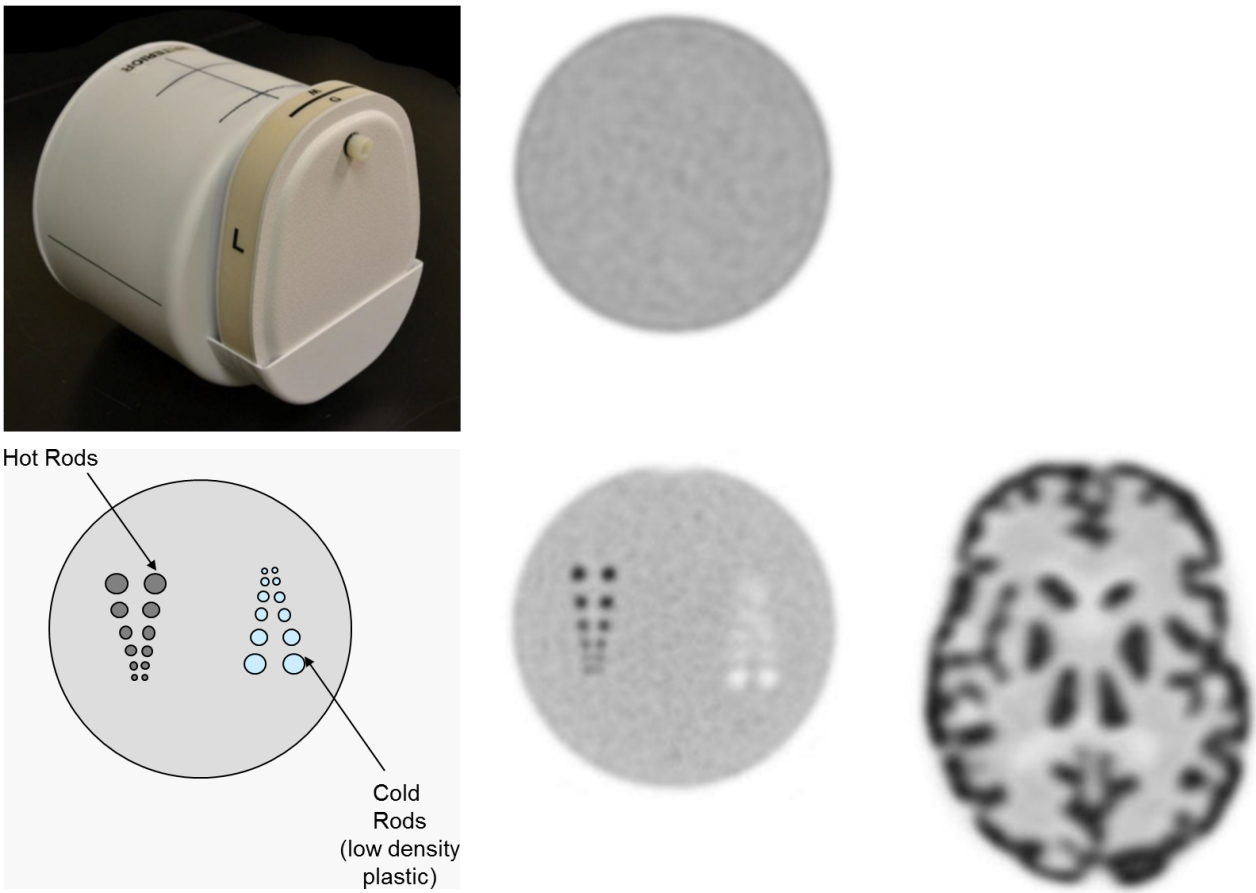


Figure 1. The SNMMI/CTN Qualification Phantom for PET Brain Imaging. A. Exterior of the phantom with the uniformity/resolution section to the left and the clinical simulation section to the right. B. Image from the uniformity section. C. Schematic of the resolution section. D. Image of the resolution section. E. An image of the clinical simulation section.

