TG126
PET/CT Acceptance Testing and Quality Assurance

Osama Mawlawi PhD, DABR, DABSNM, FAAPM, FACR
on behalf of TG126 members

THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center
Making Cancer History

Disclosures

- GE research grant
- SIEMENS research grant

Background/motivation

- Lack of standards for testing PET/CT scanners.
- NEMA NU2-2012: For acceptance testing of scanners. (newest: V.2018)
  - Describes absolute system performance
  - Very time consuming
  - Requires various phantoms/costly
  - Requires specialized software for analysis (costly)
- ACR: For accreditation of scanners
  - Primarily visual evaluation
  - Does not evaluate all system performance characteristics
  - Very simple and easy to perform
  - Requires specialized phantoms
- Requirements of accrediting bodies (joint commission) for testing reports

The Joint Commission

• Issued August 10, 2015 •

Diagnostic Imaging Requirements

For the first time, the Joint Commission is requiring phantom-based PET/CT scanner performance testing

"At least annually, a diagnostic medical physicist conducts a performance evaluation of all positron emission tomography (PET) imaging equipment. The evaluation results, along with recommendations for correcting any problems identified, are documented"

Required
- *Image uniformity/system uniformity*
- *High-contrast resolution/system spatial resolution*
- *Low-contrast resolution or detectability*
- *Artifact evaluation*

Recommended
- *Sensitivity*
- *Energy resolution*
- *Count-rate performance.*

Background

- TG126 formalized in 2006!!
- Leadership of Dr. Jon Anderson – UT southwestern
- Transitioned to Dr. Osama Mawlawi – UT MD Anderson.
- Several committee members over the years.
  - Current committee:

Jon	Anderson	UT Southwest	Paul	Kinahan	University of Washington
Ishtiaq	Bercha	WellSpan York Hospital	**Osama**	**Mawlawi**	**MDACC**
Janice	Campbell	Beaumont Hospital	Charles	Schmidtlein	MSKCC
Georges	El Fakhri	MGH	Jon	Shepard	Fusion Physics – constlt.
James	Halama	Loyola University	Dimitris	Visvikis	Insern; Brest - France
David	Jordan	University Hospitals Clevland	John	Wolodzko	Consultant
Brad	Kemp	mayo Clinic	Wesley	Wooten	Consultant

Evolution of the TG126 strategy

- Develop code to analyze data as per the NEMA standard
  - Adhere to the rigor of NEMA
  - Is that really needed for annual testing vs. acceptance testing
  - Who will maintain the software once developed
  - Are there any liabilities
  - Requires specialized phantoms (costly & difficult to move around – consultant)
- Develop testing procedures similar to the NEMA standard (NEMA-lite) that do not require specialized phantoms or software.
  - Practical and useful tests
  - Based on images rather than raw data

Evolution of TG126 strategy

- The purpose of Task Group 126, PET/CT Acceptance Testing and Quality Assurance, is to provide a standardized set of acceptance and periodic tests that can be **easily implemented** in a QA program for various PET/CT system platforms from different manufacturers.
- The intent of the Task Group members was to develop procedures that **adhere to the spirit of the NEMA document**
- Do **not require the purchase of specialized equipment** to perform the experiments (beyond standard, inexpensive and easily obtainable phantoms and those supplied by the manufacturer) **or specific software** to analyze the acquired data.

Evolution of TG126 strategy

- **Philosophy:** The proposed tests are to be performed following installation as well as for annual testing.
- When performed following installation of a system they represent the baseline standard.
- When performed for annual testing they represent the system performance for that year and the results are compared with the baseline values.
  - In this regard the annual testing assesses the variation from baseline rather than the absolute system performance.

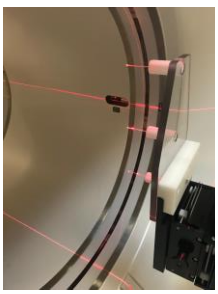
Evolution of TG126 strategy

- NEMA NU2 standard:
  - Resolution
  - Sensitivity
  - Count rate performance
  - Image quality
  - Accuracy
- Added:
  - Alignment
  - ACR (Image Quality)
  - Uniformity
- Removed
  - Image quality (replaced by ACR)

Note that there are no tests identified for timing resolution, energy resolution, gating accuracy etc.

