GUIDELINE FOR RADIATION PROTECTION AND PERFORMANCE EVALUATION OF PET-CT IMAGING

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1ST SEPTEMBER 2010

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1 Introduction

1. 1 Scope of this document

Positron emission tomography – computed tomography (PET-CT) system is a new imaging tool in the nuclear medicine department. The primary goal of PET-CT imaging is to produce highly accurate fusion images with proper registration of both CT and PET images on the same platform. An additional goal is to produce images with the lowest reasonable radiation dose consistent with the clinical use of the equipment.

Even though they can be operated to acquire either CT images or PET images, they are mainly operated to acquire both, combining two medical imaging technologies: X-ray CT for anatomical imaging, and attenuation correction and PET for functional imaging. This brings the advantages and also the complexities of both systems while providing anatomical and functional aspects through fusion images.

Therefore, PET-CT scanner shall be tested on installation and monitored by a Nuclear Medicine Physicist to ensure proper functioning within the manufacturer's specifications and accepted performance standards.

The scope of this document is to present a guideline on radiation protection related to the use of PET-CT scanner and the performance evaluation of this imaging device.

The objectives of this guideline are to:

a. provide adequate safety measures to protect patients, occupationally exposed personnel and the public from unnecessary radiation exposure from PET-CT imaging
b. improve and maintain the quality of clinical data acquired using PET-CT scanner
c. ensure that minimum standard of PET-CT scanner performance is achieved.

This guideline should be read in conjunction with all related rules and regulations enforced. It is important that the performance level of the scanner is established during acceptance testing, and that performance standards are maintained over time by an appropriate quality control program. Inadequate performance and quality control procedures may cause an unnecessary increase in dose to the patient and staff, and a decrease in the diagnostic value of the examination.

1.2 Care of patients undergoing medical imaging procedures

1.2.1 Nuclear medicine physicians, radiologists, nuclear medicine physicists, nuclear medicine technologists, and all supervising physicians have a responsibility to minimize radiation dose to individual patients, to staff, and to society as a whole, while maintaining the necessary diagnostic image quality. This concept is known as "as low as reasonably achievable (ALARA)."

1.2.2 Facilities, in consultation with the nuclear medicine physicist, should have in place and should adhere to policies and procedures, in accordance with ALARA, to vary examination protocols to take into account patient body habitus, such as height and/or weight, body mass index or lateral width.

1.2.3 The dose reduction devices that are available on imaging equipment should be active. If not, manual techniques should be used to moderate the exposure while maintaining the necessary diagnostic periodically measured by a nuclear medicine physicist in accordance with the appropriate standards.

2. Radiation protection in PET-CT imaging

2.1 Principles of safe radiation protection

2.1.1 General principles

2.1.1.1 Radiation protection is based on principles defined by the International Commission on Radiological Protection (ICRP). Three general principles apply to safe radiation practice, namely justification of practice, optimization of protection and individual dose limits.

2.1.2 The justification of practice

2.1.2.1 No practice shall be adopted unless its introduction produces a positive net benefit to the exposed individuals.

2.1.3 The optimisation of protection

2.1.3.1 In relation to a particular practice, the magnitude of individual dose, the number of people exposed, and the likelihood of incurring exposure, shall be kept as low as reasonably achievable (usually referred to as the ALARA principle), economic and social factors being taken into account.

2.1.3.2 This should be an over-riding principle in all aspects of radiation protection when using ionising radiation for imaging purposes. As a result, all practices where ionising radiation emitting devices are used for imaging purposes shall be designed so as to reduce to a reasonable level:

(a) the undesired exposure of individuals from radiation,
(b) the risk of equipment failure leading to an uncontrolled exposure,
(c) the occurrence of errors when in use.

2.1.4 Individual dose limits

2.1.4.1 The effective and equivalent dose to individuals shall not exceed the limits defined in the IAEA Basic Safety Standards.

2.1.4.2 These objectives are in general achieved by a combination of engineering design features of the equipment, facility and administrative procedures.

