INTERNATIONAL STANDARD

IEC 61675-1

First edition
1998-02

Radionuclide imaging devices – Characteristics and test conditions –
Part 1: Positron emission tomographs

Dispositifs d'imagerie par radionucléides – Caractéristiques et conditions d'essai –

Partie 1: Tomographes à émission de positrons

Reference number
IEC 61675-1:1998(E)

Numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series.

Consolidated publications

Consolidated versions of some IEC publications including amendments are available. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Validity of this publication

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology.

Information relating to the date of the reconfirmation of the publication is available in the IEC catalogue.

Information on the revision work, the issue of revised editions and amendments may be obtained from IEC National Committees and from the following IEC sources:

- **IEC Bulletin**
- **IEC Yearbook**
  On-line access*
- **Catalogue of IEC publications**
  Published yearly with regular updates
  (On-line access)*

Terminology, graphical and letter symbols

For general terminology, readers are referred to IEC 60050: *International Electrotechnical Vocabulary* (IEV).

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to publications IEC 60027: *Letter symbols to be used in electrical technology*, IEC 60417: *Graphical symbols for use on equipment. Index, survey and compilation of the single sheets* and IEC 60617: *Graphical symbols for diagrams.*

IEC publications prepared by the same technical committee

The attention of readers is drawn to the end pages of this publication which list the IEC publications issued by the technical committee which has prepared the present publication.

* See web site address on title page.

INTERNATIONAL STANDARD

IEC 61675-1

First edition
1998-02

Radionuclide imaging devices – Characteristics and test conditions –

Part 1: Positron emission tomographs

Dispositifs d'imagerie par radionucléides – Caractéristiques et conditions d'essai –

Partie 1: Tomographes à émission de positrons

International Electrotechnical Commission 3, rue de Varembé Geneva, Switzerland
Telefax: +41 22 919 0300 e-mail: inmail@iec.ch IEC web site http: //www.iec.ch

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

CODE PRIX
PRICE CODE W

Pour prix, voir catalogue en vigueur
For price, see current catalogue

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

RADIONUCLIDE IMAGING DEVICES – CHARACTERISTICS AND TEST CONDITIONS –

Part 1: Positron emission tomographs

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.
6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61675-1 has been prepared by subcommittee 62C: Equipment for radiotherapy, nuclear medicine and radiation dosimetry, of IEC technical committee 62: Electrical equipment in medical practice.

The text of this standard is based on the following documents:

FDIS	Report on voting
62C/205/FDIS	62C/214/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

In this standard, the following print types are used:

– TERMS DEFINED IN CLAUSE 2 OF THIS STANDARD OR LISTED IN ANNEX A: SMALL CAPITALS.

The requirements are followed by specifications for the relevant tests.

Annex A is for information only.

A bilingual version of this standard may be issued at a later date.

RADIONUCLIDE IMAGING DEVICES – CHARACTERISTICS AND TEST CONDITIONS –

Part 1: Positron emission tomographs

1 General

1.1 Scope and object

This part of IEC 61675 specifies terminology and test methods for declaring the characteristics of POSITRON EMISSION TOMOGRAPHS. POSITRON EMISSION TOMOGRAPHS detect the ANNIHILATION RADIATION of positron emitting RADIONUCLIDES by COINCIDENCE DETECTION.

The test methods specified in this part of IEC 61675 have been selected to reflect as much as possible the clinical use of POSITRON EMISSION TOMOGRAPHS. It is intended that the test methods be carried out by manufacturers, thereby enabling them to declare the characteristics of POSITRON EMISSION TOMOGRAPHS. So, the specifications given in the ACCOMPANYING DOCUMENTS shall be in accordance with this standard. This standard does not imply which tests will be performed by the manufacturer on an individual tomograph.

No test has been specified to characterize the uniformity of reconstructed images, because all methods known so far will mostly reflect the noise in the image.

1.2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this part of IEC 61675. At the time of publication, the edition indicated was valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 61675 are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60788:1984, *Medical radiology – Terminology*

2 Terminology and definitions

For the purpose of this part of IEC 61675, the definitions given in IEC 60788 (see annex A) and the following definitions apply.

Defined terms are printed in small capitals.

2.1 TOMOGRAPHY (see annex A)

2.1.1
TRANSVERSE TOMOGRAPHY
in TRANSVERSE TOMOGRAPHY the three-dimensional object is sliced by physical methods, for example collimation, into a stack of OBJECT SLICES, which are considered as being two-dimensional and independent from each other. The transverse IMAGE PLANES are perpendicular to the SYSTEM AXIS.