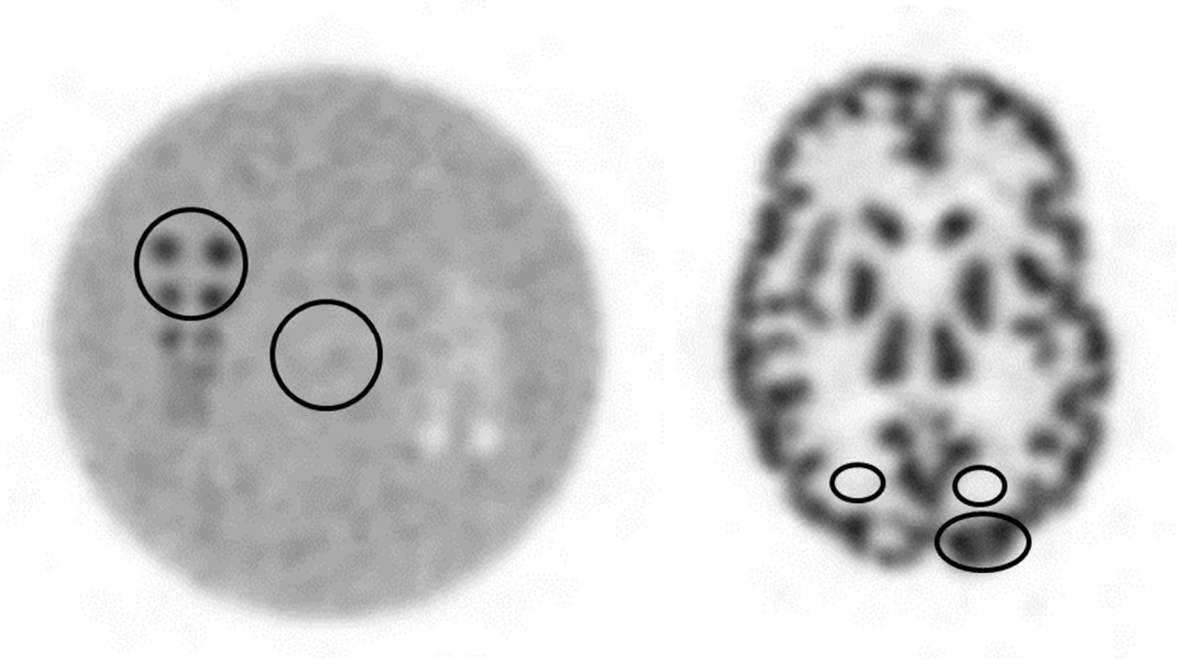


Figure 2. Resolution and clinical simulation phantom with ROIs drawn. A. Resolution section. B. Clinical simulation section.

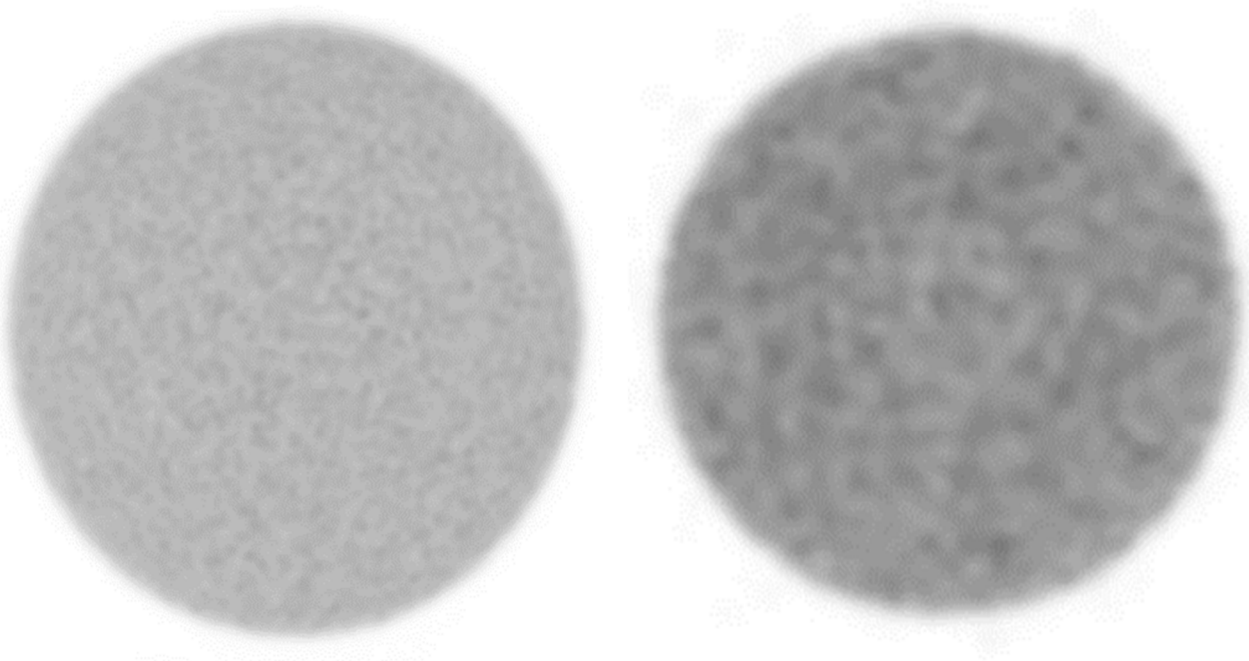


Figure 3. Images from uniformity section. A. Imaged judged “excellent”. B. Image judged “good”

