UK PET Core Lab

Work Instruction: ^{18}F Image Quality Phantom Acquisition

This work instruction describes the procedure for filling and scanning the NEMA image quality phantom for submission to the UK PET Core Lab based at the King's College London & Guy's and St. Thomas' PET Centre as part of the site accreditation procedure.

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The UK PET Core Lab is operated by GSTT and KCL and is endorsed by the BNMS

Contents

1 Introduction

This work instruction applies to PET staff at local PET sites acquiring data for the purposes of site accreditation by the UK PET Core Lab at King's College London & Guy's and St Thomas' PET Centre. Specifically, this procedure applies to the filling and acquisition of the NEMA image quality phantom with ^{18}F.

2 Aim

The purpose of this document is to provide instructions for filling the NEMA image quality phantom with ^{18}F and acquiring a PET-CT scan for assessment of image quality and quantitative accuracy. to ensure consistent and accurate results

3 Roles and Responsibilities

Staff at the local PET site are responsible for ensuring they have read the local rules, follow the relevant systems of work and complete risk assessments as appropriate prior to starting any phantom work.

Only persons trained in radiation safety for unsealed sources and competent at filling PET phantoms should attempt this procedure. As filling the phantom involves the use of radioactivity, appropriate radiation protection procedures of time, distance and shielding must be used at all times. Users must also be familiar with the local department policies regarding use of radioactivity – contact the local Radiation Protection Supervisor for advice. It is recommended that users practice this procedure using water first to familiarise themselves with all the steps involved.

4 Prerequisites

Sites should ensure they have a copy of the accompanying *18F_NEMA_Acquisition_Form_ER_PET* spreadsheet.

Details about the PET scanner and local QC schedule should be entered into the relevant cells on the tab called **PET QC FORM**. Sites are also requested to provide details of the local protocol for scanning adult patients with 18F-FDG for oncological indications. If parameters such as injected activity or scan duration are varied according to patient size/weight, we ask that the formula or ranges are provided in the form.

4.1 Radionuclide Calibrator – ^{18}F Factor

Centres seeking UK PET Core Lab accreditation should have an ^{18}F factor traceable to a primary standard and the cross calibration for ^{18}F on the PET scanner checked using a uniform cylinder. The most recent results for the cross-calibration check should be recorded on the **NEMA ACQUISITION FORM** tab of the spreadsheet.

4.2 NEMA IQ Phantom

The volume of the background compartment has been found to vary between phantom designs. Where possible, please measure the volume for the phantom used (with the spheres and lung insert included), and record on the **NEMA ACQUISITION FORM** tab of the spreadsheet.

4.3 Scanner Clocks

Before starting the procedure, make sure that the clock(s) used to record assay times is calibrated to the scanner clock.

5 Phantom Filling Procedure

The steps in the following procedure are recommended to achieve the required spheres and background activity concentrations at the time of scanning. Deviations to the phantom filling protocol are allowed providing they result in the same activity concentrations. Where a different procedure is followed please make sure the exact activities and volumes used for dilution are recorded along with measurement times for decay correction.

5.1 NEMA Phantom Filling

The following instructions have been written for the Data Spectrum NEMA IEC body phantom set which has a background volume of 9800 ml with the lung insert included. Users should allow about 1 hour for filling the phantom plus 20 minutes scanning time. To speed up this process, the background compartment can be filled with water in advance (steps 3 to 6). The target activities in this procedure are calculated assuming the PET scan is started 60 minutes after the activity in syringe 2 (background) is measured.

If there are any deviations to the procedure (timing, dilution volumes etc), users are expected to use the **NEMA ACQUISITION FORM** tab on the provided spreadsheet to determine the activities to dispense to achieve the required activity concentrations in the spheres and background.

Sites may use phantoms from other manufacturers but as the design may vary users should refer to the manufacturer's instructions for filling and will need to measure the background volume to determine the activity required for the background.