2.1.2
EMISSION COMPUTED TOMOGRAPHY (ECT)
imaging method for the representation of the spatial distribution of incorporated RADIONUCLIDES in selected two-dimensional slices through the object

2.1.2.1
PROJECTION
transformation of a three-dimensional object into its two-dimensional image or of a two-dimensional object into its one-dimensional image, by integrating the physical property which determines the image along the direction of the PROJECTION BEAM

NOTE – This process is mathematically described by line integrals in the direction of projection (along the LINE OF RESPONSE) and called Radon-transform.

2.1.2.2
PROJECTION BEAM
determines the smallest possible volume in which the physical property which determines the image is integrated during the measurement process. Its shape is limited by SPATIAL RESOLUTION in all three dimensions.

NOTE – The PROJECTION BEAM mostly has the shape of a long thin cylinder or cone. In POSITRON EMISSION TOMOGRAPHY, it is the sensitive volume between two detector elements operated in coincidence.

2.1.2.3
PROJECTION ANGLE
angle at which the PROJECTION is measured or acquired

2.1.2.4
SINOGRAM
two-dimensional display of all one-dimensional PROJECTIONS of an OBJECT SLICE, as a function of the PROJECTION ANGLE. The PROJECTION ANGLE is displayed on the ordinate, the linear PROJECTION coordinate is displayed on the abscissa.

2.1.2.5
OBJECT SLICE
slice in the object. The physical property of this slice, that determines the measured information, is displayed in the tomographic image.

2.1.2.6
IMAGE PLANE
a plane assigned to a plane in the OBJECT SLICE

NOTE – Usually the IMAGE PLANE is the midplane of the corresponding OBJECT SLICE.

2.1.2.7
SYSTEM AXIS
axis of symmetry, characterized by geometrical and physical properties of the arrangement of the system

NOTE – For a circular POSITRON EMISSION TOMOGRAPH, the SYSTEM AXIS is the axis through the centre of the detector ring. For tomographs with rotating detectors it is the axis of rotation.

2.1.2.8
TOMOGRAPHIC VOLUME
juxtaposition of all volume elements which contribute to the measured PROJECTIONS for all PROJECTION ANGLES

2.1.2.8.1
TRANSVERSE FIELD OF VIEW
dimensions of a slice through the TOMOGRAPHIC VOLUME, perpendicular to the SYSTEM AXIS. For a circular TRANSVERSE FIELD OF VIEW, it is described by its diameter

NOTE – For non-cylindrical TOMOGRAPHIC VOLUMES the TRANSVERSE FIELD OF VIEW may depend on the axial position of the slice.

2.1.2.8.2
AXIAL FIELD OF VIEW
dimensions of a slice through the TOMOGRAPHIC VOLUME, parallel to and including the SYSTEM AXIS. In practice, it is specified only by its axial dimension, given by the distance between the centre of the outmost defined IMAGE PLANES plus the average of the measured AXIAL SLICE WIDTH

2.1.2.8.3
TOTAL FIELD OF VIEW
dimensions (three-dimensional) of the TOMOGRAPHIC VOLUME

2.1.3
POSITRON EMISSION TOMOGRAPHY (PET)
EMISSION COMPUTED TOMOGRAPHY utilizing the ANNIHILATION RADIATION of positron emitting RADIONUCLIDES by COINCIDENCE DETECTION

2.1.3.1
POSITRON EMISSION TOMOGRAPH
tomographic device, which detects the ANNIHILATION RADIATION of positron emitting RADIONUCLIDES by COINCIDENCE DETECTION

2.1.3.2
ANNIHILATION RADIATION
ionizing radiation that is produced when a particle and its antiparticle interact and cease to exist

2.1.3.3
COINCIDENCE DETECTION
a method which checks whether two opposing detectors have detected one photon each simultaneously. By this method the two photons are concatenated into one event.

NOTE – The COINCIDENCE DETECTION between two opposing detector elements serves as an electronic collimation to define the corresponding PROJECTION BEAM or LINE OF RESPONSE (LOR), respectively.

2.1.3.4
COINCIDENCE WINDOW
time interval during which two detected photons are considered being simultaneous

2.1.3.5
LINE OF RESPONSE (LOR)
the axis of the PROJECTION BEAM

NOTE – In PET, it is the line connecting the centres of two opposing detector elements operated in coincidence.