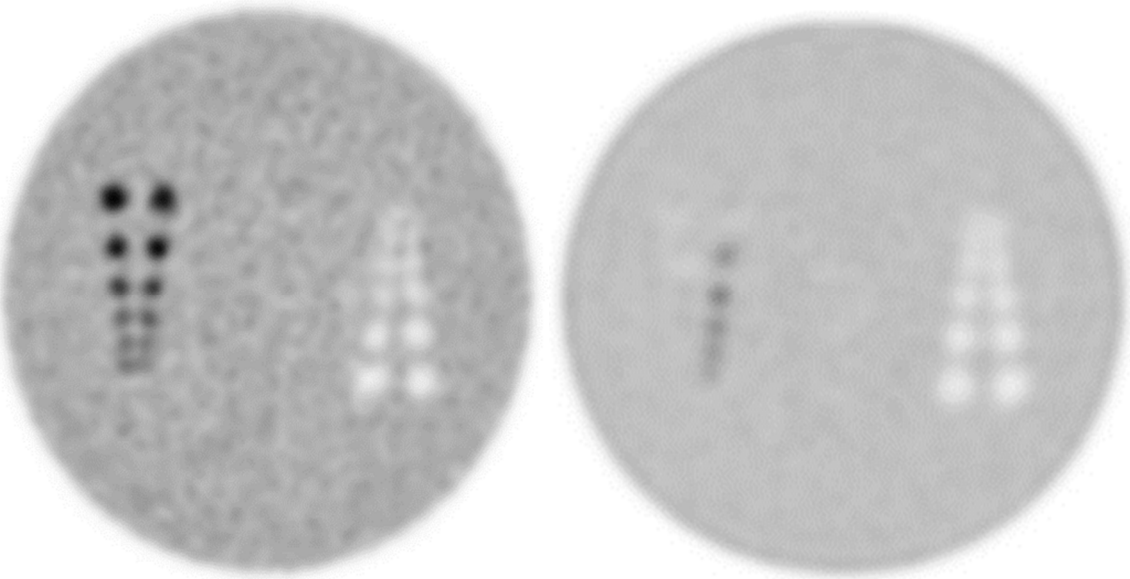


Figure 4. Images from the resolution section. A. Image with proper filling. B. Image with improper filling.

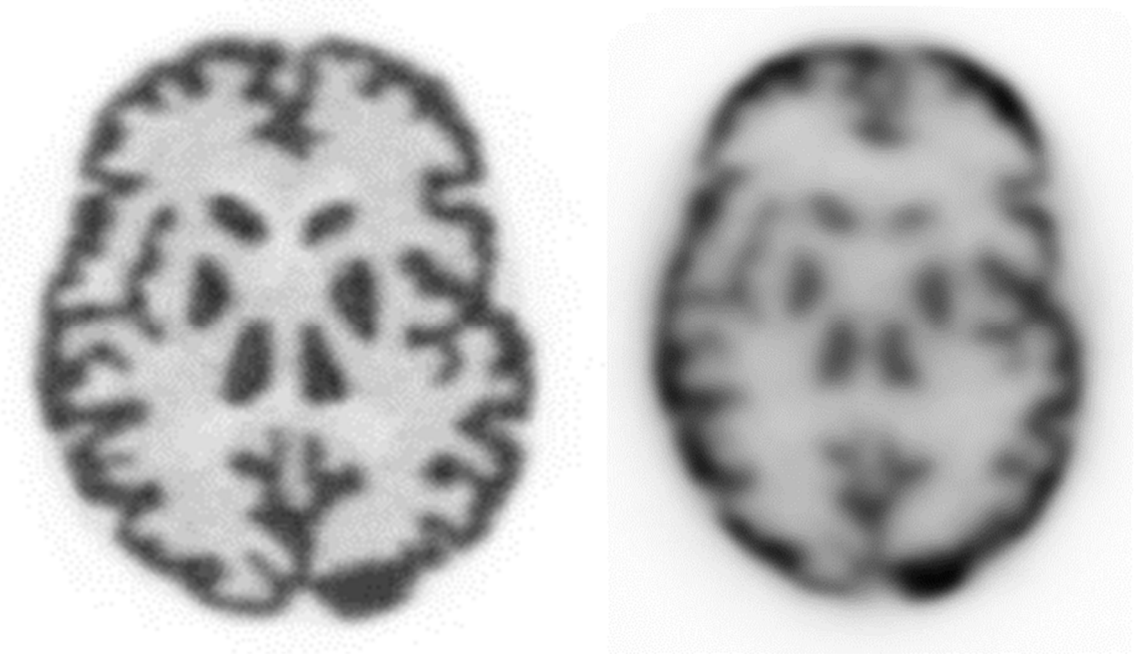


Figure 5. Images from clinical simulation section. A. Imaged judged “excellent”. B. Image judged “unacceptable”.