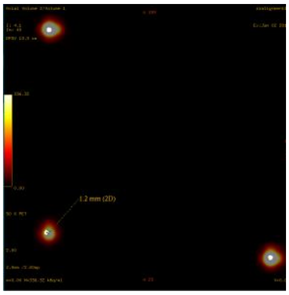
Resolution

- Same approach as NEMA.
- Use capillary tubes for point sources in air positioned at different locations (0,1), (0,10), (0,20) at center and ¼ or 3/8 FOV.
- Acquire the data for 5-10 million counts.
- Reconstruct images using FBP or clinical protocol
- Use the smallest pixel size (largest matrix with the smallest FOV) to properly sample the PSF. Pixel size < 1/3 of the FWHM
- Use imageJ or similar software to generate a PSF to measure the FWHM in the transverse and axial direction for each point source and location.



Alignment

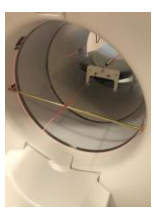
- The resolution test can also be used to perform the Alignment of the PET and CT components of the scanner.
- When making the point sources in the capillary tubes, add CT contrast to the F-18 mixture such that the point source can be see in the PET as well as the CT scan.
- Few drops of contrast is enough.
- On the fused images, measure the distance between the centroids of the PET and CT images. Determining the Centroids can be done by visual inspection or using software such as imageJ



Sensitivity (cps/kBq)

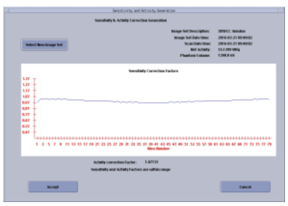
- Two approaches for this measurement.
- (1) NEMA approach – using cascaded tubes (cheap phantom $300) or your own site specific tube.
  - Use only the smallest tube (no need for the other tubes).
  - Fill line source with 100-150 uCi (make sure to record the activity and time)
  - Position at iso-center of the PET scanner
  - Acquire data for two minutes and repeat 2 more times.
  - Obtain from the DICOM header the total prompts, randoms, and scan start time.
  - Procedure to find this info for different vendor scanners is provided in the report.
  - Subtract randoms from prompts (if randoms are available) and divide by scan duration.
  - Do the same for the other 2 acquisitions while performing decay correction and average.
  - Sensitivity is then obtained by dividing the average count rate by the assayed activity
  - Repeat the process while source is at 10 cm off iso-center.

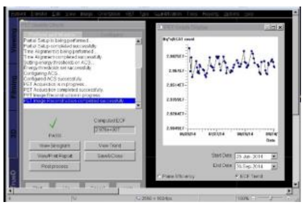
Sensitivity



Sensitivity

- (2) use the calibration factor as a measure of sensitivity
  - For GE systems this is called the WCC factor
  - For SIEMENS systems this is called the ECF
  - Procedures for obtaining this value for different vendor systems is available in the TG report.
  - Tracking this value over time shows the variability of the system sensitivity performance.





Count rate performance

- Done using the same method as NEMA but using a standard 20cm phantom.
- Fill the phantom with 15-20 mCi and position it at iso-center in the PET FOV.
- **For baseline testing:** Image the phantom over 6-7 halflives, each scan of 15 min duration with 15 min delay. Reconstruct the images with all corrections.
- **For annual testing:** Image the phantom 2-3 times at different activity levels. Each scan with 15 min duration and reconstruct the images with all corrections.
- For each scan obtain the total prompts and total delays from the DICOM header

Count rate performance

- $R_{NEC} = \dfrac{R_T^2}{R_T + R_S + k f R_R}$
  - f is the fraction of the FOV subtended by the phantom
  - k is a factor that depends on the Randoms correction technique (k = 1 for noiseless randoms estimate and k = 2 for noisy randoms estimate).