2.2 Medical exposures

2.2.1 The justification of practice

2.2.1.1 A patient may be exposed to radiation for medical imaging purposes with the patient's approval when in the professional judgement of the nuclear medicine physician or other authorised medical practitioner, the proposed usage of radiation will be of net benefit to the patient.

2.2.2 Optimization

2.2.2.1 Optimization of the protection of the patient should take place by proper protection design, operation and quality assurance. In addition, protecting the patient requires optimization of the imaging procedure as a whole to deliver adequate dose to the diseased tissues and to reduce unwanted radiation dose to other tissues to as low as reasonably achievable, economic and social factors being taken into consideration.

2.2.3 Dose Limits

2.2.3.1 Dose limits do not apply to medical exposures, since the total benefit of the exposure is directed to the individual exposed, and because of the individual medical requirements of each patient.

2.3 Radiation shielding for PET-CT facility design

2.3.1 Shielding requirements

2.3.1.1 Special care must be exercised regarding radiation shielding requirements for PET-CT facility design. Appropriate shielding must be provided for patient injection/uptake rooms, PET-CT imaging suites, and any other areas where PET radiopharmaceuticals are prepared, used, or stored.

2.3.1.2 Due to the high energy of annihilation radiation used in PET, the amount of shielding materials needed to protect adjacent areas is typically much larger than that for conventional CT scanners or other diagnostic imaging modalities including conventional nuclear medicine imaging.

2.3.1.3 A nuclear medicine physicist should be consulted early in facility design planning stages so that shielding requirements can be determined and structural design issues, created from using the larger amounts of shielding can be assessed. The design and shielding information should be forwarded to the appropriate authority for the licensing purposes.

2.3.1.4 Appropriate radiation shielding should be provided for the doors, walls, floor and ceiling of the room in which the PET-CT scanner is installed and for any protective barrier intended for use as a shield for the operators, to ensure that the radiation dose to any personnel is as low as reasonably achievable.

2.3.1.5 Where a fixed protective shield is provided for use by the operator it must, in the case of new installations, be clearly and durably marked with the lead equivalent and the kVp of the x-ray beam at which the lead equivalent was measured.

2.3.1.6 Where a viewing window is used as part of the protective shield the lead equivalent and the kVp of the x-ray beam at which the lead equivalent was measured must, in the case of new installations, be clearly and durably marked on the viewing window.

2.3.2 Shielding assessment

2.3.2.1 Specifications for radiation shielding of protective barriers and the design details of rooms used for PET-CT scanner should be determined and documented by the nuclear medicine physicist before building works start.

2.3.3 Radiation warning sign

2.3.3.1 A radiation warning sign complying with the IAEA safety standards regulation must be displayed on the outside of the entry doors to any room housing a PET-CT scanner.

2.3.3.2 A radiation warning light must be positioned at the entry doors to a rooms housing PET-CT scanner.

2.3.3.3 Where a radiation warning light is provided, it should illuminate whenever the x-ray tube is placed in the preparation mode before exposure or when exposure is in progress. The light must remain illuminated for the duration of the exposure and must bear the words **'X-RAYS—DO NOT ENTER'** or similar. Immediate illumination should be ensured.

2.3.4 Personnel present during PET-CT examination

2.3.4.1 The operator should ensure that no personnel, other than the patient, remains in the x-ray room during an exposure, unless the personnel is behind a protective screen or is wearing a protective apron.

2.3.4.2 The only personnel who should be present in the room during the scanning are those:
(a) whose presence during the procedure is necessary, or
(b) who are responsible for the care of the patient, or
(c) who are receiving instruction from the personnel conducting the procedure.

2.3.5 Markings on CT x-ray generators and tube assemblies

2.3.5.1 X-ray generators and tube assemblies must be permanently marked and the markings must be clearly visible.

2.3.5.2 X-ray generators must bear the following markings:
(a) the name or trademark of the manufacturer
(b) the type or model number
(c) the serial number or registration number.