Table 1 - Participating Institutions of the PBTC at time of phantom experiment

Boston Children's Hospital
Cincinnati Children's Hospital Medical Center
Duke University
Children’s Hospital Los Angeles
Ann & Robert H. Lurie Children’s Hospital of Chicago
Memorial Sloan Kettering Cancer Center
National Institutes of Health
UPMC Children's Hospital of Pittsburgh
St. Jude Children’s Research Hospital
Lucile Packard Children’s Hospital at Stanford
Texas Children's Hospital

Table 2 - Camera Models

GE 600
GE 690 (4)
GE STE (2)
GE VCT
Phillips Gemini Tru Flight
Phillips Gemini 3000
Phillips Ingenuity TF-64
Siemens mCTX
Siemens mCT 64

Numbers in parentheses represent the number of scanner types. No parentheses indicates a single scanner type

Table 3 - Evaluation of Uniformity Section

Scanner	SUV_{ave}	COV (%)	Max Slice Deviation	Subjective Rating
Scanner 1	1.04	3.68	0.62	1.5
Scanner 2	0.94	6.93	-3.50*	1.5
Scanner 3	1.15	5.10	-0.93	2.0
Scanner 4	1.18	5.20	-8.50*	1.5
Scanner 5	1.11	6.82	-0.83*	2.0
Scanner 6	1.11	6.33	2.21*	1.0
Scanner 7	1.22	5.93	-6.51*	1.5
Scanner 8	0.75	4.16	-4.09	1.5
Scanner 9	1.12	7.32	2.28	3.0
Scanner 10	1.20	3.38	0.36	1.0
Scanner 11	1.84	3.74	-1.80	2.0
Scanner 12	1.04	3.98	-2.81	2.0
Scanner 13	1.06	6.38	4.23*	1.5
Ave	1.14	5.30	-1.48	

* near end or mis-fill

Table 4 - Evaluation of Resolution Section

Scanner	Cold Rods	Hot Rods	Rod Contrast
Scanner 1	3.5	5	3.30
Scanner 2	2	4	3.07
Scanner 3	2.5	5	3.47
Scanner 4	2.5	5	3.66
Scanner 5	1	4	2.72
Scanner 6	1	4	2.96
Scanner 7	1	4	2.37
Scanner 8	3	4.5	-
Scanner 9	1.5	3.5	2.76
Scanner 10	1	4.5	2.55
Scanner 11	3.5	5	4.58
Scanner 12	1	4.5	2.28
Scanner 13	3.5	5.5	5.18
		Ave	3.24

Table 5 - Evaluation of Clinical Simulation Section

Scanner	Gray SUV_{max}	White SUV_{ave}	Gray/White Ratio	30 min Quality	6 min Quality
Scanner 1	4.25	1.14	3.76	2.0	2.0
Scanner 2	4.30	0.40	10.65	1.5	1.5
Scanner 3	4.30	0.28	15.39	1.5	1.5
Scanner 4	4.49	2.57	1.75	1.5	1.5
Scanner 5	4.49	1.96	2.29	2.0	2.5
Scanner 6	4.46	1.13	3.94	1.5	2.5
Scanner 7	4.50	0.58	7.76	3.0	3.5
Scanner 8	3.24	0.63	5.19	1.5	1.5
Scanner 9	3.06	0.51	6.05	2.0	2.0
Scanner 10	3.98	1.80	2.22	3.0	3.0
Scanner 11	8.27	1.50	5.51	1.0	1.0
Scanner 12	3.61	0.97	3.72	2.0	2.0
Scanner 13	5.57	1.21	4.61	1.0	1.0
Ave	4.50	1.13	5.60		
COV	28.83%	60.37%	68.02%		

