PET-CT Scanner

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General

1. Introduction

Although the PET scanner was developed over 40 years ago, in clinical terms, PET is still a young technology. The systematic use of PET for scientific and clinical research dates from the late 80s to early 90s of the previous century. The breakthrough for clinical use of PET, through FDG whole body scanning, came at around the turn of the century. In the Netherlands, the breakthrough occurred around 2005 with a major expansion of the scanning capacity, making PET-CT available for larger groups of patients.

PET-CT is now an established technique, yet it is continually undergoing substantial and rapid changes. Since our 2007 Recommendations, major technological advances in PET-CT have been made. Examples include:

a. PET detector technology

PET detector technology has changed in two major aspects . The first is the development of faster detector systems allowing for Time of Flight (ToF) detection. The second is the development of detectors which are compatible with MRI thereby allowing the construction of integrated PET-MRI systems and systems using digital PET detectors. Other ongoing developments are the increase in the number of detector rings and the associated increase in axial FOV length and sensitivity.

b. PET image reconstruction techniques

Over the last years iterative reconstruction techniques have become the de-facto norm for clinical studies. This has resulted in the improvement of signal to noise ratio in images obtained by iterative reconstruction which incorporates the system characteristics into the reconstruction process, as compared to filtered back-projection images. Thus not only Time of Flight (ToF) but also the system response in the form of, for instance, the position specific Point Spread Function (PSF) is now used in PET-CT systems resulting in improvements in both the signal to noise ratio (SNR) and spatial resolution. This allows for further optimization of image quality versus administered activity and total scan time.

c. CT radiation dose reduction

PET-CT systems have benefited from dose reduction techniques which were developed for standalone CT systems. Currently, iterative reconstruction of CT data allows a further dose reduction while maintaining or even improving low-dose CT image quality. In addition, all CT scanners allow for mAs modulation as a function of the measured patient's transmission, thus reducing the dose for body regions that show small photon attenuation. Finally, some scanners provide the possibility to also adapt the kVp to the patient's size.

As a consequence of these improvements, current PET-CT systems are technologically superior to the first generation of PET-CT systems. However, since these improvements are

ahead of current testing protocols, they are not always expressed in standard quality testing. For example, spatial resolution measurements according to the NEMA NU-2012 stipulate FBP reconstruction. Thus PSF recovery techniques cannot be used and the test will give a clear underestimation of the system's potential. Nevertheless, PET-CT specifications are generally measured using these internationally accepted NEMA protocols; they are still the gold-standard for acceptance testing. See par.7 'Selection of test and frequency' for further details. Considering the improvements already made in the past few years and those which are envisioned, the relationship between technical specifications and clinical usefulness is still evolving. This is not an impediment to the various QC tests and the advised frequency of the different tests. However, current system performance may be exceeded by the next generation of scanners. Therefore QC threshold values are often specified as "within specifications".

2. Qualitative versus quantitative imaging

To reconstruct a PET image from a set of measured coincidences, a number of corrections must be applied such as, but not limited to, normalization, dead-time correction, random coincidences correction, scatter correction and attenuation correction. For more information about these corrections see a standard text book about PET technology.

Currently, new PET systems are only available as combined PET-CT (or even PET-MR) systems. For PET-CT systems the attenuation correction is derived from the CT data which are collected in the same (single) imaging session. During a PET-CT session, one or more CT scans can be made for various reasons. The main two reasons are:

a. Firstly, CT for attenuation (and scatter) correction and for localisation of the FDG avid lesions as seen on the PET images. These CT scans are usually referred to as low-dose CT or CT-AC.

b. Secondly, a CT scan can be performed for diagnostic purposes (diagnostic CT), generally with the use of intravenous or oral contrast agents. This usually involves not only a higher beam current or higher kVp (increasing the radiation dose) than those applied for CT-AC, but also comes with additional instructions for patient positioning (arms) and breath-hold. Diagnostic CT's covering the thorax are usually performed during maximal inspiration breath-hold.

CT-based attenuation correction is routinely applied. Yet, there are still a number of pitfalls which may result in attenuation artefacts in the reconstructed PET image as discussed in more detail in paragraph 3. Therefore it is common practice to also reconstruct the non-attenuated PET image which can be used by the clinician to exclude possible attenuation artefacts. After attenuation correction the PET image should meet all specifications of the system such as uniformity, spatial resolution, contrast etc. However, it is not yet quantitative, i.e. the image values cannot be expressed in Bq/cm^3 or SUV. In order to quantify the image, additional calibration must be performed. For more details see the Calibration protocol on p.651.

3. Pitfalls in CT based attenuation correction

A CT scan made for attenuation and scatter correction, the CT-AC, has to meet a number of requirements in order to provide accurate attenuation correction during reconstruction of the PET emission images. Quantification of PET images can be affected by several factors related

to the CT-AC acquisition. These factors must be avoided. In summary these factors are:

a.   *Presence of contrast agents (oral and i.v.).* The presence of contrast agents, both oral and i.v., produces a substantial increase of Hounsfield units (HU) in the CT image and can lead to an overcorrection of the attenuation and thus an upward bias in the quantification of the PET image, see Boelaard, 2015 for further details. Several studies have shown a deviation of SUV in liver and spleen up to 11% and in tumour of 13% when the diagnostic CT with use of i.v. contrast was also used for attenuation correction purposes. The adverse effects of i.v. contrast on the performance of attenuation correction cannot be corrected. Thus the use of i.v. contrast should be avoided when attenuation corrected PET data is required. High intraluminal concentrations of positive oral contrast, such as those containing barium or iodine, can also disturb the attenuation correction of PET, resulting in a local overestimation of FDG uptake. The effects of oral contrast can be minimized (or even fully avoided) by using negative oral contrast or diluted positive oral contrast. Findings reported in the literature suggest that after the use of (diluted) positive oral contrast the SUV shows biases up to 4% only, when the lesion is located near or in the intestinal wall.

b.   *Truncation*

Truncation of CT images can occur when parts of the patient are outside the field of view of the CT. Incorrect attenuation correction can occur in the entire PET image of those axial slices in which the CT truncation occurs. At present, truncation corrections are often not fully accurate to be used in combination with attenuation correction of PET data.

c.   *Beam hardening*

Beam hardening (for example when arms are located alongside the patient) can lead to a decrease of HU and therefore to underestimation of the attenuation correction of the PET image. The latter will, in turn, result in a negative (downward) bias of PET quantification.

