

PET Phantom Instructions for Evaluation of PET Image Quality



ACR Nuclear Medicine Accreditation Program

PET Module

Instructions and Test Image Data Sheets for Submission of PET Phantom Images

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I. INTRODUCTION

This booklet is to be used by the facility applying for accreditation in PET imaging. Site scanning data forms should be completed for each PET system that is undergoing accreditation. The facility should make additional copies of the forms as needed.

PET Imaging

This module is for the accreditation of PET imaging systems. Phantom data must be acquired with the ACR-approved PET phantom that may be purchased from Data Spectrum. The phantom described below was chosen for evaluating PET tomographic systems because it is relatively easy to fill and set up for a PET study and can be used to measure tomographic uniformity, spatial resolution, and the detectability of “hot” lesions. The variety of resolution and “hot” components enables the reviewers to see relatively subtle differences in system performance.

Evaluation of the Submitted Images

Phantom images will be submitted to a review panel of qualified medical physicists for scoring. The Nuclear Medicine Accreditation Committee has defined acceptable standards for uniformity, spatial resolution and lesion detection. The standards are based on results obtained from a variety of PET systems operating satisfactorily.

Uniformity and noise are evaluated qualitatively by inspection of reconstructed tomographic sections. Optimal density ranges should be comparable to those used for clinical images. Spatial resolution is judged by identifying the smallest “cold” rods in the ACR-approved phantom and lesion detectability is determined from the “hot” cylinders using the region-of-interest protocol on page 8. The same protocol is also used for the “cold” cylinders that demonstrate the effectiveness of the attenuation and scatter corrections.

Evaluation of SUV Analysis Worksheet

*******NEW 2010 PASS/FAIL CRITERIA for SUV Values (revised December 2, 2009):**

Mean Bkgd: 0.85 – 1.15

25 mm cylinder: >1.8 - <2.8

16/25 ratio: >.7

Old 2009 criteria currently being used:

25 mm cylinder: >1 - < 4

NOTE: Data must be collected and images prepared according to the instructions. The procedures may differ from those normally used by the applicant but were designed to minimize the variability in the images that are submitted. Despite the use of a specific protocol, it is understood that there will still be differences in the appearance of the images even when the data are collected on the same type and model of PET system and/or scintillation camera.

II. PHANTOMS

For each PET system, the applicant is required to submit a list with the frequency of all PET-related quality control procedures (see “PET Quality Control Summary” form on page 13). This should include yearly, quarterly, monthly, weekly, and daily tests.

The ACR-approved PET phantom must be used for evaluating tomographic image quality. It is a cylinder with an internal radius of 10.8 cm. The faceplate has fillable thin-walled cylinders (8, 12, 16, and 25 mm in diameter), two additional 25 mm cylinders, one for air and one for “cold” water, and a Teflon cylinder.¹ The **lower portion** of the cylinder contains six sets of acrylic rods arranged in a pie-shaped pattern with the following diameters: 4.8, 6.4, 7.9, 9.5, 11.1, and 12.7 mm. In addition, for the SPECT/PET version of the phantom, the **upper section** contains six solid spheres. **The spheres must be removed for PET acquisitions. RODS MUST REMAIN.**

The protocols for preparing the PET phantom are presented on pages 5 and 6. The Table of Dilutions to produce the 2.5 concentration ratio (2.5:1 ratio may represent a lesion in the liver) is found in the Appendix, page 10. The values that you select should be the one with the activity (first column of the Table) used by your facility for clinical whole body scans. However, if the activity is between the values, you must use the one with the higher level. For example, if your facility uses a 5 mCi dose for the whole body scan, you must select the 6 mCi row from the Table. The activities that are used for the initial Dose A and for the phantom itself, Dose B, are calculated from the F-18 activity normally used by the facility for whole body scans. As indicated above, the second 25 mm vial must be filled with water and the third left empty (“air”).

The spreadsheet indicates the activity that must be used for filling the phantom (this will also be referred to as the “background”) and the “hot” cylinders (“lesions”). Care must be taken to ensure that the solutions in the background and 1,000 ml bag (or bottle) are thoroughly mixed.

Acquire the best possible images on your system with the same protocol as a routine clinical whole-body scan. All settings must be documented. Reconstruct the entire phantom as you would for clinical studies.