SNM Clinical Trials Network

www.snm.org/clinicaltrials

Society of Nuclear Medicine
Multi-Center Trial Brain PET Phantom

Facility Name: _____

Address:_____

Address:_____

City _____, State _____ Zip code_____

Department Contact for phantom data: _____

Title: _____

Email Address: _____

Telephone: (_____)_____

Fax Number: (_____)_____

PET SCANNER DATA

Manufacturer _____

Model _____

Year Purchased _____

# of Detectors _____

Crystal Type BGO _____ LSO _____ GSO _____ LYSO _____
Other (specify) _____

Mode for oncology PET 2D____ 3D____ TOF____

Attenuation Correction by: CT_____ (number of slices _____)

Dose Calibrator
Manufacturer _____ Model _____ Year Purchased _____

Have you adjusted the F-18 setting, if recommended by the manufacturer (Y/N)____

Record the F-18 calibration number_____

READ ALL INSTRUCTIONS CAREFULLY AND BEFORE COMMENCING WITH THIS EXERCISE TO FILL AND USE THE PET BRAIN IMAGING SIMULATOR

SAVE THE BOX AND PACKING MATERIALS

PET Brain Phantom
Filling Instructions

READ ALL FILLING INSTRUCTIONS TWICE PRIOR TO LOADING THE PHANTOM.

PRE-FILL LEAK TEST:

Fill the cylinder of the phantom through the top fill port with deionized water; if not available, use tap water.
Dry the outside of the phantom and place it on its side, then let sit for several hours.
Check the phantom to ensure that there is no leakage of water.

IF YOU LEAK TEST THE PHANTOM PLEASE EMPTY THE CYLINDER COMPARMENT BEFORE FILLING FOR FILLING AND IMAGING.

Items needed:

PET Brain Phantom and funnel (provided)
Dose Calibrator with F-18 setting
Two 10 cc (or 12ml) syringes
Four 1 cc syringes with removable needle
One 3 cc syringe
Two 3-way disposable stopcocks
One 50 or 60 ml syringe with Lure connection
1,000 ml bag of sterile water (or saline) for injection (not glucose)
1,500 ml 70% isopropyl alcohol
5 mCi [185 MBq] F-18 FDG
absorbent plastic-backed pads
sink or water supply (distilled water preferred if readily available)
disposable gloves
radiation badges
lab coat
timer or clock

Filling the phantom for imaging:

NOTE: The amounts of radioactivity used are for one hour prior to imaging and should not be changed. Adhere to the filling and imaging times.

Synchronize your clock with the time on the PET scanner.

NOTE: You may prepare the dilution bag (sterile water or saline) and the clinical brain slab section of the phantom one day prior to imaging the phantom.

Preparing the dilution bag of 70% Isopropanol.

1. Completely empty the 1,000 ml bag of all liquid.
2. Label the bag as "Isopropanol – not for patient use."
3. Using the 50 or 60 ml syringe fill the bag with 1,000 ml of 70% Isopropanol. Fill as accurately as possible to have a 1,000 ml volume. You may set the bag aside for use below in step 9 (page 7).

Signature of person filling bag with 70% Isopropanol._____

Preparation of the clinical brain slab "W" section of the phantom.

1. Take the brain slab section of the phantom and remove the fill port screw from the compartment labeled "W".
2. Place the phantom on a flat horizontal surface with the open "W" fill port facing up.
3. Using the 50-60 ml syringe, fill the "W" compartment with 70% Isopropanol (approximately 275 ml).
4. When the compartment is filled to overflowing, carefully elevate the fill port end of the phantom slightly to ensure that it is completely full. Add additional 70% Isopropanol if necessary.
5. Take a 3 cc syringe and remove 2 ml of the Isopropanol and replace the "W" fill port screw.

You may set this section aside for use in step 7 (page 6).

DATE PHANTOM SCANNED:_____

Record the serial number on the bottom of the phantom _____

Don lab coat, radiation badges, and gloves. Clear a work area to fill the phantom and place absorbent plastic-backed pads on the work area under the phantom.

Preparation of three syringes of F-18 FDG.

HELPFUL HINT: Place the 5mCi of FDG in a 5ml syringe and add saline or water to bring the volume to 5 ml (1mCi/ml). This will then be relatively easy to obtain the three doses of activity needed to fill the compartments of the phantom.

1. Using a 1 cc tuberculin syringe draw up F-18 FDG into a syringe to measure approximately 1.014 millicuries [37.52MBq] (**the amount must be between 0.984 and 1.045 mCi [36.42 and 38.67 MBq**).

Label this as syringe "U" to fill the uniform section of the phantom.

Record the exact activity _____ (circle one) mCi MBq
Record the clock time _____ (imaging will need to begin in exactly 1 hour)

2. Using a 1cc tuberculin syringe draw up F-18 FDG into a syringe to measure approximately 0.979 millicuries [36.23 MBq] (**the amount must be between 0.950 and 1.008 mCi [35.15 and 37.32 MBq]**).