2.3.5.3 X-ray tube assemblies must bear the following markings on the outer side of the tube housing:
(a) the name or trademark of the manufacturer of the x-ray tube insert
(b) the type or model number of the x-ray tube insert
(c) the serial number of the x-ray tube insert
(d) the name or trademark of the manufacturer of the x-ray tube housing
(e) the type or model number of the x-ray tube housing
(f) the serial number of the x-ray tube housing

3 Acceptance testing

3.1 When acceptance testing of PET-CT scanner perform

3.1.1 Acceptance testing of PET-CT scanner shall be performed upon installation and should be completed before clinical use.

3.2 Standard of acceptance testing of PET scanner

3.2.1 Acceptance testing and data analysis of the PET scanner should be done according to the procedures in the appropriate National Electrical Manufacturers Association (NEMA) publication.

3.3 Acceptance testing and data analysis

3.3.1 Acceptance testing and data analysis of the CT scanner should be done according to Appendix B.

4 Performance characteristics of PET-CT

4.1 Quality Control procedures

4.1.1 Quality control (QC) procedures approved by a nuclear medicine physicist must be instituted and maintained properly. The procedures should ensure that consistent, optimum-quality images are produced while the exposure of patients, staff and the public to radiation satisfies the 'as low as reasonably achievable' principle.

4.1.2 The QC procedures should include checks and test measurements on all parts of the imaging system, as indicated in this guideline.

4.1.3 The nuclear medicine physicist must design quality control procedures that include regular testing procedures to insure proper operation on a daily basis. Quarterly testing with a 3D phantom for uniformity, resolution, and contrast is recommended.

4.1.4 The QC activities for PET-CT should be reviewed regularly.

4.1.5 The test results must be reviewed by the nuclear medicine physicist and documented in an annual survey reports.

4.1.6 Each facility is required to submit a summary of the quality control and frequency of testing currently being done on each PET-CT unit to the appropriate authority.

4.2 Qualifications and Responsibilities of a Nuclear Medicine Physicist

4.2.1 Qualifications

4.2.1.1 A nuclear medicine Physicist is an individual who is competent in applying the physics knowledge in nuclear medicine.

4.2.1.2 The nuclear medicine physicist may be assisted by properly trained individuals in obtaining QC data. However, the ultimate responsibility is on the nuclear medicine physicist.

4.2.2 Responsibilities

4.2.2.1 The nuclear medicine physicist must be familiar with the principles of imaging physics and radiation protection; laws and regulations pertaining to the use of the equipment being tested; the function, clinical usage, and performance specifications of the imaging equipment; and calibration processes and limitations of the instruments and the techniques used for testing performance.

4.2.2.2 A nuclear medicine physicist has to ensure that instruments used for routine radiation dosimetry or equipment performance monitoring should have a current calibration certificate that is traceable to an appropriate national standard.

4.3 Performance evaluation of PET scanner

4.3.1 PET characteristics to be monitored

4.3.1.1 The performance evaluation procedures should include as a minimum, those recommended by the manufacturer. The following characteristics shall be evaluated for the equipment to which they apply on at least an annual basis:

a. Spatial resolution
b. Count rate performance (count rate versus activity), including count loss correction. Specific measurements of the following are recommended.
    a. Total coincidences
    b. Random coincidences
    c. Scatter coincidences
    d. Net true coincidences
    e. Noise equivalent count rate
c. Sensitivity (kcps/ kBq)
d. Scatter Fraction (SF)
e. Image quality, accuracy of attenuation and scatter corrections

4.31.2 Performance evaluation tests, tolerances and checklists for PET equipment is shown in Appendix C.

4.4 Performance evaluation of CT scanner

4.4.1 Characteristics to be monitored

4.4.1.1 Performance of each CT unit must be monitored at least annually. This evaluation should include, but not be limited to:

1. Alignment light accuracy
2. Alignment of table to gantry
3. Multiple-row detector assembly and available scan modes
4. Slice localization from scanned projection radiograph (localization image)
5. Table increment accuracy
6. Slice thickness
7. Image quality
    a Spatial resolution
    b. Low-contrast resolution
    c. Image uniformity
    d. Noise
    e. Artifact evaluation
8. CT number accuracy and linearity
9. Display devices.
    a. Image display monitor(s)
    b. Hardcopy display unit(s), if available

10. Dosimetry
    a. CT dose index (CTDI)
    b. Patient radiation dose for representative examinations
    c. Review of pediatric dose reduction protocols
    d. Monitoring of pediatric specific (typically weight-based) doses
11. Safety evaluation
    a. Visual inspection
    b. Work load assessment
    c. Scatter radiation measurements
    d. Audible and visual signals
    e. Posting requirements
12. Other tests as required by state and/or local regulations

4.4.2 CT baseline values

4.4.2.1 Baseline values for noise, mean CT number, uniformity, slice thickness, high contrast resolution and CT dose index should be established at the start of operation and following any maintenance likely to affect these parameters.

4.4.2.2 Values for parameters in clause 4.4.2.1 should be defined using the appropriate image quality phantoms for all field sizes.

4.4.2.3 Deviations from baseline values should not exceed those given in Table 1.

Table 1 Acceptable deviations from CT baseline levels

Parameter	Deviation
Noise	± 10% or 0.2 HU* (whichever is greater)
Mean CT number	± 4 HU
Uniformity	± 2 HU
Slice thickness	± 1.0 mm for thicknesses > 2.0 mm or ± 50% for thicknesses ≤ 2.0 mm
Dose index	± 20%
High-contrast resolution	± 15% modulation
Couch positioning	± 2.0 mm

* HU = Hounsfield unit

4.4.3 Diagnostic reference levels

4.4.3.1 Dose exposure evaluation of CT procedures should be conducted as part of the QA program.

4.4.3.2 Dose levels that consistently exceed those in Table 2 should be investigated and justified.

Table 2 Some diagnostic guidance levels for CT procedures[1]

Examination	CT Dose Indexw (mGy)*	Dose Length Product (mGy cm)
Routine Head	60	1050
Routine Chest	30	650
Routine Abdomen	35	780
Routine Pelvis	35	570
Pediatric	25	

*EC, Report EUR 16262, European Guidelines on Quality Criteria for Computed Tomography, 1999.

4.5 Specific tests for PET-CT

4.5.1 Overall performance

4.5.1.1 The performance of either the PET or the CT system can affect the overall performance of dual-modality imaging. Each system should be tested individually, as stated previously, and together to examine co-registration. For this purpose, specially designed phantoms shall be scanned on both the PET and CT systems.

4.5.1.2 Accuracy of co-registration should be determined by established procedure.

4.5.2 Patient radiation dose: CT only

4.5.2.1 Patient radiation dose represented by CTDI shall be evaluated at least annually.

4.5.2.2 Doses to adult and pediatric patients (if performed) for CT examinations (e.g., head, thorax, abdomen, pelvis, and whole-body) shall be assessed. These results shall be compared with appropriate guidelines or recommendations when they are available. Appropriate steps should be taken if the reference doses are not consistent with the recommendations.

4.5.3 Organ doses from radiopharmaceuticals: PET only

4.5.3.1 The activity of radiopharmaceuticals used must be optimum so that the dose to a patient is optimum without compromising the quality of the image.

5 Documentation

5.1 QC report and follow-up procedures

5.1.1 The nuclear medicine physicist shall report the findings to the physician(s), to the responsible professional(s) in charge of obtaining or providing necessary service to the equipment.

5.1.2 The head of department should take immediate action by direct verbal communication if there is imminent danger to patients or staff using the equipment due to unsafe conditions.

5.2 Record keeping

5.2.1 A record of maintenance and QC test results should be kept for each item of radiation apparatus. Information on any defects found and their repair must be included.