d.   *Misalignment between PET and CT*

Each discrepancy in alignment between the CT and PET will result in incorrect attenuation correction. Therefore, it is of utmost importance that the patient is positioned in exactly the same way (e.g. position of arms) during both PET and CT image acquisition. However, artefacts in the PET image due to respiratory and cardiac motion will generally be present. Despite appropriate measures, differences in the location of the diaphragm during PET (blurred over several respiratory cycles) and CT (snapshot image) often occur. Next to PET image artefacts, this also leads to errors in quantification.

e.   *Metal implants*

Metal implants, such as hip protheses and pacemakers, can result in strong PET image artefacts (due to strongly enhanced HU in the CT image). When CT images, affected by metal implants, are used for PET attenuation correction, they will lead to an increased SUV at the site of the metal implant. For correct interpretation of the PET examination, visual inspection of both the attenuation and non-attenuation corrected PET images is required. Locally enhanced FDG uptake, at or near the site of the metal implant, which is visible only on the attenuation corrected PET images, must be interpreted as an artefact due to the presence of the metal implant. Most manufacturers offer the possibility of metal artefact correction (often setting a checkmark to "on" or "off"). Nevertheless, it is advised to always inspect both the uncorrected and attenuation-corrected images in the presence of metal implants.

4. Pitfalls in PET quantification

Even after proper attenuation correction, it is not guaranteed that the apparent activity (or SUV) in a lesion is identical to the "true" value. Therefore the following issues must be addressed.

a. *Resolution dependent quantification*

Due to the partial volume effect the activity measured with a calibrated PET-CT system will still depend on the image resolution. Since image resolution depends on the reconstruction protocol, differently calibrated systems may give different results for the same patient. To overcome this problem, international guidelines have been published detailing all steps in PET-CT imaging. The most recent guideline aiming to harmonise FDG PET-CT quantification in oncology was published in 2015 by the EANM. In this guideline, specific QC experiments with performance specifications are provided. Systems that meet the specifications described in this guideline will provide quantitative results that are comparable between sites and PET-CT systems within the accuracy specifications indicated in the guideline.

b. *Dynamic PET-CT imaging*

Quantitative measurements of the dynamics of the radioactivity distribution, as a function of time, enable pharmacokinetic models to be applied. For this purpose, the plasma radioactivity (corrected for metabolites) is usually needed. In that case, the entire chain of radioactivity measurements (dose calibrator, PET scanner, and, if necessary, also well counter and HPLC equipment) must be calibrated. See the Calibration protocol on p.645. In addition, dynamic scans are often characterized by high count-rates in the first few minutes of the study which are stored in short frames of only a few seconds. Provided that the maximum count-rate capability of the system is not exceeded, the PET-CT system should give the correct quantitative results. Nevertheless, it may be advisable to test this at least once for a new system.

c. *Gated PET-CT imaging*

With a gated PET-CT acquisition, PET images and/or CT images can be recorded in phase with the periodic motions due to breathing or the beating heart. Respiratory gating can be employed to enhance image quality and quantification in the thorax region. Imaging of lesions located in the lungs or at a short distance from the liver/diaphragm is influenced by respiratory motion. Several effects occur. Qualitatively, images will look more blurred than those from static parts of the body. Quantitatively, the tumour volumes observed will appear smoother and larger and the activity concentrations measured will be lower, especially near the boundaries of the smoothed lesion. Moreover, mismatches between PET and CT images occur because the PET image is generally recorded during many respiratory cycles, whereas the much faster CT recording leads to "frozen" images in arbitrary phases of the respiration cycle. (See also paragraph 3.d.). These effects can be reduced by respiratory gating of the PET or CT data , or both. The respiratory cycle can be recorded using pressure sensors located in a belt fastened around a patient's chest, or tracked by an optical camera system. When using this type of sensor, attention should be paid to proper adjustment of the respiratory belt. It is essential that the full respiratory cycle be measured, and clipping of the signals at full inspiration or expiration be avoided. In addition, the pressure sensors must be calibrated at regular time intervals (typically several months) to guarantee the absence of data clipping.

In addition to respiratory gating, cardiac gating can be used to "freeze" the motion of the

heart into a number of gates using the ECG signal. This allows for better assessment of wall thickness and wall motion. In addition, it may be used to assess the left ventricle volume and the ejection fraction.

In general, gating can be performed in both a retrospective and a prospective manner. With the latter, data will be collected for a pre-specified phase/ set of phases only. Prospective gating can be used to reduce the radiation dose resulting from CT image acquisition. With retrospective gating, both PET and/or CT data are collected continuously along with the gating signal and data is sorted afterwards (or online) into multiple time bins. Note that with list mode PET acquisition the data can be reconstructed as a static, dynamic, or gated study retrospectively. Retrospective CT gating results in much higher patient radiation doses than obtained with prospective gating. Users should follow the recommendations of the vendor for performing gated studies as the type of gating feasible for cardiac or oncology studies as well as options for the use of devices for recording the gating signal may depend on the specific PET-CT systems and version.

Both types of gating allow collection of PET and CT data in a gated manner. There are no specific tests described for verification of correct data collection, but useful tests to consider include:
- Visual inspection of the quality of each of the phase images
- Visual inspection of the alignment of PET and CT gated images (to exclude phase shift between PET and CT images). For the latter, a periodically moving phantom (e.g. Quasar phantom), which also triggers the gating signal, can be used. When such a phantom is not available, careful inspection of the clinical data is warranted.
- Use of a uniform phantom (e.g. calibration phantom) in combination with a simulated gating signal to verify uniformity and calibration accuracy for each gate.

5. Image quality as a function of FDG activity, scan duration and patient weight

Image SNR as well as quantification depends on the underlying PET image quality upon which interpretation and quantification are based. Quantification, in particular when based on the so-called SUV_{max}, is prone to upward bias for increasing noise levels. Images should therefore have sufficiently low noise to guarantee proper visual interpretation and quantification. It has been shown that image quality depends on the administered FDG activity, the scan duration per bed position, the percentage of bed overlap, PET-CT system sensitivity and patient weight. Initially (up to the late 90's) the activity administered was usually fixed (370 or 185 MBq depending on the use of 2D or 3D systems), sometimes adjusted to higher amounts for heavy patients (>85 kg). In a first attempt to refine the FDG dosage, the Dutch guidelines suggested the FDG activity be based on patient weight (linear), scan duration (time per bed), % bed overlap and scanning mode. In this paper a linear relationship between required FDG activity and patient weight was assumed, although the authors already suggested that this assumption only resulted in a first order improvement in estimating the correct FDG activity over the fixed activity regime. The approach followed by the Dutch guideline was subsequently adopted in the EANM guideline published in 2010. Since then, several attempts have been undertaken to further refine and optimize the assessment of the (minimally required or) optimal FDG activity. The refinements include:
a. A procedure based on a decaying experiment with the NEMA 2012 Image Quality phantom to determine the minimally required FDG activity for the clinically desired

scan duration per bed position. This procedure was approved by the NVNG in 2012. It was subsequently included in the EARL (EANM Research Ltd) procedure for assessing PET-CT system specific patient FDG activity preparations for quantitative FDG PET-CT studies in 2013. In this procedure (see http://earl.eanm.org) a linear relationship is still applied between activity and weight in order to adjust the FDG activity for variations in patient weight.

b. Secondly, the relationship between FDG activity and image quality as a function of patient weight was further explored by several authors, De Groot et al, EJNMMI Research 2013. This study showed that a quadratic relationship between FDG activity and patient weight is preferred. To date, these findings have been adopted in EANM 2015. In order to facilitate applicability in the clinic, the relationship needs to be translated into FDG activity look-up tables.