Label this as syringe "G" to fill the gray matter (G) section of the phantom.

Record the exact activity _____ (circle one) mCi MBq
Record the clock time _____

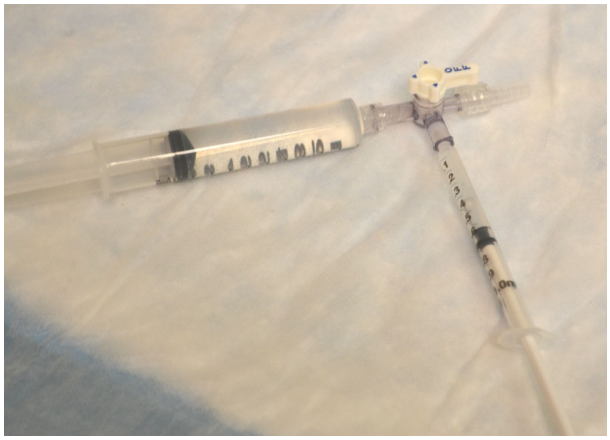
3. Using a 1cc tuberculin syringe draw up F-18 FDG into a syringe to measure approximately 0.673 millicuries [24.91 MBq] (**the amount must be between 0.653 and 0.693 mCi [24.16 and 25.66 MBq]**).

Record the exact activity _____ (circle one) mCi MBq
Record the clock time _____

Label this as syringe "W" to fill the white matter (W) section of the phantom.

4. Take a 10 ml syringe and add 10.0 ml of 70% Isopropanol. Look at the volume in syringe W. From the 10 ml syringe, eject the volume of liquid that is in syringe W. Label the 10ml syringe as "W/10".

5. Connect the 10ml syringe to the 3-way stopcock as shown below and also attach syringe W containing the 0.673 mCi of FDG. Carefully add the radioactive FDG to the 10cc syringe and wash between the two syringes to flush all activity out of the 1cc syringe. Deposit all activity and volume into the 10ml “W/10” syringe.

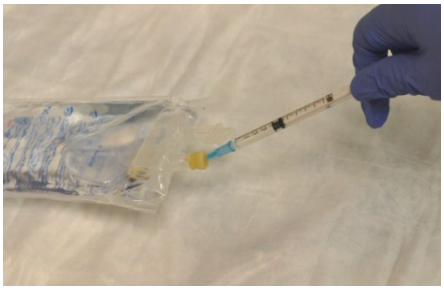


6. Attach the 10cc syringe to a new 3-way stopcock and attach a new 1cc tuberculin syringe. Fill the 1cc syringe with 1.00ml of the diluted FDG from the 10cc syringe.

7. Add the activity from this 1.00cc syringe to W compartment, which was previously filled with Isopropanol. Flush the syringe 2-3 times to deliver all of the radioactivity.

8. Place the short screw “W” in the W side fill port and secure. Gently rotate the phantom in several directions for 30 second to mix the radioactivity thoroughly.

9. Inject **syringe G** (0.979mCi or 36.23MBq) into the 1,000 ml bag of Isopropanol and flush the syringe 2-3 times to ensure that all of the activity has been injected into the bag.



10. Record the residual radioactivity of syringe G _____(circle one) mCi MBq and time _____.

11. Carefully mix the bag several times to ensure uniform distribution of F-18 within the solution.

12. As shown in the figure on page 8, remove the fill port screws from the cylinder section of the phantom and place the phantom with the rectangular packing material or clinical slab under the edge of the phantom to level the phantom.

13. Withdraw 10cc of liquid from the 70% Isopropanol bag using a 10cc syringe. Remove the needle and connect to the tubing as shown below. Slowly inject the liquid to completely empty the syringe. Inject no faster than 1ml/5 seconds. **REPEAT FILLING TO DELIVER A TOTAL OF 40cc INTO THE TUBING.** Do NOT add air behind the injected liquid. Replace the tubing cap when finished.

14. Remove the fill port screws and place the funnel into the one of the fill ports and add room temperature water (distilled water preferred if available) until filled (approximately 4,145 ml).

**THE PHANTOM IS VERY HEAVY WHEN FULL –
HANDLE WITH CARE**

15. Remove 5 cc of water from the main fill port. Inject syringe “U” (1.045 mCi or 37.52 MBq) and flush the syringe several times to ensure all activity has been injected into the phantom. Replace the fill port screws.

    Measure the residual radioactivity of the syringe and record this measurement and the time. _____(circle one) mCi MBq, time_____.