5.2.2 Records should include necessary information to allow retrospective dose assessment.

5.2.3 All QC records, including faults, modifications and maintenance, must be made available to the appropriate authority on request.

5.2.4 Written survey reports shall be provided in a timely manner consistent with the importance of any adverse findings.

6 References

American Association of Physicists in Medicine Task Group 108 report "PET and PET-CT Shielding Requirements," in conjunction with the National Council on Radiation Protection Report 147, should be used as a reference in determining PET-CT shielding requirements.

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Appendix A – Terminology

absorbed dose. Energy delivered from radiation per unit mass of absorbing material, measured in Gray (Gy) or mGy. One Gray equals one joule per kilogram.

acceptance testing. Testing prior to delivery of a system.

air kerma. Kinetic Energy Release per Unit Mass (KERMA) measured in a mass of air.

analog-to-digital converter (ADC). These devices convert continuous electrical voltages to discrete integer numbers in a defined range. When a digital image is acquired from an analog gamma camera an ADC converts the electrical signal that represents the x and y positions for a detected photon to a matrix location in the ranges of, for example, 1–64 or 1–128.

annihilation photons. When a positron is emitted it travels a short distance in tissue, losing energy. It eventually combines with an electron and the two annihilate (disappear), with the mass being converted into energy in the form of two gamma rays (511 keV) that travel in opposite directions.

asymmetric energy window. Normally, the energy window is centred on the main peak(s) of the radionuclide being imaged. To reduce scatter, an offcentre energy window, shifted up on the peak, is sometimes used. This is referred to as an asymmetric window.

axial field-of-view (FOV). The maximum length parallel to the long axis of a positron emission tomograph along which the instrument generates transaxial tomographic images.

back-projection. This is the process used in reconstruction, which allocates counts in the reconstructed image at each voxel proportional to the number of recorded counts on the projection, defined by the geometry of detection. In the simplest case assuming a parallel hole collimator, each voxel will be allocated counts from a projection pixel, defined by a line drawn at right angles to the projection that passes through the voxel.

bismuth germanate oxide. This is a detector material commonly used in PET cameras. It has a higher density than NaI and is therefore well suited to detection of the high energy (511 keV) annihilation photons.

centre of rotation. This defines the point that should correspond to the exact centre around which the detectors rotate; it should correspond exactly to the centre of the projections recorded at all angles. Any error in this point will lead to loss of resolution.

coincidence detection. In order to detect the two gamma rays emitted from a positron annihilation event, two detectors are used and a valid event is recorded when both detectors record an interaction at the same time (or within a very short time of each other). The

detectors operate in electronic coincidence. This term is used with detectors in dedicated PET systems as well as in gamma camera based PET systems.

convolution. Convolution is the filtering procedure undertaken in the spatial domain. It involves replacing each pixel value by a weighted sum of the neighbouring values and the value itself. The result will depend on the weighting values, usually resulting in a smoother image (e.g. nine point smooth).

CT. This abbreviation stands for computed tomography.

CT dose index. The integral of the dose profile along a line perpendicular to the tomographic plane from -7T to +7T (where T is the nominal slice thickness), divided by the product of the nominal slice thickness and the number of tomograms (*N*) produced in a single scan.

CT number. The number used to represent the mean x-ray attenuation associated with each elemental area of the CT image. It is normally expressed in Hounsfield units.

cut-off/critical frequency. The shape of a filter is defined by some mathematical function, with the value 1 at zero frequency and lower values at progressively higher frequencies. The cut-off or critical frequency is a parameter that defines the shape of the function, a lower cut-off frequency defining a curve that drops to zero faster, resulting in a smoother result. In the case of the Butterworth filter the cut-off frequency defines the point when the amplitude reaches half the maximum value.

electronic collimation. Since annihilation photons travel in opposite directions, the origin of the annihilation can be defined by the straight line joining the points of detection of the two photons without the need for conventional collimation.

energy spectrum. A plot of the number of gamma photons detected as a function of the energy of the gamma rays. Such spectra are useful for setting energy windows with the pulse height analyser and for observing the amount of scatter present.

energy window. Setting a lower and upper energy threshold, the energy window determines which gamma ray energies are accepted and displayed.