2.1.3.6
TOTAL COINCIDENCES
sum of all coincidences detected

2.1.3.6.1
TRUE COINCIDENCE
result of COINCIDENCE DETECTION of two gamma events originating from the same positron annihilation

2.1.3.6.2
SCATTERED TRUE COINCIDENCE
TRUE COINCIDENCE where at least one participating photon was scattered before the COINCIDENCE DETECTION

2.1.3.6.3
UNSCATTERED TRUE COINCIDENCE
the difference between TRUE COINCIDENCES and SCATTERED TRUE COINCIDENCES

2.1.3.6.4
RANDOM COINCIDENCE
result of COINCIDENCE DETECTION in which both participating photons emerge from different positron annihilations

2.1.3.7
SINGLES RATE
COUNT RATE measured without COINCIDENCE DETECTION, but with energy discrimination

2.1.4
Reconstruction

2.1.4.1
TWO-DIMENSIONAL RECONSTRUCTION
in TWO-DIMENSIONAL RECONSTRUCTION, the data are rebinned prior to reconstruction into SINOGRAMS, which are the PROJECTION data of transverse slices, which are considered being independent of each other and being perpendicular to the SYSTEM AXIS. So, each event will be assigned, in the axial direction, to that transverse slice passing the midpoint of the corresponding LINE OF RESPONSE. Any deviation from perpendicularity to the SYSTEM AXIS is neglected. The data are then reconstructed by two-dimensional methods, i.e. each slice is reconstructed from its associated SINOGRAM, independent of the rest of the data set.

NOTE – This is the standard method of reconstruction for POSITRON EMISSION TOMOGRAPHS using small axial acceptance angles, i.e. utilizing septa. For POSITRON EMISSION TOMOGRAPHS using large axial acceptance angles, i.e. without septa, this method is also called 'single slice rebinning'.

2.1.4.2
THREE-DIMENSIONAL RECONSTRUCTION
in THREE-DIMENSIONAL RECONSTRUCTION, the LINES OF RESPONSE are not restricted to being perpendicular to the SYSTEM AXIS. So, a LINE OF RESPONSE may pass several transverse slices. Consequently, transverse slices cannot be reconstructed independent of each other. Each slice has to be reconstructed utilizing the full three-dimensional data set.

2.2
IMAGE MATRIX
arrangement of MATRIX ELEMENTS in a preferentially cartesian coordinate system

2.2.1
MATRIX ELEMENT
smallest unit of an IMAGE MATRIX, which is assigned in location and size to a certain volume element of the object (VOXEL)

2.2.1.1
PIXEL
matrix element in a two-dimensional IMAGE MATRIX

2.2.1.2
TRIXEL
matrix element in a three-dimensional IMAGE MATRIX

2.2.2
VOXEL
volume element in the object which is assigned to a MATRIX ELEMENT in the IMAGE MATRIX (two-dimensional or three-dimensional). The dimensions of the VOXEL are determined by the dimensions of the corresponding MATRIX ELEMENT via the appropriate scale factors and by the systems SPATIAL RESOLUTION in all three dimensions

2.3
POINT SPREAD FUNCTION (PSF)
scintigraphic image of a POINT SOURCE

2.3.1
PHYSICAL POINT SPREAD FUNCTION
for tomographs, a two-dimensional POINT SPREAD FUNCTION in planes perpendicular to the PROJECTION BEAM at specified distances from the detector

NOTE – The PHYSICAL POINT SPREAD FUNCTION characterizes the purely physical (intrinsic) imaging performance of the tomographic device and is independent of for example sampling, image reconstruction and image processing. A PROJECTION BEAM is characterized by the entirety of all PHYSICAL POINT SPREAD FUNCTIONS as a function of distance along its axis.

2.3.2
AXIAL POINT SPREAD FUNCTION
profile passing through the peak of the PHYSICAL POINT SPREAD FUNCTION in a plane parallel to the SYSTEM AXIS

2.3.3
TRANSVERSE POINT SPREAD FUNCTION
reconstructed two-dimensional POINT SPREAD FUNCTION in a tomographic IMAGE PLANE

NOTE – In TOMOGRAPHY, the TRANSVERSE POINT SPREAD FUNCTION can also be obtained from a LINE SOURCE located parallel to the SYSTEM AXIS.