6. The adjustment of the PET-CT

The starting point for any quality control is a system initialised and calibrated as prescribed by the manufacturer. Generally, the initialisation and calibration procedure comprise the following steps: initialisation of the scanner and all its subsystems, calibration of detector gains, calibration of coincidence timing, energy corrections, and normalisation to correct for differences in sensitivities between lines of response. Calibration with a uniform source of a precisely known specific activity enables the scanner to measure absolute activity concentrations. Earlier generation scanners may require acquisition of a reference blank scan. Blank scans performed later on are then compared to this reference scan for early detection of detector drift. The nomenclature manufacturers apply to the various steps in this adjustment procedure may differ.

All systems are nowadays equipped with some daily QC procedures. After completion of this quality control procedure the system must meet all of the manufacturer's specifications. Many state of the art scanners perform adjustments based on the results of the daily QC. If a system is not properly initialised and calibrated the quality of the system cannot be guaranteed. Understanding the system used, the points needing attention and the possible consequences of (errors during) the procedures employed is essential. In addition, many state of the art scanners perform adjustments based on the results of the daily QC.

7. Selection of QC tests and frequency

QC tests of PET-CT scanners can be divided into two groups i.e. acceptance tests and routine QC tests. The acceptance tests are always performed for new systems in order to determine whether the system meets its specifications. Acceptance tests may also be repeated after repairs or after major hardware or software changes. Routine QC tests are performed to determine the stability of the performance of the system. An adaptive frequency can be used following the principles described in the general introduction to equipment.

Acceptance tests should preferably follow or approximate the NEMA NU protocols as given in the specifications by the manufacturer. Ideally, the specifications are given in accordance with latest international standard (currently NEMA NU 2-2012). As a generalisation of the previous NU2-2001 standard, the NU2-2007 standard was adapted to deal also with

detector materials that show low levels of intrinsic radioactivity (such as LSO or LYSO crystals with 2,6% [176]Lu; see Erdi et al, 2004). Specifically the procedures for sensitivity assessment, count losses and randoms and resolution have been adapted. Relative to the NU2-2007 standard, the current NU2-2012 standard contains only minor changes. These changes have the purpose of making the tests easier to conduct, more reproducible or more clearly defined. Sometimes, however, the manufacturer's specifications are based on older NEMA standards or even proprietary protocols. The NEMA NU2 tests focus on spatial resolution, sensitivity and count rate. Additionally, NEMA tests specify the measurement of the scatter fraction, count losses and randoms and image quality. Protocols for measuring the specifications are usually supplied or can be supplied by the manufacturer. In this respect, it has become clear, however, that the NEMA protocols are not always closely followed. Preferably, an agreement is reached with the manufacturer prior to the implementation of the acceptance tests regarding the availability of relevant acquisition and processing protocols and phantoms.

NEMA tests are time-consuming, sometimes difficult to perform and may require phantoms that are not, or not permanently, available. Therefore, in the QC protocols given below, a simplified method is also provided whenever possible. Although these simplified approaches are indicative, in most cases they are insufficient for (re-)acceptance testing. Even if acceptance testing is performed using NEMA protocols, we recommend that on acceptance, a number of simplified and rapid tests (spatial resolution, sensitivity, homogeneity and count rate) be carried out to establish baseline values. During re-acceptance testing these baseline values can then be used to determine whether repeating the "official" acceptance tests is necessary. An additional problem with NEMA protocols is that the user is not free in the choice of, for example, the reconstruction method, and so clinically relevant software (precisely the latest reconstruction methods) is not tested. Therefore, acceptance tests should also be carried out with a clinical (acquisition and reconstruction) protocol.

For day-to-day QC, modern PET-CT scanners are generally equipped with several measurement protocols for daily checks of all essential components. Typical parameters that are checked are timing performance (both for time-of-flight use as well as for normal coincidence timing, detection sensitivity of crystals and electronic detectors, constancy of the sensitivity over time and between crystals, etc. These protocols are more and more automated, and are often in the form of "pass-warning-fail" tests of which the meaning is not always documented or comprehensible to the user. We advise performing all protocols as recommended by the manufacturer.

Although a PET scanner is technically more complex than a gamma camera, the quality control is easier. When using "full ring" scanners, the detectors are mechanically fixed in position, so all related, potential mechanical problems can be automatically excluded. By definition, the photo peak is 511 keV and the energy window is usually fixed and collimators are not present. This may explain the experience so far that the daily quality check is sufficient to ensure the day-to-day quality of the scanner for qualitative use. The basic premise here is that as long as a completely adjusted and accepted PET scanner meets the criteria for the daily quality control, it will remain within the acceptance specifications. Given the importance of this daily test, and the possibility of (largely) automating it, this test should really be carried out every day.

To ensure that the performance of the system does not change slowly over time, more specific QC tests should be performed with a lower frequency. In this way, potential changes due to regular maintenance, repairs or minor software updates are also checked. Of course the acceptance tests can be repeated at regular intervals but a simpler approach is suggested here i.e. by use of the NEMA image quality phantom. This measurement will check the constancy of the effective spatial resolution by assessment of the recovery coefficients of hot spheres of different diameters, and check the constancy of image noise and uniformity by analyses of the uniform phantom background.

Most PET-CT systems are used quantitatively, in particular for SUV assessment. Therefore, an additional calibration of the system is required. This is generally performed using a cylindrical uniform phantom with a known activity concentration. For day-to-day calibration a point source or a uniform phantom filled with a long-lived isotope such as 68Ge can be used. For the PET scanner, this is usually included in the daily QC (see section protocol daily QC). Note however, that only the constancy of the calibration is hereby tested; there is no guarantee of proper quantification of the PET images relative to the dose calibrator. The calibration measurement should also be performed with a known activity of 18F, at regular intervals. If necessary, the latter measurement can be combined with a cross calibration of well counters. If multiple dose calibrators are available, the cross-calibration between them should also be considered. Also, if a ^{68}Ge source is replaced, the relationship to the clinical radionuclide should once again be determined.

