

PAT NEMA IQ Phantom Analysis

The NEMA IQ Phantom Analysis is meant to provide three measures of scanner performance.

1. Recovery Coefficient Curve (Partial volume vs. size)
2. Coefficient of Variation (Noise)
3. Lesion Detectability

The NEMA Image Quality (IQ) phantom is a simple geometric phantom with 6 spherical inserts ranging in size from 10 mm – 37 mm. For nearly two decades it has been the standard phantom used to measure partial volume effects as a function of object size. Initially the two largest spheres (28 mm and 37 mm) were used as cold objects, but over the last decade more phantom programs have been filling all six spheres with activity. The new 2018 NEMA instructions now fill the 28 mm and 37 mm spheres with the hot solution.

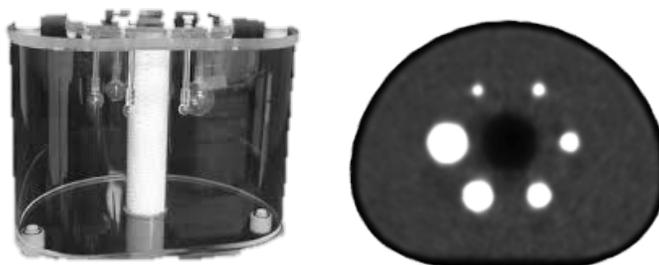


Figure 1: The NEMA IQ Phantom

By virtue of having a range of sphere sizes, the NEMA IQ phantom is designed to generate a recovery coefficient curve – which is a standard measure of the partial volume effects of the PET scanner using the chosen reconstruction.

When the phantom is filled as per instructions, the contrast will be approximately 5:1. The fill activities can be changed to simulate different noise levels and contrasts for special purposes. The standard EANM EARL fill uses a 9.7:1 contrast, but that higher contrast fill does not meaningfully fulfill the Joint Commission low contrast lesion detectability requirement.

How the Phantom Data is Acquired and Reconstructed

This phantom study is meant to automatically generate several measures of scanner performance under clinically simulated conditions. These measures include the Recovery Coefficient curve (a standard measure of partial volume effect as a function of object size), and a coefficient of variation measure taken from several regions of uniform background to assess background noise.

To get accurate measures this test is meant to be performed using:

1. A multi-bed position scan to fully image the phantom using your standard clinical acquisition duration.
2. Your standard clinical oncology reconstruction to get an accurate assessment of your clinically-used reconstruction algorithm and parameters.

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How the Software Works

The recommended approach expects the NEMA IQ phantom data to be acquired at the standard clinical acquisition time, although the acquisition time can be adjusted for special purposes. The software understands the geometry of the NEMA IQ phantom and the sizes of the spheres. The software is robust in identifying which spheres are what sizes, as long as the spheres are sequentially small to large either clockwise or counterclockwise. It will also adjust to oblique positioning of the phantom in the gantry; so even if the phantom is not centered in the gantry or is not aligned with the axis of the gantry, the software should be capable of matching the phantom model to the image data. It has been tested extensively using many different scanner models, reconstructions, and noise levels.¹

- The software first automatically detects the location of the detected lesions from the image data and calculates the physical distance of the centroids of each of the lesions to each of the others.
- The software then looks at relative object sizes and assigns sphere diameters from 10 mm – 37 mm sequentially from smallest to largest sphere.
- Spherical volumes of interest (VOI) of the exact size of each sphere are then placed over the 6 spherical inserts.
- SUV_{max} , SUV_{peak} , and SUV_{mean} values are calculated for each of the spheres.
- Six additional spherical VOIs are then placed in known uniform regions inside the phantom. The mean, and more important, the standard deviations of the voxels inside these regions are calculated to generate the average Coefficient of Variation, a simple measurement of image noise.
- As a check that the model has correctly identified the location of all spheres, the scanner report generates a transaxial image with the detected spheres and their respective VOIs and centroids superimposed (Figure 3).

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Understanding the Report

Report Header

The header of the report is at the top of the first page. Example below.

Facility: University of Iowa Hospitals	Phantom: NEMA	Contrast: 4.8:1
Scanner Model: SIEMENS Biograph64_Vision 600	Scan: 07/17/2019	Time Per Bed: 3.0min
Reconstruction: PSF+TOF 4i5s Gauss3.00		

Figure 2. Report header

This Section reads the facility name, scanner make and model, reconstruction, scan date, and time per bed position from the image header. It also reports the actual contrast in the phantom based upon the reported activity injected into the phantom, spheres, and the phantom volume.

Recovery Coefficient Curve

The automated analysis data is presented in a box below the header information. Four pieces of information are reported. The first is the transaxial image with superimposed VOIs. This should always be checked to assure that the model has correctly identified lesions and their relative locations.