The ACR strongly recommends quarterly testing of each PET system with an appropriate phantom such as described above in addition to other tests recommended by the vendor.

¹ The PET phantom faceplate design is being used by the ACR with the permission of Peter D. Esser, Ph.D., Columbia University. The intellectual property rights belong to Dr. Esser, and uses other than through the ACR require his permission.

III. PREPARATION OF PHANTOM

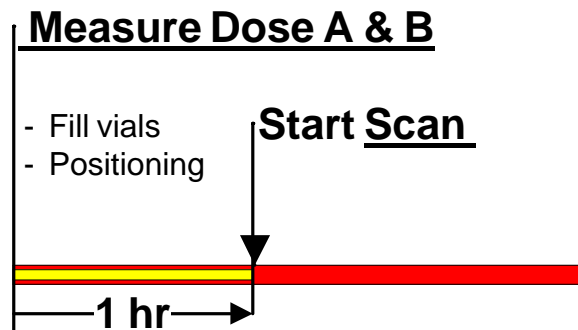
Please read all of these instructions before preparing the phantom.

Select the appropriate dose in the Appendix (see page 10) that is equal to, or the next one above, the dose that is used by your facility for clinical whole body scans. You will need this spreadsheet for preparing the phantom. Confirm that all calibrations and quality control procedures are current.

Summary

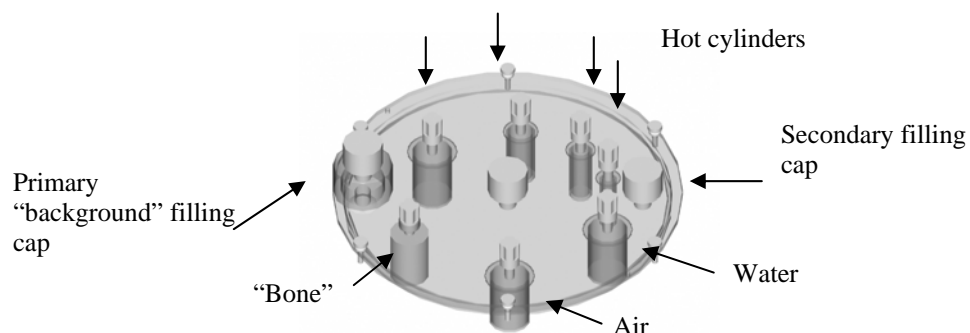
One scan will be acquired with the ACR-approved PET phantom. The phantom scan starts 1 hour after Dose A is measured. During the 1 hour preparation time the other doses are measured, vials are filled, background added to the phantom, and phantom positioned in the gantry.

Scanning Time Line for PET Phantom



Equipment Required:

- 1 ACR-approved PET Phantom
- 1 1,000 ml bag or bottle of distilled water or saline solution
- 2 tuberculin syringes (for measuring **Doses A & B**)
- 3 large syringes (60 ml)
- Large-bore needles (18 gauge)
- Dose: FDG or F-18 are acceptable (Most vendors provide F-18 for calibrations/tests of scanners at a significantly lower price than FDG.)
- Clock or timer
- Phantom Dilution Worksheet (Page 12)



PET phantom viewed from above

For ACR PET Phantom

- 1) Measure F-18 activity (**Doses A, B**) using the tuberculin syringes and enter the dose and time in the appropriate boxes on the Phantom Dilution Worksheet. The F-18 solution may need to be diluted to facilitate measurement because the concentration is often as high as 75 mCi/cc. For future reference, enter times into the table below.
- 2) Fill the phantom with water. Be sure that the Teflon cylinder on the faceplate is secure before fastening the faceplate to the phantom.
- 3) Add **Dose A** to the 1,000 ml bag or bottle of distilled water or saline and flush syringe several times. Mix thoroughly. Using a large syringe, withdraw a 60 ml test **dose #1**. Set aside. From this bag or bottle, using the second large syringe, withdraw approximately 40 ml for use in filling the four appropriate empty cylinders (8, 12, 16, and 25 mm) in the phantom faceplate (see above illustration). Fill the cylinders at this time with the “hot” solution. There should be two 25 mm cylinders remaining. Leave the 25 mm cylinder next to the primary extended filling cap empty (see diagram above), and fill the neighboring 25 mm cylinder with “cold” water.
- 4) Inject **Dose B** into phantom and flush syringe several times (phantom background activity). Thoroughly mix (a bubble of air will help ensure a well-mixed solution).
- 5) Using a large syringe, remove a 60 ml test **dose #2** from the phantom.
- 6) Measure test **doses #1 and #2** in the dose calibrator and fill in the appropriate boxes. After recording the activity for **doses #1 and #2**, inject the activity from **dose #2** back into the phantom background. *Note: The plastic holder must be removed from the dose calibrator before the individual syringes are assayed. The change in geometry will not affect measurements because the parameters of interest are ratios*
- 7) **Scan must begin 1 hour after the initial Dose A was measured.**