Apart from initial acceptance testing the IQ and calibration measurements should be performed according to the most recent EANM guideline, instead of NEMA. The most up-to-date version of these protocols can be found on the EARL website (http://earl.eanm. org). There are two advantages to the use of the EARL protocols. Firstly, it allows easy comparison between different PET-CT systems and different hospitals. Secondly, it allows easy transition to the EARL certification programme for hospitals that participate, or want to participate, in multicenter studies. Table 3 shows a summary of the tests described in these recommendations.

QC tests are divided into (re)acceptance and maintenance tests. Acceptance tests consist of spatial resolution, sensitivity, count rate, scatter, uniformity and co-registration measurements. For most of these tests NEMA protocols are available. Since these protocols are often not easy to perform and may require specific phantoms as well as vendor specific software, simplified protocols are also provided. Note however, that these provide indicative results. Acceptance test are generally only performed upon acceptance of a new system or when indicated by the maintenance tests i.e. when large deviations from the baseline values are observed.

Maintenance tests consist of the daily QC, calibration and IQ phantom measurements. The Daily QC is required to ensure day-to-day performance of the system. Calibration is required to ensure proper cross-calibration with the dose calibrator. The IQ phantom measurement is required to prevent drift of the system. For these tests a minimum frequency is recommended. After (re)acceptance these tests should be performed to determine (new) baseline values. In addition these tests should be performed after

replacing fixed sources or after major software updates to determine consistency with previous results.

S: **S**pecification available from the manufacturer
B: Determining **B**aseline value for constancy test
U: Informative for the **U**ser.
EARL: Specification and rational are described in the EU guideline for FDG PET/CT tumour imaging.

Table 3: Summary of quality control for PET scanner (see Section 4).

|	Test	Criterion	Recommended Minimal Frequency	Remarks
Maintenance	Daily QC	S,U	Daily	
	Calibration if used quantitatively	B,U	Quarterly, at (re)acceptance, after replacing fixed sources or after major software upgrades.	EARL protocol recommended
	IQ phantom for recovery and uniformity.	B,U	Annually, at (re)acceptance, after replacing fixed sources or after major software upgrades.	EARL protocol recommended
(Re)acceptance	**Spatial Resolution**			
	• NEMA	S,B,U	(Re)acceptance	
	• Simplified	B,U	(Re)acceptance	Indicative
	Sensitivity			
	• NEMA	S,B,U	(Re)acceptance	
	• Simplified	B,U	(Re)acceptance	Indicative
	Count rate (accuracy)			
	• NEMA	S,B,U	(Re)acceptance	
	• Simplified	B,U	(Re)acceptance	Indicative
	NEMA Scatter fraction, randoms	S,B,U	(Re)acceptance	Full range of clinically used activities
	Uniformity	S,B,U	(Re)acceptance	
	Co-registration	S,B,U	(Re)acceptance	Depending on the use of Radiotherapy

8. Required equipment, phantoms and sources

The most common sources are the uniform cylinder phantom, the NEMA IQ phantom, the line source and the point source. For the acceptance measurements, specific (NEMA) phantoms and sources are needed. The uniform cylinder phantom exists as a fillable variant and as a sealed source with ^{68}Ge. For systems with transmission line sources, old specimens can be employed as ^{68}Ge line sources. The use of ^{68}Ge instead of ^{18}F may lead to different results because of the difference in positron range (for example in determining the spatial resolution). Whenever a line source is required, this cannot simply be replaced by a homogenous phantom, as the latter could possibly produce too much scatter.

When using open sources, protect the scanner against possible contamination.

9. CT QC

For quality control procedures regarding the CT section, reference is made to current protocols available within the field of diagnostic radiology. A PET-CT will often also be used specifically for planning radiotherapy. QC procedures relevant to radiotherapy applications are described in chapter PET-CT in radiation treatment planning, starting on page 716.

Emphasis will be on the geometric precision (sagging of the table, more rigorous verification of the co-registration between PET and CT, and co-registration with external lasers).
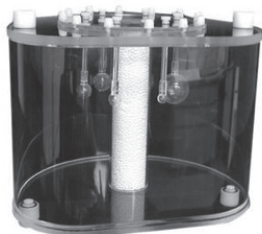
Figure 1: NEMA IQ (image quality) phantom. NEMA specifies zero activity for the two largest spheres, while EARL requires all spheres to have an equal activity concentration. In addition, NEMA specifies activity concentration ratios of 4:1 and 8:1 (spheres to background), whereas EARL requires 10:1

10. Archiving and log book

Archiving of test results and the use of log books describing problems, faults and maintenance are essential. These can be kept either on paper or in electronic form (with sufficient back-ups).

11. Miscellaneous

a. These recommendations describe the specific requirements for nuclear medicine equipment. Apart from these, a number of other issues also need to be addressed:

- The equipment must meet the (electrical) requirements, as described in IEC 601 (such as the presence of a working emergency switch).
- Mechanical safety (above all, pay attention to points where the patient can be trapped when the movement of the bed is remotely operated).

- Interfering influences from the environment, such as susceptibility to electromagnetic fields (especially if there is an MRI scanner in the vicinity) and interference due to the presence of radioactive materials (especially of 511 keV, also note the presence of patients).

- The presentation of the images on a display (or on film/paper). Image presentation is a decisive factor determining the quality of the overall imaging chain. The quality of the monitor must be adequate to assess the images. For PET viewing no general criteria have been defined. Functionality of the viewing application (level, window, gamma adjustment) also affects which requirements should be set for the monitor. For diagnostic CT viewing a system meeting radiology specifications (e.g. the Standard Greyscale Display Function) is required. Please also pay attention to the viewing conditions (e.g. prevent incident sunlight).

- Software validation: for equipment provided with a CE or FDA mark of approval, it may be anticipated that the software is bug-free. However, the user should remain alert to minor software bugs. In addition, a PET-scanner uses a number of algorithms that are not always perfect and can affect quantitative measurements. For example this might cause the results from different types of scanners to vary. Especially if there have been upgrades to the software, it may be necessary to check the quantification. A software validation strategy is described in chapter Preliminary procedure guidelines on quality control of (medical) software in nuclear medicine, starting on page 696. Manufactures generally specify limits on scanner room temperature and humidity. The first may be required due to temperature dependency of the PET detectors. Humidity must be controlled to prevent condensation.

b. Experience with isotopes other than ^{18}F (which usually requires the availability of a cyclotron in the vicinity of the scanner) is still so limited that the tests described here are limited to use of ^{18}F. If the scanner is used with other radionuclides, some tests will have to be repeated with those nuclides. Specific attention is needed when using isotopes other than ^{18}F. For example:

- Differences in positron range. This will lead to differences in spatial resolution. This is particularly relevant when using PSF reconstructions (in which the scanner's PSF is used during reconstruction to enhance the resolution of the PET images). The PSF is applicable to ^{18}F, but may not (exactly) fit the PSF for other isotopes. The latter may result in increased or more pronounced image artefacts (Gibbs artefacts) or in under correction of the intended resolution enhancement.