FOV. This abbreviation stands for field of view.

full width at half maximum (FWHM). This term refers to resolution measurements (e.g. spatial and energy resolutions). FWHM is usually measured from a profile through an image of a line or point source, or, in the case of energy, from the energy spectrum of a single gamma emitting radionuclide. The spread is due to resolution effects and is measured by the full width of the profile at a point which is half the maximum height of the profile.

contrast resolution. The ability to resolve different objects in the displayed image, when the difference in attenuation between the objects and the background is large compared to noise. Also known as spatial resolution.

Kerma (K). Kinetic Energy Released in a material by ionising radiation and is determined as the quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all the charged ionising particles liberated by uncharged ionising particles in a material of mass dm ($K = dE_{tr}/dm$). The unit of kerma is the gray (Gy), or joule per kilogram.

Kerma rate. *kerma* per unit time and is determined as the quotient of dK by dt, where dK is the increment of kerma in the time interval dt.

lead equivalent. The thickness of lead causing the same attenuation of a beam of a specified radiation quality as the material under consideration.

line source. A thin line (such as a capillary tube) filled with activity, which is used for measuring resolution. The diameter of the line source should typically be 1 mm.

lutetium oxyorthosilicate (LSO). This is a new detector material currently being considered for PET systems.

mean CT number. The mean value of the CT numbers of all pixels within a certain defined region of interest.

NEMA (National Electrical Manufacturers Association). NEMA develops standard specifications for imaging equipment including gamma cameras (SPECT) and PET. These form the basis for specification and acceptance testing of equipment, and some tests, with modification, can also be used for routine quality control.

noise. The variation of CT numbers from a mean value in a defined area in the image of a uniform substance.

noise equivalent count rate (NEC). Noise equivalent Count rate used to estimate the numbero f true count acquired per sec exempt of scatter, randoms and intrinsic contributions.

performance evaluation tests. Those tests which are undertaken either regularly, or after maintenance or repairs, to detect whether any changes in the performance of the equipment has occurred. They are also referred to as quality control

phantom. A test object that simulates the average composition of various structures.

positron emission tomography (PET). Tomography based on detection of the dual annihilation photons that originate from positron emission. The technique involves detection of the dual photons in coincidence (at the same time).

primary beam. A ionising radiation that emerges through the specified aperture of the protective shielding of the x-ray tube and the collimating device.

projections (count profiles). This term refers to the counts recorded during tomographic acquisition. The counts in a single row of the images recorded in SPECT at a given angle represent a projection of the emitted counts. These can also be referred to as count profiles.

The set of projections, recorded at different angles, form the data that are used for tomographic reconstruction.

prompt counts. Count that represent coincidence events acquired in the standard coincidence window of a positron emission tomograph. Prompt counts include true, scattered and random coincidence events.

quality assurance. The systematic process of checking to see whether a product or service being developed is meeting specified requirements.

quality control. quality control (QC) is a procedure or set of procedures intended to ensure that a manufactured product or performed service adheres to a defined set of performance criteria.

random coincidence. When two gammas originating from quite independent sources (e.g. two separate positron emissions) are detected at the same time, the path defined by the points of detection does not correspond to a positron emission. This incorrectly located coincidence event is referred to as a random event.

resolution. This refers to the ability of imaging systems to distinguish between two closely spaced small sources. Usually expressed in terms of FWHM, which describes the spread of the image obtained from a line or point source.

resolution recovery. This is the opposite of smoothing, and is achieved by filtering or deconvolution. By use of an appropriate filter the loss of resolution due to some measurable effect (e.g. due to a detector's finite resolution) can be partially recovered. However, any noise in the original image will normally be amplified.

ring artefacts. These are a common error in reconstructed images which are caused by a localized non-uniformity in the detector.