16. Hold the cylinder phantom firmly in both hands and **gently** rotate the phantom back and forth for one minute to mix the F-18.

17. Place the brain slab phantom horizontally on a flat surface covered with an absorbent pad as shown below, with the G side facing up and remove the fill port screw. Elevate the fill port end slightly to allow air to leave the chamber.

18. The G side of the phantom is filled with the dilute radioactivity from the Isopropanol bag. Use the large syringe to withdraw 50ml increments from the bag and inject into the G fill port. Repeat this process to completely fill the G side of the phantom with approximately 308 ml.

Replace and secure the screw cap. Gently rotate the phantom in several directions for 30 seconds to mix the radioactivity thoroughly.

Attestation: I have filled the phantom according to the instructions and correctly recorded the actual activity and time.

_____ Signature

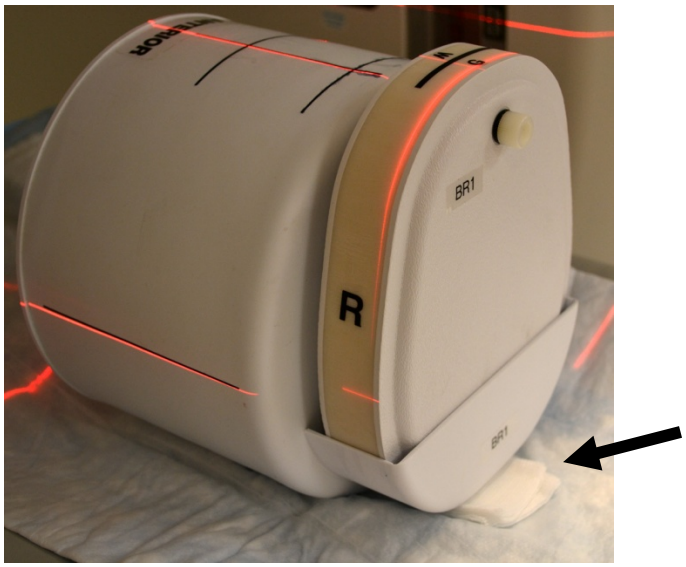
_____ Print name

_____ Date Phantom Scanned

PET Brain Phantom Imaging

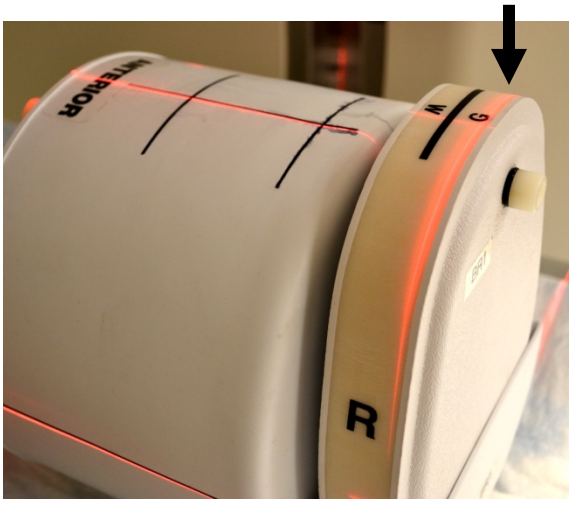
The PET acquisition should be started at exactly one hour from the time that syringe U was measured. Position the phantom and perform the CT scan before the one hour timepoint.

1. Place the cylinder part of the phantom on the imaging table with the fill ports into the gantry. Slide the clinical slab section of the phantom into the slot at the bottom of the cylinder phantom.
Carefully align the phantom with the positioning lasers in the X, Y and Z planes and center the phantom in the center of the gantry (strive for alignment to within 1 mm).

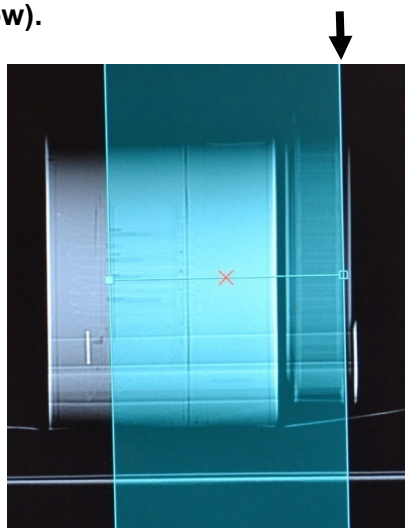


Add padding to elevate the end of the phantom if necessary so that the phantom is aligned with the lateral lasers .

As shown below position the bottom of the field of view for one bed position at the bottom edge of the clinical slab section of the phantom.