- The effects of differences in positron abundance. Positron abundance represents the fraction of radioactive desintegrations that emit a positron. For ^{18}F this equals 97%, but for other isotopes this can be substantially different. For example ^{89}Zr has a positron abundance of 22,9% and, when not correctly taken into account by the PET-CT system (or when the isotope is not known by the system) it may result in substantial errors in the reported activity concentrations derived from the reconstructed PET data.

- The effects of differences in half life. Similar to differences in positron abundance, isotopes have different decay half-lives and these should be correctly applied by the PET-CT system. Moreover, when reporting SUV (by the PET-CT system) it is essential to verify if decay correction is correctly applied, in particular when using long lived isotopes (e.g. more than 1 day). It also has to be clear whether decay correction is with regard to start time of scan, or to time of injection. In the case of long lived isotopes,

PET imaging is usually performed several days after radiotracer administration and PET-CT systems may not correctly deal with physical decays of more than 24 h.

- Single gamma's. Special attention should be paid to positron emitters that also emit single gamma's (prompt gamma's), especially when their energy cannot very well be discriminated from the 511eV for the annihilation photons. An example is [124]I, emitting a single gamma at 603 keV with abundance of 63%. Prompt gamma corrections are under development.

c. Power cut. The computers of the imaging equipment should be protected with an uninterruptable power supply to prevent data loss. Nevertheless, unexpected power failure can lead to dysfunction. After a power failure during clinical use, performance checks of the PET scanner detectors can be carried out using a short "daily QC". In view of the rapid decay of ^{18}F, the time lost in doing such a QC must be justified depending on the clinical schedule.

12. Abbreviations

cps=	counts per second
cts=	counts
EARL=	EANM Research Lab
FWHM=	Full Width at Half Maximum
FWTM=	Full Width at Tenth Maximum
IEC=	International Electrical Commission
kcps=	10^3 counts per second
kcts=	10^3 counts
LSF=	Line Spread Function
Mcts=	10^6 counts
NECR=	Noise Equivalent Count Rate
NEMA=	National Electrical Manufacturers Association
PMT=	Photo Multiplier Tube
PSF=	Point Spread Function
SUV=	Standardized Uptake VAlue
ToF=	Time of Flight

13. Literature

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Daily QC (Daily Quality Control)

1. Introduction and rationale

The experience so far shows that a relatively simple daily QC (such as prescribed by manufacturers) is sufficient to guarantee the quality of the scanner for qualitative use (though see Pitfalls and comments). Thus as long as a fully adjusted and accepted PET scanner meets the criteria for the daily QC, it also remains within the other (acceptance) specifications.

2. Frequency

Given the importance of this daily test, and the possibility of (largely) automating this test, it should be carried out every day.

If, for the checking of the sensitivity of the scanner, an additional test is needed (see Methods), an adaptive schedule for this may be adopted, determining the minimum frequency whilst taking into account the consequences of an abnormal sensitivity (such as a not entirely correct SUV value). If the consequences are considered serious, frequent checks will be necessary after all.

3. Method
The daily QC procedure is aimed at detecting several problems:
a. Defects in the scanner, in particular in one or more detectors.
b. Drift (slow deterioration) in the quality of the scanner due to divergent drift of the detectors. This will eventually erode the image quality.
c. Drift of all detectors together. This represents a deviation in the sensitivity and/ or calibration of the scanner and is particularly important when using the scanner quantitatively.

In addition, recent PET-CT systems do not only verify correct functioning of detectors and electronics, but also perform a fine tuning of various settings on a daily basis. The daily QC should be performed as follows:
• Due to the diversity of procedures, it is impossible to provide general recommendations for the execution of the daily QC. Therefore, the execution should strictly follow the instructions and procedures provided by the vendor.
• If, due to circumstances, no daily QC is available, measurement of uniformity can possibly be used to get a quick impression of the drift in calibration and image quality. The latter experiment can be performed using a uniformly filled phantom containing a solution with ^{68}Ge or ^{18}F (and/or as per the EARL calibration QC).

4. Required equipment, phantoms and sources
According to the specification and/or sources as provided by the manufacturer.

5. Procedure
According to the manufacturer's instructions.

6. Analysis and interpretation
According to the manufacturer's instructions.

7. Action thresholds and actions
According to the manufacturer's instructions and specifications.
If, due to circumstances, no daily QC is available, measurement of uniformity can possibly be used to get a quick impression of the drift in calibration and image quality. The latter experiment can be performed using a uniformly filled phantom containing a solution with ^{68}Ge or ^{18}F. Data can be visually inspected for acceptable image artefacts and intra and inter plane uniformity.

8. Pitfalls and comments
a. If a fixed source is used, poor positioning of the source may lead to deviations in the daily QC.

b.   If one develops a procedure oneself, account must be taken of the decay of the source.

c.   Uniformity is not suitable as a routine measure for the daily QC because it is not sensitive. The check should take place at the level of the individual detectors.

d.   If, owing to circumstances, the daily QC has not been performed, consider carrying out a short measurement of a fixed source (according to uniformity, 15 min scan), measuring the total number of counts (corrected for decay) to be used as a measure of the drift and visually evaluating the reconstructed image for artefacts due to defective and poor detectors. It should be noted that this test is not very sensitive or specific and is only suitable in case regular daily QC was or could not be performed.

Calibration (PET-CT system scanner, dose calibrator, and peripheral equipment)

1. Introduction and rationale

PET systems are capable of performing quantitative measurements of the radioactivity distribution (in Bq/cm^3). This makes it possible to translate the radioactivity measured into, for example, the Standardised Uptake Value (SUV). Calibration of the PET system and dose calibrator are then required (see Section Protocol Dose calibrator). If pharmacokinetic models need to be applied, calibration must also be done for the gamma sample changer and other peripheral equipment which is used to determine the plasma radioactivity corrected for the radioactive metabolite.

The purpose of this test is to ensure that the absolute and mutual calibrations remain guaranteed.