- Given that scatter or scatter fraction might not be readily available, the above equation can be modified to:

- $R_{PNEC} = \dfrac{(R_P - R_D)^2}{R_P + \left(\frac{k}{2} - 1\right) R_D}$

  Where R_{PNEC} is the psduo NECR

Count rate performance

Obtain the acquisition duration for each acquisition or frame (T).

Compute prompts rate, for acquisition i as $R_P = \dfrac{C_P}{T_i}$

Compute delays rate, for acquisition i as $R_D = \dfrac{C_D}{T_i}$

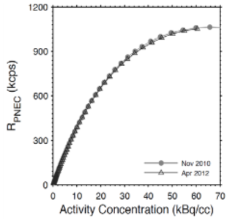
For a noiseless randoms correction (such as randoms from singles correction), R_{PNEC} is

$$R_{PNEC} = \frac{(R_P - R_D)^2}{R_P - \frac{R_D}{2}}$$

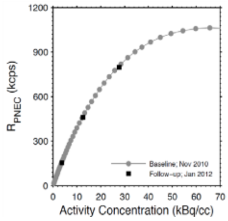
Where R_{PNEC} is the psduo NECR

Count rate performance

Baseline



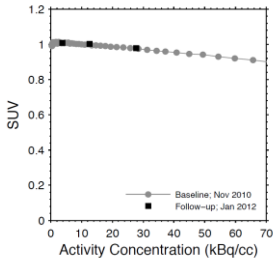
Annual



Calculate the error of the follow-up RPNEC, as compared to the baseline, by linear interpolation. Record the maximum error of the two (or three) follow-up RPNEC measurements.

Accuracy of corrections

- From the images of the count rate measurement, draw an ROI that is 75% of the diameter of the phantom
- Calculate the SUV in that ROI
- Plot the results for the different acquisitions.
- Calculate the error of the follow-up SUV, as compared to the baseline, by linear interpolation.



ACR – Image quality

- Uses the ACR phantom and follows a similar process of ACR testing
- Doubles as ACR testing for accreditation

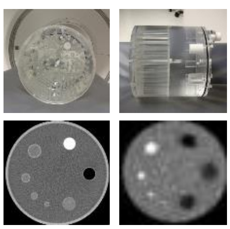


Table 10. Phantom Dose Chart

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

ACR – Image quality

- Image the phantom using the standard clinical protocol.
- Make sure the scan time post dose assay is the same (+/- 5-10 min) between the baseline and annual testing scans.
- Reconstruct the images using the standard clinical protocol and reformat the images to 1 cm thick slices.
- Measure and record the SUVmax and SUVmin for the various cylinders
- Measure the SUVmean in a 6-7 cm ROI in the background.
- Calculate the contrast ratio for the hot cylinders

ACR – image quality data reporting

Cylinder	Min SUV	Allowable Range	Mean SUV	Allowable Range	Max SUV	Allowable Range	Contrast Ratio	Allowable Range
25 mm "hot"	Measurement not required							
16 mm "hot"								
12 mm "hot"								
8 mm "hot"								
25 mm Teflon					Measurement not required			
25 mm Water								
25 mm Air								
Background								

$$Contrast\ Ratio = \frac{Max\ SUV\ of\ Hot\ Cylinder\ ROI}{Mean\ SUV\ of\ Background\ ROI}$$

Image Uniformity

- The purpose of this test is to provide a measure of the deviation in the activity concentration **within a slice** as well as **across slices** of a uniform phantom.
- Uses data that was acquired as part of the count rate test.
- Draw 5 ROIs with 3 cm diameter at 3, 6, 9, 12 and center.
- Copy ROIs to all slices
- Record mean, min and max ROI activity concentration

Image Uniformity

- Uniformity within the slice:
  - The integral uniformity within a slice is based on the mean values for the 5 circular ROIs
    - $IU_i = \frac{ROI_{max} - ROI_{min}}{ROI_{max} + ROI_{min}}$
  - ROI_{max} is the maximum of the 5 mean values in that slice, and ROI_{min} is the minimum of the 5 mean values within the slice.
- Uniformity across slices:
  - For each ROI location, determine the largest ROI mean value, $\overline{ROI_j}$ from slice *j*, and the smallest ROI mean value, $\overline{ROI_k}$ from slice *k*.
  - Integral axial uniformity is given by: $IU_{axial} = \frac{\overline{ROI_j} - \overline{ROI_k}}{\overline{ROI_j} + \overline{ROI_k}}$.