2.4
SPATIAL RESOLUTION
ability to concentrate the count density distribution in the image of a POINT SOURCE to a point

2.4.1
TRANSVERSE RESOLUTION
SPATIAL RESOLUTION in a reconstructed plane perpendicular to the SYSTEM AXIS

2.4.1.1
RADIAL RESOLUTION
TRANSVERSE RESOLUTION along a line passing through the position of the source and the SYSTEM AXIS

2.4.1.2
TANGENTIAL RESOLUTION
TRANSVERSE RESOLUTION in the direction orthogonal to the direction of RADIAL RESOLUTION

2.4.2
AXIAL RESOLUTION
for tomographs with sufficiently fine axial sampling fulfilling the sampling theorem, SPATIAL RESOLUTION along a line parallel to the SYSTEM AXIS

2.4.3
AXIAL SLICE WIDTH
for tomographs, the width of the AXIAL POINT SPREAD FUNCTION

2.4.4
EQUIVALENT WIDTH (EW)
width of that rectangle, having the same area and the same height as the response function, for example the POINT SPREAD FUNCTION

2.4.5
FULL WIDTH AT HALF MAXIMUM (FWHM)
(see annex A)

2.5
RECOVERY COEFFICIENT
measured (image) ACTIVITY concentration of an active volume divided by the true ACTIVITY concentration of that volume, neglecting ACTIVITY calibration factors

NOTE – For the actual measurement, the true ACTIVITY concentration is replaced by the measured ACTIVITY concentration in a large volume.

2.6
Tomographic sensitivity

2.6.1
SLICE SENSITIVITY
ratio of COUNT RATE as measured on the SINOGRAM to the ACTIVITY concentration in the phantom

NOTE – In PET, the measured counts are numerically corrected for scatter by subtracting the SCATTER FRACTION.

2.6.1.1
NORMALIZED SLICE SENSITIVITY
SLICE SENSITIVITY divided by the AXIAL SLICE WIDTH (EW) for that slice

2.6.2
VOLUME SENSITIVITY
sum of the individual SLICE SENSITIVITIES

2.7
COUNT RATE CHARACTERISTIC (see annex A)

2.7.1
COUNT LOSS
difference between measured COUNT RATE and TRUE COUNT RATE, which is caused by the finite RESOLVING TIME of the instrument

2.7.2
COUNT RATE
number of counts per unit of time

2.7.3
TRUE COUNT RATE (see annex A)

2.7.4
ADDRESS PILE UP
for imaging devices false address calculation of an artificial event which passes the PULSE AMPLITUDE ANALYZER WINDOW, but is formed from two or more events by the PILE UP EFFECT

2.7.4.1
PILE UP EFFECT
false measurement of the pulse amplitude, due to the absorption of two or more gamma rays, reaching the same radiation detector within the RESOLVING TIME

2.8
SCATTER FRACTION (SF)
ratio between SCATTERED TRUE COINCIDENCES and the sum of SCATTERED plus UNSCATTERED TRUE COINCIDENCES for a given experimental set-up

2.9
POINT SOURCE
RADIOACTIVE SOURCE approximating a δ-function in all three dimensions

2.10
LINE SOURCE
straight RADIOACTIVE SOURCE approximating a δ-function in two dimensions and being constant (uniform) in the third dimension

3 Test methods

For all measurements, the tomograph shall be set up according to its normal mode of operation, i.e. it shall not be adjusted specially for the measurement of specific parameters. If the tomograph is specified to operate in different modes influencing the performance parameters, for example with different axial acceptance angles, with and without septa, with TWO-DIMENSIONAL RECONSTRUCTION and THREE-DIMENSIONAL RECONSTRUCTION, the test results shall be reported in addition. The tomographic configuration (e.g. energy thresholds, axial acceptance angle, reconstruction algorithm) shall be chosen according to the manufacturer's recommendation and clearly stated. If any test cannot be carried out exactly as specified in this standard, the reason for the deviation and the exact conditions under which the test was performed shall be stated clearly.

The test phantoms shall be centred within the tomographs' AXIAL FIELD OF VIEW, if not specified otherwise.

NOTE – For tomographs with an AXIAL FIELD OF VIEW greater than 16,5 cm, this centring will only produce performance estimates for the central part. However, if the phantoms were displaced axially in order to cover the entire AXIAL FIELD OF VIEW, false results could be obtained for the central planes, if the axial acceptance angle of the detectors is not fully covered with ACTIVITY.