Enter dose A measurement time, mCi and scan start time (these are needed for the worksheet on pg 12):

- 1) **Dose A measured at** _____
- 2) **Dose in mCi** _____
- 3) **Phantom scan to start at** _____

IV. DATA ACQUISITION AND PROCESSING

A. Positioning

Phantom

If the phantom does not have a flange on the top, place the phantom on its side at the end of the imaging table. Carefully align the phantom parallel to the axis of the table (left to right). Use a bubble level to position the phantom in the horizontal plane. A folded 3 x 5 card positioned under the end of the phantom can be used to make it level. If a metal plate is present, move the phantom to a position where the plate does not attenuate the photons.

If the phantom has a flange at the top, it should be placed on the table with its flange hanging over the edge. Carefully align the phantom so it is parallel to the axis of the table. However, if the imaging table has a metal plate at the end, the phantom should be moved to a position where the plate does not attenuate the photons. Material must be placed under the bottom of the phantom, to make it level. To avoid excessive attenuation, the material should only be under the bottom (rod side) near the end of the phantom, not the entire length of the phantom. If the table is continuous, material must also be used to level the phantom.

B. Acquisition

For the acquisition, use your facility's whole body protocol (zoom =1) with the same settings that are used for routine clinical studies.

C. Reconstruction

Reconstruct the entire phantom with the same protocol used for whole body scans including pre- and post-reconstruction filters. Generate 1 cm thick transaxial slices for analysis.

(All acquisition and reconstruction parameters should be recorded on the appropriate form on page 14.)

D. Attenuation Correction

All images must be corrected for attenuation with the same protocol applied to patient data.

(Record the parameters on page 14.)

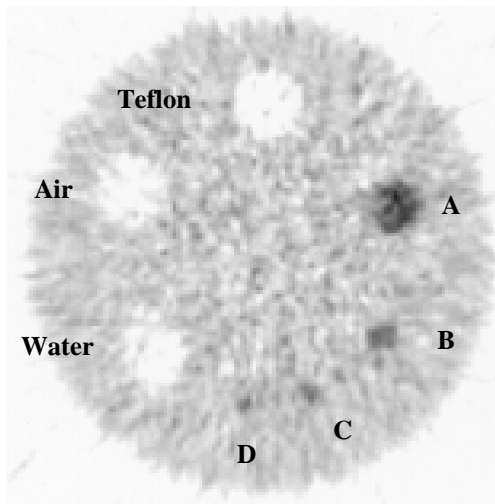
E. Analysis

The worksheet for calculations can be found on page 15.

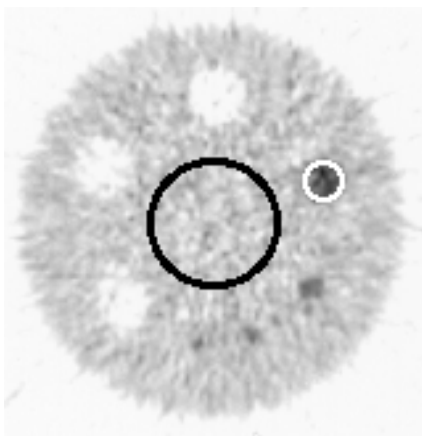
V. ROI ANALYSIS OF 1 CM TRANSAXIAL SLICE FROM PET PHANTOM

Regions-of-interest selection: use the minimum, maximum and mean SUV* statistics from these regions for the analysis section.