Equipment

- Empty NEMA IEC PET Phantom with 6 empty spheres and lung insert (Figure 1)
- Dose calibrator with traceable ^{18}F factor
- Selection of smaller size syringes 2-5 ml with syringe shields
- 2 x standard length, 21G or similar needles
- Small funnel (if available)
- Suitable container for making up the sphere solution (volume >1000ml)
- Stirrer
- selection of larger size syringes 30-60 ml
- 2 x long, 22G or similar spinal needles (length ≥ 80mm)
- Absorbent pads with plastic backing
- ~200MBq ^{18}F
- Access to tap water
- Clock or watch synchronised to the PET/CT scanner time
- Appropriate personal protective equipment (PPE) for working with unsealed radioactive sources: i.e. Film badge/finger TLDs, lab coat and disposable gloves.

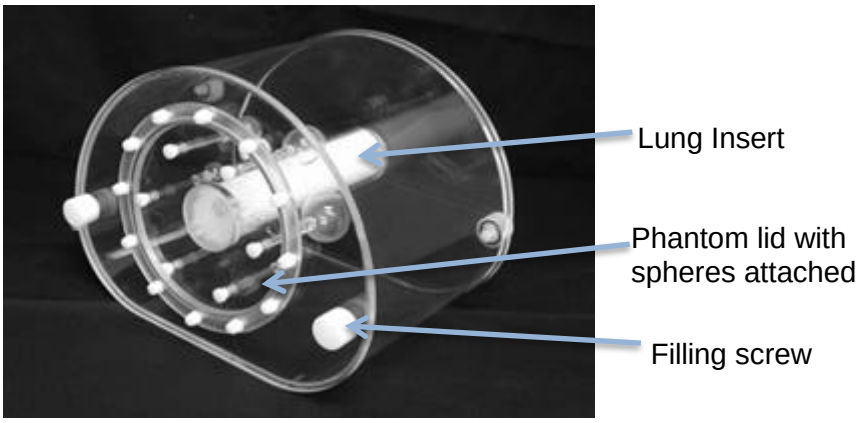

Figure 1: Picture of the NEMA IEC Image Quality Phantom (Data Spectrum)

1. Put on the appropriate PPE.
2. Prepare the work area by removing clutter and covering the surfaces with absorbent pads.
3. Unscrew the phantom lid with the spheres attached and remove from the main body of the phantom.
4. Fill the phantom body to about ¼ with tap water or until just before the lung insert floats.
5. Secure the lid with the spheres attached onto the phantom body. The spheres should be orientated as shown in Figure 2 with the 17mm and 37mm spheres aligned with the horizontal axis of the phantom.
6. Finish filling the background with water through the filling screw hole, leaving a large air bubble for mixing the activity later. Ensure there are no leaks.
7. Remove the 6 sphere stopper screws from the lid.
8. Measure out 1000 ml of water into the container for making the sphere solution **as accurately as possible**, ideally using weighing scales.

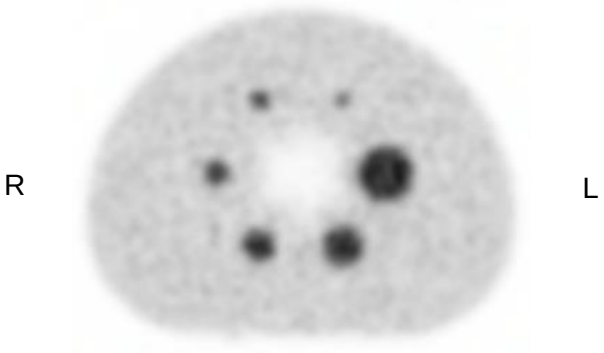

Figure 2. Axial view of the NEMA IEC phantom

Spheres - Syringe 1: Aim to get 25 kBq/ml in the spheres at the time of scanning:

9. Draw up a target activity of 37 MBq ^{18}F and label this syringe 1.
10. Measure the actual activity in syringe 1 in the radionuclide calibrator using the ^{18}F factor and record the time on the **NEMA ACQUISITION FORM** tab of the spreadsheet. If the final activity is less than 37 MBq, a smaller dilution volume should be used to avoid additional manipulations.
11. Place the syringe into a shielded area.