scatter coincidence. When one or both photons originating from a positron event are detected in coincidence, the path defined by the points of detection does not necessarily correspond to the point of positron emission. This event is referred to as a scatter coincidence.

scatter fraction (SF). A dimensionless ratio of the scattered coincidence events to the sum of scattered and true coincidence events in a defined ROI of the scanner field-of- view.

scattered photon. A gamma ray which has changed direction at least once due to Compton interaction and loss of energy in the material through which it is travelling.

scattered radiation. Ionising radiation produced from the interaction of electromagnetic ionising radiation with matter. It has a lower energy than, or different direction from, that of the original incident ionising radiation.

sensitivity. Fraction of the emitted gamma rays which pass through the collimator (collimator sensitivity) or are detected by the gamma camera (system sensitivity).

single event. In a PET system, when a photon is detected without a corresponding coincident photon, this is referred to as a single event. Owing to the probability of detection, there are many more single events detected than coincidences.

sinogram. The image formed by placing projection values in sequential rows (i.e. arranging pixels corresponding to projection position versus projection angle) is called a sinogram. It is so called since the projections from a single point describe a perfect sine wave when plotted in this form.

slit phantom. A phantom consisting of a lead mask with thin slits cut into it. Typically the slits are 1 mm wide and 30 mm apart. They are used for measuring intrinsic FWHM resolution and also linearity.

spatial frequency. Frequency normally refers to cyclic variations as a function of time (units: s^{-1}). However, if a curve represents variations in values over distance (units: 1/distance), the number of oscillations per unit distance is referred to as a spatial (rather than temporal) frequency.

tomography. Literally this means 'drawing a body slice'. Tomography involves measurement from different angles around an object with the intention to 'reconstruct' an image of the internal distribution of some parameter (e.g. activity in PET).

transverse field-of-view (FOV). The maximum diameter circular region perpendicular to the long axis of a positron emission tomograph within which objects might be imaged.

true coincidence. When two annihilation photons originating from a single positron annihilation are detected in coincidence (without being scattered), this is referred to as a true coincidence.

uniformity. A measure of how uniform the observed counts across the FOV are when the detector is irradiated by a uniform source. Integral uniformity is a measure of the maximum count deviation ((max − min)/(max + min)) over a given FOV. Differential uniformity is a measure of the maximum rate of change over a specified distance. Both shall be measured for the UFOV and the CFOV.

voxel. If one considers a digitized 3-D volume rather than a digitized 2-D image, each digital value within the volume can be considered to occupy a small volume element (e.g. a small cube) or voxel. One therefore refers to planar projections as having pixels, but to each reconstructed slice as having voxels, which also have a thickness corresponding to the spacing between adjacent slices.

X-ray tube potential difference. The peak value of the potential difference applied to the x-ray tube, expressed as kilovolts peak (kVp).

Appendix B – Performance evaluation tests, tolerances and checklists for CT

The schedule of tests and tolerances specified in this section's tables have been adopted from international literature and the tolerances should be regarded as a minimum standard for the range of equipment considered and the frequency determined. Manufacturer's tolerance specifications may be used when they approximate the tabulated values.