3.1 SPATIAL RESOLUTION

3.1.1 General

SPATIAL RESOLUTION measurements describe partly the ability of a tomograph to reproduce the spatial distribution of a tracer in an object in a reconstructed image. The measurement is performed by imaging POINT (or LINE) SOURCES in air and reconstructing images, using a sharp reconstruction filter. Although this does not represent the condition of imaging a patient, where tissue scatter is present and limited statistics require the use of a smooth reconstruction filter, the measured SPATIAL RESOLUTION provides a best-case comparison between tomographs, indicating the highest achievable performance.

3.1.2 Purpose

The purpose of this measurement is to characterize the ability of the tomograph to recover small objects by characterizing the width of the reconstructed TRANSVERSE POINT SPREAD FUNCTIONS of radioactive POINT SOURCES or of extended LINE SOURCES placed perpendicular to the direction of measurement. The width of the spread function is measured by the FULL WIDTH AT HALF MAXIMUM (FWHM) and the EQUIVALENT WIDTH (EW).

To define how well objects can be reproduced in the axial direction, the AXIAL SLICE WIDTH (commonly referred to as the slice thickness) is used. It is measured with a POINT SOURCE which is stepped through the tomographs TRANSVERSE FIELD OF VIEW axially in small increments and is characterized by the EW and the FWHM of the AXIAL POINT SPREAD FUNCTION for each individual slice.

The AXIAL RESOLUTION is defined for tomographs with sufficiently fine axial sampling (volume detectors) and could be measured with a stationary POINT SOURCE. For these systems the AXIAL RESOLUTION (EW and FWHM) is equivalent to the AXIAL SLICE WIDTH. These systems (fulfilling the sampling theorem in the axial direction) are characterized by the fact, that the AXIAL POINT SPREAD FUNCTION of a stationary POINT SOURCE would not vary, if the position of the source is varied in the axial direction for half the axial sampling distance.

3.1.3 Method

For all systems, the SPATIAL RESOLUTION shall be measured in the transverse IMAGE PLANE in two directions (i.e. radially and tangentially). In addition, for those systems having sufficiently fine axial sampling, an AXIAL RESOLUTION also shall be measured.

The TRANSVERSE FIELD OF VIEW and the IMAGE MATRIX size determine the PIXEL size in the transverse IMAGE PLANE. In order to measure accurately the width of the spread function, its FWHM should span at least ten PIXELS. A typical imaging study of a brain, however, requires a 260 mm TRANSVERSE FIELD OF VIEW, which together with a 128 × 128 IMAGE MATRIX and 6 mm SPATIAL RESOLUTION, results in a FWHM of only three PIXELS. The width of the response may be incorrect if there are fewer than ten PIXELS in the FWHM. Therefore, if possible, the PIXEL size should be made close to one-tenth of the expected FWHM during reconstruction and should be indicated as ancillary data for the TRANSVERSE RESOLUTION measurement. For volume imaging systems, the TRIXEL size, in both the transverse and axial dimensions, should be made close to one-tenth the expected FWHM, and should be indicated as ancillary data for the SPATIAL RESOLUTION measurement. For all systems, the AXIAL SLICE WIDTH is measured by moving the source in fine steps to sample the response function adequately. For the AXIAL SLICE WIDTH measurement, the step size should be close to one-tenth the expected EW. It is assumed that a computer controlled bed will be used for accurate positioning of the RADIOACTIVE SOURCE.

3.1.3.1 RADIONUCLIDE

The RADIONUCLIDE for the measurement shall be ^{18}F, with an ACTIVITY such that the percent COUNT LOSS is less than 5 % and the RANDOM COINCIDENCE rate is less than 5 % of the TOTAL COINCIDENCE rate.

3.1.3.2 RADIOACTIVE SOURCE distribution

POINT SOURCES and LINE SOURCES as defined in 2.9 shall be used.

3.1.3.2.1 TRANSVERSE RESOLUTION

Tomographs shall use LINE SOURCES, suspended in air to minimize scatter, for measurements of TRANSVERSE RESOLUTION. The sources shall be kept parallel to the long axis of the tomograph and shall be positioned radially at 50 mm intervals along Cartesian axes in a plane perpendicular to the long axis of the tomograph i.e. r = 10 mm, 50 mm, 100 mm, 150 mm ... up to the edge of the TRANSVERSE FIELD OF VIEW. The last position shall be not more than 20 mm from the edge and shall be stated. Each of these positions yields two measurements of TRANSVERSE RESOLUTION, which shall be distinguished by being in the radial or tangential direction.

NOTE – The SPATIAL RESOLUTION at r = 0 mm may yield artificial values due to sampling, so this measurement is done at the position r = 10 mm.