Background - Syringe 2: Aim to get 5 kBq/ml in the background at the time of scanning:

12. Draw up 72 ± 3 MBq ^{18}F and label this syringe 2.

13. Measure syringe 2 in the radionuclide calibrator using the ^{18}F factor and record the time (t_0) and the volume of tracer on the **NEMA ACQUISITION FORM** tab of the spreadsheet.
14. Place the syringe into a shielded area.

the PET scan should be started 60 minutes after t_0

Syringe 1: Filling the Spheres:

15. Inject the contents of syringe 1 (37 MBq) into the container of water (1000 ml). Flush the syringe several times to ensure all the activity is injected.
16. Measure the residual in syringe 1 in the radionuclide calibrator using the ^{18}F factor and record the time on the **NEMA ACQUISITION FORM** tab of the spreadsheet.
17. Stir the solution in the container to homogenise being careful not to spill any.
18. Draw up a volume of the radioactive solution from the container (spheres are ~50ml in total) into a large syringe using a long needle.
19. Carefully insert the long needle into the filling tube of the largest sphere (it should reach into the sphere itself).
20. Slowly inject the solution into the sphere being careful to remove any air bubbles.
21. Wipe off any excess solution from the top of the filling tube and screw in the stopper.
22. Repeat steps 18 to 21 for all remaining spheres working round systematically from the smallest to the largest spheres to ensure all are filled.

Syringe 2: Filling the Phantom background:

23. Remove the background filling screw and inject the contents of syringe 2 (72 MBq) into the phantom background. Flush the syringe several times to ensure all the activity is injected.
24. Measure the residual in syringe 2 in the radionuclide calibrator using the ^{18}F factor and record the time on the **NEMA ACQUISITION FORM** tab of the spreadsheet.
25. Replace the filling screw and swirl/shake the solution in the phantom to homogenise the solution.
26. Get the air bubbles in the phantom to travel to the side with the filling screw by tilting and tapping the phantom.
27. Open the filling screw carefully to avoid spillage.
28. Use the cup and funnel to fill up the remainder of the phantom with water until almost full (bend the cup to form a funnel if a funnel is not available)
29. Put the screw back in and shake/tap the phantom to get all air bubbles to the area with the filling screw.
30. Open the filling screw carefully to avoid spillage.
31. Use a non-active syringe to fill up the remainder of the phantom so there are no air bubbles
32. Replace the filling screw.
33. Check the phantom carefully for leaks before transfer to the scanner.

5.2 NEMA Phantom Acquisition

the PET scan should be performed at 60 mins after t_0

1. About 10 minutes prior to the PET scan, transfer the phantom to the scanning room using a trolley to reduce radiation dose.
2. Place absorbent pads on the couch to prevent contamination.
3. Place the phantom on the couch on its side with the lid pointing orientated towards the foot of the couch and away from the gantry.

4. Use the scanner positioning lasers to line up the phantom so the lung insert is level and centralised in the gantry.
5. When setting up the patient demographics on the scanner enter the weight to be the same value as the measured volume, and the injected activity as the total activity in the background compartment (i.e. the contents of syringe 2) and the time this was measured – also enter the residual activity measured if this is significant.

Acquisition 1:

6. The first PET scan should be set up to acquire a **single 5-minute static scan** centred on the spheres (use the contrast/brightness on the CT scout to check the sphere locations). All other parameters should match those used for routine 18F-FDG clinical scanning for oncological indications.

Acquisition 2:

7. The second acquisition should be set up to acquire a **2-bed or continuous flow scan** covering the phantom. All parameters, including time per bed or scan speed, should match those used for routine 18F-FDG clinical scanning for oncological indications.