No.	Parameters	Optimum Standard	Remedial Level	Suspension Level	Frequency
1.	**X-Ray Generator**				
	i. Accuracy of kVp	Maximum deviation : ≤ ± 5% or ± 5 kV whichever is smaller	>± 5% or ± 5 kV whichever is smaller	>± 20% or ± 20 kV whichever is smaller	Annually
	ii. Accuracy of exposure Time	Maximum deviation : ≤ ± 10%	>± 10%	>± 25%	
2.	**Radiation Dosimetry**				
	i. Patient dosimetry (CTDI)	≤ ± 20% of nominal	>Baseline ± 20%	>Baseline ± 50%	Semi-annually
	ii. Scout localisation image	≤ ± 20% of nominal	>Baseline ± 20%	>Baseline ± 50%	
3.	Scan Localization				
	i. Axial scan localisation light accuracy	≤ ± 2mm	>± 5mm	-	
	ii. Isocenter alignment, sagittal and coronal localisation light accuracy	≤ ± 5mm	>±15mm	-	
	iii. Gantry (or table) tilt accuracy	≤ ± 3^0 of intended	>± 3^0	-	Annually
	iv. Table top incrementation	≤ ± 2mm in 20 cm	>± 2mm in 20 cm	-	
	v. Couch travel accuracy (spiral Scan)	≤ ± 2mm in 20 cm	>± 2mm in 20 cm	-	
	vi. Accuracy of scan prescription from scout localisation image	≤ ± 1mm	>± 1 mm	-	
4.	**Image Scan width (sensitivity profile)**	± 20% of intended or ± 1 mm whichever is	>Optimum standard	>± 50% of intended	Annually
	Single-slice CT	• Greater for < 5 mm slice. • Smaller for ≥ 5 mm slice			
	Multi-slice CT	Within Manufacturer's spec	>± 20% of Manufacturer's spec	>± 50% of Manufacturer's spec	

No.	Parameters	Optimum Standard	Remedial Level	Suspension Level	Frequency
7.	**Image Quality**	(CATPHAN-500 or similar)			
	i. CT number uniformity	± 5HU (Head Phantom)	-	-	Monthly
	ii. Noise (% of μ_{water})	≤ ± 0.5% (Head Phantom)	>± 1.5%	-	
	iii. Image artifacts (transaxial scan localisation images)	No significant artifacts	-	-	
	iv. Low contrast resolution	5 mm	Out of Manufacturer's spec		
	v. High contrast resolution	1 mm holes (5lp/cm)	Out of Manufacturer's spec		
8.	Quantitative Accuracy				
	i. Accuracy of distance measurements (transaxial and scan localisation images)	± 1 mm	> ± 1 mm	-	Annually
	ii. CT number value	• Water: 0 ± 1.5 HU • Other material ± 20 HU (or) 5% whichever is greater	• Water: 0 ± 10 HU • Other material ± 20 HU (or) 5%	-	Monthly
	iii. CT number constancy	Value and standard deviation for water remains relatively constant	-	-	Daily
	iv. CT number dependence on scan thickness	≤ ± 3HU	> ± 3HU	-	Semi-annually
	i. CT number dependence on phantom size	≤ ± 20HU	> ± 20HU	-	Semi-annually
	ii. CT number dependence on phantom position	≤ ± 5HU	> ± 5HU	-	Annually
	iii. CT number dependence on reconstruction algorithm	≤ ± 3HU	> ± 3HU	-	Annually
9.	Leakage Radiation	0.1 mGy in one hour at 1 meter from focus	-	> 1 mGy in one hour	Acceptance Test. Tube change

Appendix C – Annual performance evaluation tests, tolerances and checklists for PET

The schedule of tests and tolerances specified in the table below has been adopted from international literature and the tolerances should be regarded as a minimum standard for the range of equipment considered and the frequency determined. Manufacturer's tolerance specifications may be used when they approximate the tabulated values.

No	Parameter (s)	Tolerance
1.	Scatter fraction	±10%
2.	Uniformity	±10%
3.	Correction for count losses and random	±10%
4.	Correction for attenuation and scatter	±10%
5	spatial resolution	±10%
6.	Count rate performance	±10%
7.	Noise Equivalent Count Rate	±10%
8.	PET sensitivity	± 10%
9.	Image quality analysis	± 10%

Appendix D – Daily and quaterly QC tests for PET-CT

The tolerance is based on the manufacturer's specifications

Daily
-Reboot the system
- Coincidence timing resolution
-Test of PET-CT in clinical mode
- Uniformity
- PET normalization (blank scan)
- 2D/3D activity concentration calibration
- PET-CT fusion accuracy
- Routine image quality PET/CT test
- CT tube warmup
- CT air calibration

Quarterly
-Normalization
- Well counter correction
- Image quality analysis