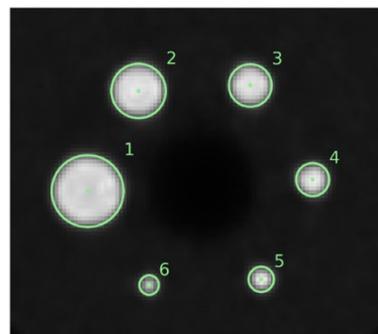


Figure 3. Transaxial MIP image of the NEMA IQ Phantom with automatically defined spherical regions of interest

Next the Recovery Coefficient curve is displayed. These are based upon SUV_{max} values. There is a solid black line/curve which represents the minimum allowable values associated with the EANM EARL program as a benchmark. This is not meant to be acceptance criteria, but simply a visual quantitative comparison. However, since this is a lower performance level, most values should be above this line. The actual Recovery Coefficient data are reported in the tables underneath the plot (Figure 5).

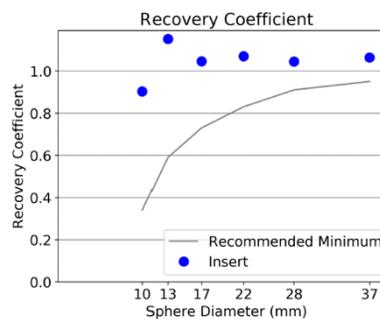


Figure 4 Recovery Coefficient Curve

It should be noted that although the curve is generated by SUV_{max} values, the SUV_{peak} values are calculated and available in a separately downloadable Microsoft Excel formatted file. It should also be noted that the Recovery Coefficients are the values that are reported in the plot and the table below it. There is a separate metric called the “Contrast Recovery Coefficient” which accounts for the contrast at which the data is acquired. The software also calculates this, but the results are embedded at the end of a JSON file that is also available for download. It can also be easily calculated from the data provided in the report tables using the actual contrast as an additional variable. It can also be easily calculated from the data provided in the report tables given the actual contrast (radioactivity concentration ratio). The classic NEMA defined definition of CRC follows the Equation 1 below

Uniform Background Lesions		
Lesion Number	Lesion Size	Recovery Coefficient
6	10.0mm	0.90
5	13.0mm	1.15
4	17.0mm	1.05
3	22.0mm	1.07
2	28.0mm	1.04
1	37.0mm	1.06

Figure 5: Recovery Coefficient curve data

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where C_{hot} and C_{bkgd} are the average of the counts measured in the hot sphere ROI and the average of the counts in all background ROIs, respectively, and a_{hot} / a_{bkgd} is the ratio of the activities in the hot sphere and background.

$$CRC_{hot} = \frac{(C_{hot}/C_{bkgd} - 1)}{(a_{hot}/a_{bkgd} - 1)} \quad (1)$$

Noise Assessment

Lastly, the Background Coefficient of Variation is calculated and displayed (Figure 6). Six spherical regions of interest in different areas of the phantom of known uniform background concentration are chosen. The Coefficient of Variations of the six regions are averaged to generate a global estimate of background noise. This is an admittedly simplistic noise measure, but it does give a meaningful assessment of image “roughness”. We typically like to see this number <10%, although this is not a formal acceptance criterium. COV’s less than 5% are sometimes indicative of overly smoothed images, although current advanced reconstructions with noise-controlling components can sometimes achieve this without compromising resolution. Steps like increasing acquisition time, using a PET scanner with Time-of-Flight capability, increasing Gaussian filtration, or using advanced reconstructions with noise suppressing properties are all means to reduce image noise.

	Value	Recommended Range
Background Coefficient of Variation	5.4%	<10%

Image Quality/Lesion Detectability

The 10 mm sphere serves as the lesion detectability feature in this phantom. This sphere should be clearly discernable by all scanners at 5:1 contrast with clinical acquisition times. The 10 mm object should be clearly visualized above noise. If it is not, attempts should be made to increase the length of the scan, or the reconstruction parameters should be reconsidered.

A 5-point Likert Scale described below in the figure was developed to help grade levels of lesion detectability, although this is a subjective reader assessment and is not performed automatically.

Optional results to be completed by expert reader, if desired:		
Lesion Detectability		
Criteria	Detectability	Recommended Range
10mm lesion ¹		≥4

1. 0=not visualized, 1=barely visualized, but wouldn't call, 2=equivocal, 3=probably visualized above noise. 4=certainly visualized above noise

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DICOM and Fill Information

Relevant DICOM header and fill information is displayed in fourth box. This is provided to provide a simple means to check the fill and reconstruction information.

Name	Value
Institution	University of Iowa Hospitals
Phantom	NEMA
Series Description	TRUEX + TOF 4i5s3mm
Scan Date	07/17/2019
Scan Time	14:50:01
Assay Time	14:30:00
Background Volume	9635.0g
Background Activity	0.99
Uptake Time	20.02
Sphere Solution Volume	1000.0g
Sphere Activity	0.98
Actual Contrast	4.8:1
Minutes per Bed	3.00
Voxel Dimensions	2.84x2.84x5.00mm
Matrix Dimensions	256x256x79
Scanner Make and Model	SIEMENS Biograph64_Vision 600
Reconstruction Method	PSF+TOF 4i5s
Reconstruction Parameters	
Reconstruction Filter	XYZ Gauss3.00

References

Ulrich EJ, Sunderland JJ, Smith BJ, Mohiuddin I, Parkhurst J, Plichta KA, Buatti JM, Beichel RR. Automated Model-Based Quantitative Analysis of Phantoms with Spherical Inserts in FDG PET Scans. *Med Phys*. 2017 Nov 1.