   *Note: If a weight-based protocol is normally used for clinical patients, please use the parameters for a **70 kg patient.***

8. Record the acquisition times for the PET scans on the **NEMA ACQUISITION FORM** tab of the spreadsheet .

5.3 NEMA Phantom Reconstructions

The UK PET Core Lab is in the process of transitioning to a new accreditation standard incorporating the latest scanner reconstructions. During this transition period existing trials will continue to require the older standard. Therefore, we ask sites to submit at least two reconstructions:

1. A reconstruction without PSF modelling or QClear. (old standard)

2. A reconstruction including time-of-flight (TOF) and PSF modelling. (new standard)

Unless instructed otherwise by the UK PET Core Lab, sites should reconstruct the PET and CT using the standard parameters for clinical oncology patients. If not used clinically, the core lab can provide suitable reconstruction parameters to use for the new standard.

Older PET-CT systems without TOF and PSF modelling available can submit a single reconstruction but it should be noted that these systems are being phased out and so may not pass the accreditation requirements for new trials.

5.4 Phantom Checks

Sites are asked to perform a few simple checks on the acquired data before transfer to ensure it is of the required standard.

Quantitative Checks:

1. Load the PET and CT data for the single 5-minute static PET-CT scan into the viewing software used for local clinical review. Display the corrected PET images in axial view and navigate to a slice showing the spheres. Set the viewing software to display values in activity concentration (i.e. Bq/ml).

2. Draw a 5cm diameter circular ROI in the background. Use a slice that doesn't contain the spheres or filling tubes. Measure the **mean activity concentration** for the background.
3. Draw a 3D VOI over the largest sphere and measure the **maximum activity concentration** for the whole sphere. If a 3D VOI is not available, use a 2D ROI and scroll through the slices to find the maximum voxel.
4. Enter all the results for the quantitative checks on the **PHANTOM CHECKS** tab of the spreadsheet. If the either the background or sphere recovery coefficient are outside the tolerances, carefully check the assayed activities, timings and volumes entered in the spreadsheet.

    a. If the background recovery coefficient fails, this could simply be a filling error, or it could be indicative of an issue with the cross-calibration on the scanner. If a scan of an ^{18}F uniform cylinder has been acquired recently and the cross-calibration factor was within tolerance (ideally 0.95 to 1.05), this suggests it was most likely a filling error and sites should repeat the NEMA phantom acquisition. If there is concern however that the cross-calibration on the scanner is at fault, sites should discuss further with the local MPE.

    b. If the background recovery coefficient passes but the sphere recovery coefficient is outside the tolerance, the data can be submitted for review and the Core Lab can advise if the reconstruction parameters need to be adjusted.

Visual Checks:

1. Scroll though the slices and check the following:
    a. The PET and CT are visually aligned (in all directions). If the scans are visibly misaligned, this could be indicative of an issue with the PET to CT alignment and sites should discuss this further with the local MPE.
    b. All 6 spheres are filled with activity. If not, sites need to repeat the scan with all 6 spheres filled.
    c. The phantom is free from artefacts (in particular, the background compartment should appear uniform to ensure the solution is well mixed).
2. Enter the results for the visual checks on the **PHANTOM CHECKS** tab spreadsheet.

5.5 Data Transfer

All PET and CT data sets should be transferred in original DICOM format making sure the private header fields are kept intact during transfer from the scanner. Electronic transfer is preferred, and sites should refer to the *MIMcloud_Upload_SOP* for further details. Where electronic transfer is unavailable, scans can be transferred to the Core Lab on CD, but this may delay the accreditation process:

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A copy of the completed *18F_NEMA_Acquisition_Form_ER_PET* spreadsheet should be emailed to **pet-trials@kcl.ac.uk.**

The raw PET data should be retained until accreditation is confirmed in case additional reconstructions are required by the Core Lab.