Image Uniformity

Exclude the front and end slices from this calculation due to noise in edge slices

	ROI Mean					
Slice	ROI_1	ROI_2	ROI_3	ROI_4	ROI_5	Integral Uniformity within Slice IU_i
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
Axial Uniformity (Between Slices) IU_{axial}						

Additional component of the report

- PET quality control program elements
- CT quality control program elements.
- Described for the major 3 manufacturers (GE, SIEMENS, PHILIPS).
- Table showing the frequency of these testing.

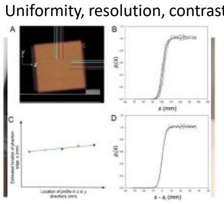
Table 2. Periodic Tests

Test	Daily	Weekly	Quarterly	Semi-annual	Annual
Daily CT QC	X				
Daily PET QC	X				
Siemens Weekly PET QC		X			
GE PET Singles Update Gain		X			
GE Coincidence Timing Calibration			X		
Philips SUV verification and calibration			Every two months		
Siemens Quarterly PET QC and timing alignment			X		
GE PET Normalization			X[2]		
GE PET Well Counter Correction			X[2]		
System PM and inspection				X	
Siemens Source replacement and scanner cross-calibration					X
PET Spatial Resolution					X
PET & CT Registration			X[1]		
PET Sensitivity					X[2]
PET Count Rate Performance					X[3]
PET Accuracy of Corrections					X
PET Image Contrast and Scatter/Attenuation Evaluation			X		
PET Image Uniformity Assessment					X[4]
Image Display Monitor Evaluation (TG-18)					X
Emergency Buttons Testing					X
Synchronize System Clocks		X			

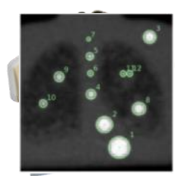
Additional Daily Tests[4]					
Restart Computers	X				
Manufacturer recommended CT warm-up cycle and calibrations	X				
Archive patient data	X				
Clear Scheduler	X				
Clear local, network and film queries	X				
[1]Or after the gantry is opened.					
[2]Or if a detector module is replaced.					
[3]Or if the electronic boards are replaced.					
[4]Philips recommends this test to be done on a quarterly basis					

SNMMI & JC : effort towards standardization

- Uniformity, resolution, contrast

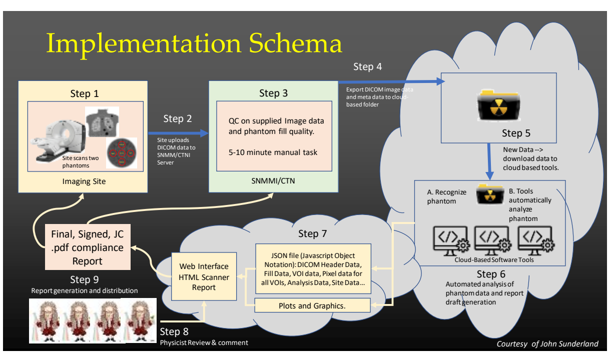


Uniform Phantom imaged at a slightly oblique angle
Imaged at high statistics (15 minute/bed position)



Imaged using standard clinical acquisition.
Reconstructed using standard clinical reconstruction.

Courtesy of John Sunderland



TG 126 Report

- Draft finalized
- Reviewed and approved by the NMSC
- Currently under review with IPC
- Next steps:
  - Implement corrections/comments of IPC
  - Send to SC for approval
  - Transition to a WG to generate look up tables for different systems
  - Submit as a JACMP paper

Thank you