2. Frequency

Upon (re)acceptance of the PET scanner the mutual calibration of all relevant equipment should be checked with the radionuclide that has been used for the calibration. Also a baseline must be determined for each device using sealed sources.

Afterwards, the constancy of the calibration can be determined for each device using the same fixed source, see the various section protocols. In principle, an adaptive frequency is recommended. It depends on the application which minimum frequency can be incorporated into the maintenance routine. For the PET scanner, this check is incorporated in the daily QC.

If a fixed source is replaced, its relationship relative to the clinical radionuclide should be (re)determined. It is recommended to periodically test the calibration and image quality according to the EARL standard as described below. Sites that participate in quantitative multicentre studies, should apply for EARL accreditation.

3. Method

A full check of the mutual calibration takes place using a quantity of activity which has been measured in the dose calibrator, the PET scanner and the other equipment to be calibrated. The calibration is checked for each radionuclide. The procedure for these comprehensive checks of the mutual calibration is described below.

To ensure that the mutual calibration is maintained, the calibration would need to be done

over and over again with the appropriate radionuclides. This is a laborious process, whilst the chance of errors in preparing the sources is not negligible. Therefore, the constancy should be maintained for each device using fixed sources, see the separate section protocols of the relevant equipment (for the PET scanner: see section protocol daily QC).

4. Required equipment, phantoms and sources
Cylindrical phantom to be filled with water (the homogeneous phantom) and a few syringes and counting tubes.

5. Procedure
• Measure the radioactivity in the dose calibrator. It is preferable to use the clinically relevant counting geometry so there will be no need to correct for this. To minimise exposure to the operator, no more activity than necessary should be used in order to measure the PET scanner under clinical conditions. In clinical practice, a measurement will be taken inside the dose calibrator before injection when the activities are clearly higher. Therefore, if necessary, correct for any deviations in the linearity of the dose calibrator.
• Add the activity to the homogeneous phantom, shake well and top up until it is full.
• Potential linearity problems can be avoided by carrying out the PET measurements when the activity density is comparable to the clinical and research practice.
• At the same time, take a sample from the homogeneous phantom and use it to calibrate the gamma sample changer and other peripheral equipment. Here too, the volume and the activity must be comparable to the clinical and research practice (e.g. 500 Bq in 0,5 ml). If necessary, the sample may be diluted for this purpose. The volume must be determined by weighing.
• More details can be found in the EANM FDG PET guideline for tumour imaging.

6. Analysis and interpretation
• Reconstruct the PET data with all corrections that are needed for quantification of the data.
• Check the PET images visually in order to ensure that the activity has been well mixed.
• Determine the calibration value by dividing the number of counts measured per second per unit volume by the given activity concentration. In so doing, correct for the decay between the various measurements.

7. Action thresholds and actions
A 10% reproducibility of the calibration measurements is realistic and 5% is feasible by working carefully. A 10% threshold is recommended by international standards. The desired higher reproducibility is dependent on the application of the PET or PET-CT scanner, and the results of the tests should therefore be discussed with users. If deviations exceed the agreed limit, action is required. Assuming that there are no defects in the equipment, the check should be repeated in the first instance. If the deviation is found again, it can be decided, depending on a further analysis of the data, either to have an accelerated calibration of the dose calibrator undertaken or alternatively to perform a new set-up and normalisation of the PET scanner. Abnormalities in the gamma sample

changer and other peripheral equipment can be a sign of drift or defects.

8. Pitfalls and comments

a. If the amounts of activity and volumes used are not standardised, deviations may arise from volume effects (dose calibrator and gamma sample changer) and from any deviations in the linearity.

b. Because the measurements are made at different times, an accurate correction for decay is essential.

c. Dilution of the activity may give rise to errors.

EARL calibration QC and image quality /SUV recovery test

1. Introduction and rationale

The FDG PET-CT accreditation performed by EARL, and recommended in the EANM FDG PET-CT guideline, aims at harmonizing quantitative reads of whole body FDG PET-CT examinations that are performed in the context of multicentre studies. As part of the accreditation two tests are performed. One quality control test to verify the correct (within 10%) cross-calibration of the PET-CT system against the dose calibrator (local or remote) used to determine patient activities. The second quality control test verifies if the SUV recovery as function sphere size comply with a harmonizing standards.

2. Frequency

Calibration QC is performed quarterly (4 times a year)
The image quality and SUV recovery test is performed annually and/or after major maintenance of the PET-CT system (hardware changes and/or software updates)

3. Method

For the the calibration and image quality/SUV recovery tests the details can be found at the EARL website and/or in the EANM guidelines. The latest procedures can be found at the EARL website (http://earl.eanm.org/cms/website.php?id=/en/projects/fdg_pet_ct_accreditation.htm).

4. Required equipment, phantoms and sources

Uniform cylindrical fillable phantom with known volume.
The NEMA NU2 image quality phantom.
See EARL website for detailed information on required phantoms and sources.

5. Procedure

See it EARL website for detailed information in required phantoms and sources

6. Analysis and interpretation

Analysis and interpretation are described in the EARL website. The analysis is performed by EARL upon uploading the data to the EARL dbase. However, a copy of the analysis software can be provided upon request by contacting EARL.

7. Action thresholds and actions
• The cross-calibration of the PET-CT systems should be within 10%
• SUV recoveries should meet the harmonizing EARL standards

8. Pitfalls and comments
Details can be found in the EU guideline for FDG PET-CT tumour imaging and instructions and specifications to obtain EARL accreditation can be found at http://earl.eanm.org/cms/website.php?id=/en/projects/fdg_pet_ct_accreditation.htm.

NEMA performance tests

Spatial Resolution (NEMA: Spatial resolution)

1. Introduction and rationale
The spatial resolution of the PET scanner determines the ability of the scanner to discern two closely located defects as being separate. In combination with the sensitivity, the spatial resolution also determines the ability of the camera to detect small lesions.

2. Frequency
During acceptance, the spatial resolution should be measured either according to NEMA or according to the manufacturer's described method. For the simplified stipulation tests, a baseline must be determined during acceptance, then the measurement is repeated after reacceptance or if there are problems.

3. Method
• According to NEMA, the resolution is determined using a point source of ^{18}F (NEMA: Spatial Resolution).
• Making this point source is laborious and for the simplified method, it is thus also recommended that a fixed encapsulated point source be used.

4. Required equipment, phantoms and sources
• According to NEMA NU2 2012, the resolution is determined using a point source of ^{18}F.
• *Simplified method:*
• A fixed encapsulated positron emitting source (e.g. ^{22}Na) with a diameter of less than 1 mm. Alternatively (see also Pitfalls and comments) a line source or even a planar source can be used: a piece of clamped filter paper impregnated with an ^{18}F solution.