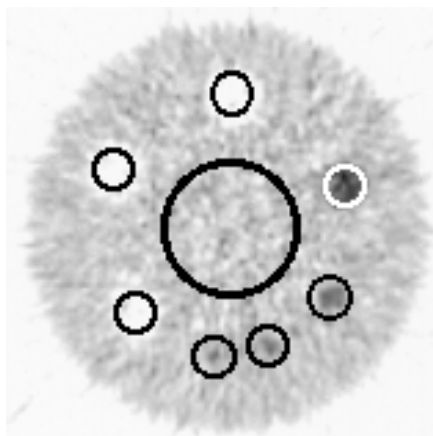
Select the “best” 1 cm slice showing “hot” cylinders (A, B, C & D). An example is shown on the right.



B) Draw a background region (ROI) in the center of the slice as shown below (diameter = 6 to 7 cm). Small variations in size or location of this ROI are not important. Next draw an ROI just inside the largest hot cylinder found in the slice (the ROI is shown below in white over the 25 mm cylinder).



C) Place copies of the smaller ROI (as shown in B) over the other visible objects in the phantom slice as shown below. The ROIs should be inside the Teflon, water, and air regions. Note that all four of the hot cylinders may not be observed; only the visible cylinders require ROIs. Make a hard copy of the final ROIs.



* See the Phantom Dilution Worksheet, page 12, for SUV parameter instructions.

VI. Hard Copy*

A. Transaxial Slices for Phantom Scan

Prepare films that show all of the transaxial slices (1 cm thick) of the phantom. ***This should include the rod portion of the phantom.***

Each image on the film should be between 3 and 6 cm in diameter. Images less than 3 cm are too difficult to read and will be returned to the facility without being reviewed.

Use linear mapping of the display with the lower threshold set at zero and the upper threshold set to the maximum count (or whatever is satisfactory to produce a good gray scale). When there is linear mapping in an image, an ROI with twice the number of counts will have twice the intensity. *Use appropriate bar-coded labels.*

B. ROI Images from Phantom Scan

Prepare a sheet of film that shows the image of the “best” 1 cm slice of the **hot cylinders** from phantom Scan with the final **ROIs** image (see previous page). *Use appropriate bar-coded labels.*

Each image should be between 3 and 6 cm in diameter.

****Sites may also submit images (JPEG, TIFF, etc.) on CDs (please seeing testing instructions)***

APPENDIX: PET Phantom Activation Based on Patient Dose

From the left column on the Chart below, select the administered FDG whole-body dose for your site. The corresponding phantom Doses A and B are along the same row as the Patient dose. Be sure to adjust the "zero" and "background" settings on your dose calibrator. Follow the directions below to measure ($\pm 10\%$) the doses and activate the PET phantom. Scanning begins 1 hr after Dose A is measured. (Please record all information on the "Phantom Dilution Worksheet" found on page 12.)

Phantom Dose Chart

Patient Dose	Dose A mCi	Dose B mCi
4 mCi	0.14	0.33
6 mCi	0.21	0.50
8 mCi	0.28	0.66
10 mCi	0.35	0.83
12 mCi	0.42	0.99
14 mCi	0.49	1.15
16 mCi	0.56	1.32
18 mCi	0.63	1.48
20 mCi	0.70	1.65

Directions for Activating Phantom and Vials

Protocol Summary for the Two Required Doses (from Chart)

- **Dose A** will be added to 1000 ml bag (or bottle) to diluted activity for the 4 test vials;
- **Dose B** will be added to the phantom as background activity.

1) Measurement of Doses A and B

Measure and record the activity of **Dose A** and **Dose B** (tuberculin syringes) with time on the work sheet (next page). Scanning begins 1 hr after the Dose A measurement time.

2) Activation of Test Vials on Phantom Cover

Add **Dose A** to the 1000 ml bag or bottle and mix well. Then with the first 60 ml syringe withdraw 60 ml — this is test **Dose #1** (set aside, see Step 4). Next, using the second 60 ml syringe withdraw 40 ml from the bag and fill the 4 appropriate chambers in the phantom top.

3) Activation of the Phantom

Thoroughly mix **Dose B** into the main chamber of the PET phantom (a bubble of air will help ensure a well-mixed solution). After mixing, using the third 60 ml syringe, withdraw 60 ml from the phantom — this is test **Dose #2** (set aside, see Step 4).

4) Test Dose Measurement with Time

Measure the activity of test **Dose #1** and **Dose #2** and record. Then, inject **Dose #2** back into the phantom. Fill any remaining air-space in the phantom with water and mix again. Scan at the specified time. Dispose of syringes appropriately.