2. Once the phantom has been properly aligned <u>select the brain protocol</u> and perform the scout scan. Position the area to be scanned at the bottom of the clinical slab section of the phantom (arrow).



Patient Information:
Patient name: (use facility name**:_____**
(Example: **Whoville MedCenter**)
MRN:_____ (enter date of acquisition as the Medical Record Number)

Patient weight: 63 kg (or 140 lbs) **Weight entered_____**
Patient height: 64 inches or 163 cm **Height entered_____**
F-18 Dose – enter 15 mCi **Dose entered _____mCi (or MBq)**
(circle one)

Enter the injection time – enter time of F-18 syringe U dose calibrator reading (1hr prior to PET imaging)

3. Low dose CT Parameters:

Scout scan parameters may be selected at the discretion of the site.
Following the scout scan select the center portion of the phantom to acquire a two or three bed position scan using your most commonly used clinical protocol.
Record the number on the bottom of the phantom _____
Date of imaging _____
Time imaging CT started _____
Low dose CT parameters used:
kVp _____ kVp
mA _____ mA **(do not use an mA lower than 50)**
rotation time _____ sec
collimator setting _____ mm
pitch _____
table feed per 360 rotation _____ mm/sec

slice thickness _____ mm **(4mm recommended)**

AC-CT Reconstruction Parameters (use factory settings for the CT for attenuation correction).

CT Reconstruction Parameters

slice thickness _____ mm **(4mm recommended)**
increment _____ mm **(same as slice thickness)**
FOV _____ mm
matrix size _____X_____
filter _____

4. PET Parameters

Date of phantom imaging _____

Enter PET scan start time:_____ **(should be exactly one hour from F-18 syringe U dose calibrator reading)**

Scan time per bed position ___30____minutes

Imaging mode: 2D____ 3D____ Time of Flight____

Reconstruct images with and without attenuation correction and label files accordingly.
PET parameters: Parameters you used:
Iterative reconstruction algorithm _____

Matrix size _____
FOV _____ mm
Filter name (Gaussian, etc) _____
Filter parameter _____ mm
If 3D mode use: (FORE rebinning, SSRB…) _____
Iterations (if applicable) _____
Subsets (if applicable) _____
Segmented CT-AC (turn on) _____ **(turn on if available, on GE use AC CT file for attenuation correction)**
Scatter correction (on or off) _____
PET slice thickness _____ mm
Does system have advanced HD filtering? _____ Did you use HD(PFS) filtering?____
If yes please describe this software option_____
_____

If you have technical questions regarding filling and imaging of the phantom contact:
Paul Christian at paul.christian@hci.utah.edu or (801) 581-2882.

IMAGE RESULTS

Using the PET scanner, create a copy of the DICOM PET and CT axial reconstructed slices on CD. **Do not include DICOM display software.**

Please provide only 3 scan files on CD:

_____ Axial CT (not the CT-AC map)
_____ AC PET (attenuation corrected PET axial)
_____ Non-AC PET (no attenuation correction PET axial)

DO NOT CREATE CDs on any computer except the commercial PET scanner acquisition station.

GE systems please use the AW workstation (not Xeleris)
Siemens systems please use the eSoft workstation
Philips systems please use Philips workstation

Name of person creating CD:_____

Type of workstation used and model:_____

Retain a copy of the DICOM images at your site for future analysis.

As soon as the images are received at the location below you may be asked to perform further review/analysis of the images.

Using a personal computer connected to the internet upload the images to the CTN Keosys server according to the instructions provided.

Email or fax all pages of the completed forms to:

Tina Kiss
tkiss@snm.org
Fax: (440) 356-5473

Decay and emptying of the brain phantom

1. Following imaging place the phantom in an appropriately shielded area for decay for 48 hours prior to emptying.

2. After decay you may empty the phantom by removing the fill and vent port screws and empty the water.

3. Empty the G side of the clinical slab phantom by pouring out the water.

4. If you may be repeating the phantom for another session of imaging you could keep the Isopropanol that is in the W side of the clinical slab phantom by pouring it into a container for later use.

5. Empty the cylinder section of the phantom by removing both gray fill port screws and drain the phantom.

6. To empty the tubing, place the phantom with the fill port and tubing up. Use a 10 cc syringe and drawing all liquid back into the syringe.

7. The phantom contains no radioactivity and may now be stored or shipped.

NOTE: if the phantom will be shipped please do not completely tighten the fill port screws.

<u>Packing for shipping</u>. To ship the phantom, please pack the phantom with the Styrofoam pads on the ends of the phantom cylinder.

Be sure to include ALL PARTS of the phantom as well as the funnel.

Version 05182012