5. Procedure
• See NEMA NU2-2012.
• *Simplified method:*
  Place the point source in a standardised position (carefully measured in all directions), a few cm off-centre and collect enough counts in order to be able to determine a profile in all directions. When using a line source or a planar source, multiple measurements are needed in order to check the spatial resolution in all directions. Record the position in the measurement report.

6. Analysis and interpretation
- See NEMA NU 2-2012.
- *Simplified method:*
  Determine the FWHM in three directions.

7. Action thresholds and actions
Upon acceptance, the stipulation according to NEMA (or according to the manufacturer's described method) must meet the specifications. Also ensure that the user is informed of the resolution that may be expected from the scanner.
By carrying out the simplified method during the acceptance, a baseline is determined. One may be guided by the assumption that changes in the value obtained using the simplified measurement method are representative of changes in the "official" value. Thus, in principle, changes must be so small that it is not possible for the scanner specification to be exceeded. Nevertheless, if this were to happen, a new set-up and normalisation must first be performed. If the problem persists, the manufacturer must be contacted and, if necessary, the NEMA test must be repeated.

8. Pitfalls and comments
a. Positron annihilation is not limited to the location of the activity in the source, but also occurs in the surrounding material. Consequently, the source may appear larger than expected. This problem arises in practice mainly with point sources, but is also not excluded when using line sources or a planar source.
b. The spatial resolution of a PET scanner is dependent upon position of the source in the scanner's field of view, so ensure a standardised position when using the simplified measurement method.
c. Optimal centering in the axial direction (in the middle of the central slice) is critical for achieving a properly measured axial spatial resolution. The reason is that axial matrix size is half the crystal thickness, that is around 2-3 mm. Improper centering would lead to a not optimally recorded line profile. This could, however be circumvented by axialy moving the source in steps of e.g. one fifth of the crystal size, such that interleaved data are recorded.

Sensitivity (NEMA: Sensitivity)

1. Introduction and rationale
Sensitivity is a measure of the total count rate for a given activity present in the PET scanner. At low sensitivity, a longer recording time is needed to obtain statistically reliable images. The sensitivity is expressed as the number of true counts per second per MBq.

2. Frequency
During acceptance the sensitivity should be measured either according to NEMA NU 2-2012 or according to the manufacturer's described method. For the simplified stipulation, a baseline must be determined during acceptance. This should be repeated after reacceptance.

3. Method

A recording is made of a source with an accurately known activity. Using that source (after correction for decay), the count rate per MBq is derived.

When carrying out the full stipulation according to NEMA, a line source filled with ^{18}F must be used with a set of 5 coaxial cylinders. These cylinders are required in order to obtain annihilation balance but they cause attenuation. By taking successive measurements using multiple cylinders, it is possible to correct for attenuation. The simplified measurement keeps a close watch on constancy. Here, a line source is recommended, but a point source may also be used, provided an unchanging positioning can be guaranteed.

4. Required equipment, phantoms and sources

- NEMA NU 2-2012: line source with ^{18}F, freely suspended within the FOV (see for further details NEMA NU 2-2012: Sensitivity).
- *Simplified methods:*
     a. ^{68}Ge line source of a length greater than the axial FOV.
     b. ^{68}Ge cylindrical phantom of a length greater than the axial FOV.
     c. Cylindrical phantom filled with water and ^{18}F (e.g. the homogeneous phantom used for calibration).
     d. A point source (e.g. ^{22}Na) with a constant positioning.

The count rate must be low so no count rate losses occur and the random/true ratio is low (NEMA: less than 5%). It is essential to always use the same sized phantoms, since when phantoms are larger than the axial field of view, the measured sensitivity is related to the specific phantom size.

5. Procedure

- NEMA: see NEMA NU 2-2012.
- *Simplified methods:*
     a. ^{68}Ge line source:
       Position the line source in the axial direction at 1 cm distance from the centre of the transaxial FOV. Measure for several minutes (until at least 10.000 true counts per slice). Repeat the measurement at 10cm distance from the centre of the transaxial FOV.
     b. ^{68}Ge cylindrical phantom:
       Position the phantom in the middle of the FOV. Measure for several minutes (at least 10.000 true counts per slice)
     c. ^{68}Ge Cylindrical phantom filled with water and ^{18}F (e.g. the homogeneous phantom used for calibration). Position the phantom in the middle of the FOV. Measure for several minutes (at least 10.000 true counts per slice).
     d. ^{68}Ge Point Source:
       As per the calibration procedure, registering around 10.000 true counts per axial slice will suffice.

6. Analysis and interpretation

- NEMA
- *Simplified methods:*

    a. ^{68}Ge line source: Record the total number of true counts aggregated over all slices per MBq source intensity for both measurement positions.

    b. ^{68}Ge cylindrical phantom: Record the number of true counts per MBq source intensity.

    c. ^{18}F filled cylindrical phantom: Record the number of true counts per MBq source intensity.

    d. Point Source: Record the number of true counts per MBq source intensity.

Note that the sensitivity is given for the total activity in the source and not the activity in the FOV. Thus in those cases where the source is longer than the FOV, appropriate corrections must be made when using a different source. With the cylindrical phantoms the best solution is to always use exactly the same phantom.

7. Action thresholds and actions

Upon acceptance, the stipulation according to NEMA (or according to the manufacturer's described method) must meet the specifications.

By carrying out the simplified method during the acceptance as well, a baseline is determined. One may be guided by the assumption that changes in the value obtained using the simplified measurement method are representative of changes in the "official" value. Thus in principle, changes must be so small that it is not possible for the scanner specification to be exceeded.

If in doubt, the manufacturer must be contacted and, if necessary, the NEMA test must be repeated.

Uniformity (NEMA: Uniformity)

1. Introduction and rationale

Uniformity is not specified in NEMA NU 2-2012, but it is in NEMA NU2-1994. The uniformity gives a quick picture of the state of the scanner and can be used to check the correct functioning of the acquisition and reconstruction protocols after software updates. The reconstruction can also be checked by reconstructing an old study. A stipulation of uniformity alone, however, gives limited insight into the quality of the set-up and normalisation.

2. Frequency

If a specification is available, the NEMA check should be performed on acceptance. For the simplified stipulation, a baseline must be determined during acceptance. Repetition is recommended after software upgrades and if problems are suspected.

3. Method

A recording of a homogeneous phantom is made in a standardised manner. According to NEMA NU 2-1994, ^{18}F must be used for this and a very large number of counts must be collected. With the simplified method, a phantom filled with ^{68}Ge may also be used and a lower number of counts will be sufficient.