Place label here

PET Phantom – Site Scanning Data Forms

Please complete one copy of these data forms for each unit being evaluated. Photocopy the forms for additional units. Detailed instructions for scanning the PET phantom are attached. Please print or type. Please place your Phantom Data Form Label in the space above. Return completed form with phantom images.

Equipment

PET or PET/CT INFORMATION

Unit Vendors: check one					
<input type="radio"/> ^{PHIL} Philips		<input type="radio"/> ^{GEMS} GE		<input type="radio"/> ^{SIEC} Siemens (or CTI)	
<input type="radio"/> ^{OTH} Other, specify:					
PET Model Name	CT Model Name/Slices	Year of Manufacture	Year of Installation	Date of Last Hardware Upgrade	Serial Number
	/				

PROCESSING SOFTWARE

Version of Software	Vendor	Date of Last Software Upgrade	Operating System (e.g., UNIX)

Has all submitted data from the PET system been processed with this computer system? Y N

TRANSMISSION SOURCES (if used)

Type / Number of Sources	Vendor	Total Activity, mCi	Date of Installation	Time since Installation	Frequency of Updates
/					

Rod sizes (small to large):	_____ 4.8 _____ 6.4 _____ 7.9 _____ 9.5 _____ 11.1 _____ 12.7 mm
Cylinder sizes (small to large):	8 12 16 25 mm

Other information or comments: _____

Phantom Dilution Worksheet

Enter dose and time below

	Dose	Time	Dose Ratios
Patient Dose:			
FDG dose (A), mCi:			FDG Doses: B/A (enter ratio value below)
FDG dose (B), mCi:			
Test dose #1, μCi:			Test Doses: 1/ 2 (enter ratio value below)
Test dose #2, μCi:			
Actual start time of phantom scan:			

When entering SUV parameters for the PET scanning protocol assume a 70 kg patient and use the Patient Dose (e.g. 10 mCi) from above with the measurement time entered for dose A.

PET Quality Control Summary (Brief Descriptions)

Type of PET unit: _____

QC for PET Scanner	Frequency	Last Performed (mm/dd/yy)
QC for CT (for PET/CT units)		
QC for Diagnostic Displays/Printers		

Acquisition and Reconstruction Parameters (Whole Body Protocol)

Type of PET(/CT) unit: _____

Enter all appropriate acquisition parameters below (list other parameters that may be relevant):

Time per bed position:

Transmission scan: _____ Emission scan: _____

Number of bed positions: _____

Matrix size: _____ Zoom: _____

For CT:

Topogram: mAs _____, kVp _____

CT: mAs _____, kVp _____, Num. Slices _____, Thickness _____ mm

Are different protocols used for children? Y N

Describe any modified pediatric protocols and dose reduction techniques: _____

Enter all reconstruction parameters below:

Reconstruction Parameters

Type of reconstruction (OSEM, FBP, etc.): _____

OSEM: iterations _____, Subsets _____

Processing Filter: _____, Setting: _____

Slice Thickness: _____ cm

Additional information:

SUV Analysis Worksheet

Patient Dose: _____

PET(/CT) Model: _____

For SUV calculations, enter the following into the site's computer: Use the patient dose previously selected from the phantom dose chart on page 10. DO NOT use the value of dose B. Use 70 kg (154 pounds) as the patient's weight. Use the ROI data obtained for the minimum (min.), maximum (max.) and mean SUV values to complete tables 1 & 2 below.

A) Contrast – Table 1

	Hot Vial 8 mm	Hot Vial 12 mm	Hot Vial 16 mm	Hot Vial 25 mm
<u>max.</u> SUV				

B) Scatter/Attenuation – Table 2

	Background	Bone	Air	Water
<u>mean</u> SUV				
<u>min.</u> SUV				

C) Ratio Calculations (using data from Tables 1 & 2 above):

<u>max.</u> vial SUV to <u>mean</u> background SUV e.g., Contrast = 8mm SUV / bkgd SUV	8mm/bkgd	12mm/bkgd	16mm/bkgd	25mm/bkgd

<u>max.</u> vial SUV to <u>max.</u> 25 mm vial e.g., Contrast = max16 mm SUV / max 25 mm SUV	8mm/25mm	12mm/25mm	16mm/25mm

<u>min.</u> air or water to <u>min.</u> bone e.g., ratio = min air SUV / min bone SUV	air/bone	water/bone