4. Required equipment, phantoms and sources

- NEMA NU 2-1994:
  20 cm diameter cylindrical phantom (homogeneous phantom used for calibration) to be filled with water and ^{18}F.
- *Simplified method:*
  The same as above or a 20 cm diameter cylindrical phantom filled with a homogeneous ^{68}Ge solution and of a length greater than the axial FOV.

5. Procedure

Position the phantom in the middle of the FOV. Measure the emission scans for several minutes to hours (up to approximately 500.000 true counts per plane) and perform a transmission scan.

- NEMA NU 2-1994:
  Collect 20 Mcounts per slice
- *Simplified method:*
  Measure up to about 500.000 true counts per slice.

6. Analysis and interpretation

- According to NEMA NU 2-1994:
  Square ROIs of 10 mm^2 in an area with a radius of 17,5 cm. Reconstruct the emission scans with all corrections that are needed for quantification of the data. Determine the average pixel value per plane in the phantom (axial profile).
- *Simplified method:*
  Determine the uniformity for each slice in a standardised manner. For example, the variation of pixel values in a centred ROI with a diameter of 17 cm or the relative progress of the activity concentration along a 1 cm wide trans axial horizontal and vertical profile through the middle of the phantom.

7. Action thresholds and actions

By repeating this test with various protocols, the user gets an impression of the uniformity that can be reasonably anticipated. If abnormalities occur and they are noticeably greater than expected, the cause must be sought.

Count rate (NEMA: Accuracy: Corrections for count losses and randoms)

1. Introduction and rationale

In a well installed PET-CT system, dead-time effects at high count rates as well as the influence of randoms are corrected in such a manner that there is a linear relationship between number of counts measured over a wide (specified by manufacturer) range of activities and the current activity present. However, if not done correctly, large errors can occur in quantitative measurements.

2. Frequency

During acceptance the count rate should be measured either according to NEMA or

according to the manufacturer's described method. According to NEMA NU 2-2012 (sections 4 and 6), measurements must be done with sufficient high activity in order to reach peak count rate and peak noise equivalent count rate. The initial activity needed should be supplied by the manufacturer. Reaching the peak count rate (especially, for instance, with LSO scanners) may require a very high source activity. Upon acceptance linearity should be verified for the clinically relevant activity range. Repetition is recommended at (re)acceptance.

3. Method
In accordance with NEMA NU 2-2012, an ^{18}F line source is mounted in a solid phantom and the count rates are measured during many decay periods.

4. Required equipment, phantoms and sources
NEMA: line source with ^{18}F at 45 mm from the centre in a 70 cm polyethylene cylinder with a diameter of 203 mm.

5. Procedure
See NEMA NU 2-2012, sections 4 and 6 (however, see the note under Frequency)

6. Analysis and interpretation
See NEMA NU 2-2012

7. Action thresholds and actions
Upon acceptance, the stipulations according to NEMA (or according to the manufacturer's described method) must meet the specifications. One may be guided by the assumption that changes in the value obtained using the simplified measurement method are representative of changes in the "official" value. Thus, in principle, changes must be so small that it is not possible for the scanner specification to be exceeded. If in doubt, the manufacturer must be contacted and, if necessary, the NEMA test must be repeated. If, in the clinically relevant range of activity, the scanner deviates from linearity, its user must be informed.

Scatter fraction (NEMA: scatter fraction, count losses, and randoms measurements)

1. Introduction and rationale
The NEMA NU 2-2012 test for "scatter fraction, count losses and random measurements" is carried out using the same experiment as for the count rate test indicated above. The result of this NEMA test is very important for verifying the correct functioning of the PET-CT. In principle, this test uses the same experimental data as the one for the count rate test. However, if this would not be the case then the manufacturer's recommendations should be followed. The main benefit of using the same experimental data is that the phantom needs to be filled only once. The disadvantage could be that the acquisition cannot be done automatically using a dynamic protocol (which is usually in the manufacturer's protocol).

2. Frequency

During acceptance the scatter fraction should be measured either according to NEMA or according to the manufacturer's described method. According to NEMA NU 2-2012 (sections 4 and 6), measurements must be done with sufficiently high activity in order to reach peak count rate and peak noise equivalent count rate. The initial activity needed should be specified by the manufacturer. During acceptance the linearity should be verified for the clinically relevant activity range. Repetition of these tests is recommended at (re)acceptance.

3. Method
- In accordance with NEMA NU 2-2012
- Alternatively, in case the test cannot be performed according NEMA the vendor recommendations should be followed

4. Required equipment, phantoms and sources
- NEMA: line source with ^{18}F at 45 mm from the centre in a 70 cm polyethylene cylinder with a diameter of 203 mm
- According to the vendor's recommendations

5. Procedure
- See NEMA NU 2-2012, sections 4 and 6
- According to the vendor 's recommendations

6. Analysis and interpretation
- See NEMA NU 2-2012
- According to the vendor 's recommendations

7. Action thresholds and actions

Upon acceptance, the stipulations according to NEMA (or according to the manufacturer's described method) must meet the specifications. If in doubt, the manufacturer must be contacted and, if necessary, the test must be repeated.

8. Pitfalls and comments

When performing an acceptance test the version of the NEMA performance standard should match the version listed on the manufacturer's specifications sheet. A serious obstacle when planning NEMA tests based on a more recently published standard is the unavailability of scan protocols, reconstruction scripts and analysis tools on systems marketed before the release of this standard. Often the manufacturer of the PET-CT systems offers to perform the NEMA NU 2 test during acceptance testing. We strongly recommend that the execution of these tests by the vendor, both for acceptance and re-acceptance testing, should be a part of the purchase of the PET-CT system. After major PET-CT system revisions (hardware) it is desirable to repeat the NEMA NU 2 tests to verify performance of the system within (new) specifications.

Reaching the peak count rate (especially, for instance, with LSO scanners) may require a high source activity. Therefore, radiation safety should be carefully considered when performing this test.

<u>Co-registration or spatial PET-CT alignment</u>

1. Introduction and rationale

PET-CT systems are usually supplied with a special calibration procedure for the initial establishment of the co-registration of the PET and CT fields of view. Routinely checking the accuracy of image alignment in these multimodality devices is of importance for two reasons. Errors in the alignment will cause inaccuracies in attenuation correction and improper correlations of anatomy and function. The accuracy of the image alignment becomes even more important when considering the scanner in conjunction with radiotherapy applications.

2. Cross references

The chapter "Co-registration in hybrid imaging devices" provides means of verifying the accuracy of co-registration in PET-CT devices.The chapter "PET-CT in radiation treatment planning" is dedicated to quality control procedures for PET-CT when incorporating PET in radiation treatment planning.