3.1.3.2.2 AXIAL SLICE WIDTH

The AXIAL POINT SPREAD FUNCTION for POINT SOURCES suspended in air shall be measured for all systems. The POINT SOURCES shall be moved in fine increments along the axial direction over the length of the tomograph, at radial positions of r = 0 mm, 50 mm, 100 mm, ... in 50 mm steps up to the edge of the TRANSVERSE FIELD OF VIEW. The last position shall be not more than 20 mm from the edge and shall be stated. The source is stepped in the axial direction by one-tenth of the expected EW of the axial response function. For each radial position, the measured values shall be corrected for decay. This measurement does not apply to THREE-DIMENSIONAL RECONSTRUCTION.

3.1.3.2.3 AXIAL RESOLUTION

For systems having axial sampling at least three times smaller than the FWHM of the AXIAL POINT SPREAD FUNCTION the measurement of AXIAL RESOLUTION can be made with stationary POINT SOURCES. POINT SOURCES suspended in air are positioned at radial intervals of 50 mm, starting at the centre and extending to a distance which depends on the TRANSVERSE FIELD OF VIEW, as described in the measurement of AXIAL SLICE WIDTH (3.1.3.2.2.). Each POINT SOURCE shall be imaged at axial intervals of 20 mm, starting at the centre of the tomograph and extending to within 10 mm from the edge of the AXIAL FIELD OF VIEW.

3.1.3.3 Data collection

Data shall be collected for all sources in all of the positions specified above, either singly or in groups of multiple sources, to minimize the data acquisition time. At least fifty thousand counts shall be acquired in each response function, as defined below.

3.1.3.4 Data processing

Reconstruction using a ramp filter with the cutoff at the Nyquist frequency of the PROJECTION data, shall be employed for all SPATIAL RESOLUTION data.

3.1.4 Analysis

The RADIAL RESOLUTION and the TANGENTIAL RESOLUTION shall be determined by forming one-dimensional response functions, which result from taking profiles through the TRANSVERSE POINT SPREAD FUNCTION in radial and tangential directions, passing through the peak of the distribution.

The AXIAL RESOLUTION of the POINT SOURCE measurements is determined by forming one-dimensional response functions (AXIAL POINT SPREAD FUNCTIONS), which result from taking profiles through the volume image in the axial direction, passing through the peak of the distribution in the slice nearest the source.

The AXIAL SLICE WIDTH is determined by forming one-dimensional response functions (AXIAL POINT SPREAD FUNCTIONS), which result from summing the counts per slice collected for each slice at each axial location of each radial source location.

Each FWHM shall be determined by linear interpolation between adjacent PIXELS at half the maximum PIXEL value, which is the peak of the response function (see figure 11). Values shall be converted to millimetre units by multiplication with the appropriate PIXEL size.

Each EQUIVALENT WIDTH (EW) shall be measured from the corresponding response function. EW is calculated from the formula

$$\mathrm{EW} = \sum_i \frac{C_i \times PW}{C_m}$$

where

$\sum C_i$ is the sum of the counts in the profile between the limits defined by 1/20 C_m on either side of the peak;

C_m is the maximum PIXEL value;

PW is the PIXEL width (or axial increment in the case of the AXIAL SLICE WIDTH) in millimetres (see figure 12).

3.1.5 Report

RADIAL and TANGENTIAL RESOLUTIONS (FWHM and EW) for each radius, averaged over all slices, shall be calculated and reported as TRANSVERSE RESOLUTION values. AXIAL SLICE WIDTHS (EW and FWHM) for each radius, averaged over all slices for each type (e.g. odd, even) shall be reported. Transverse PIXEL dimensions and axial step size shall also be reported.

For systems, where AXIAL RESOLUTION is to be measured, AXIAL RESOLUTION (FWHM and EW), averaged over all slices, shall be reported. For these systems, the axial PIXEL dimension in millimetres shall also be reported.

For systems utilizing THREE-DIMENSIONAL RECONSTRUCTION, RESOLUTION data as listed above shall not be averaged. Graphs of TRANSVERSE RESOLUTION and AXIAL RESOLUTION shall be reported, showing the RESOLUTION values (RADIAL RESOLUTION, TANGENTIAL RESOLUTION, and AXIAL RESOLUTION) for each radius as a function of slice number.

3.2 RECOVERY COEFFICIENT

3.2.1 General

The finite resolution of a tomograph leads to a spreading of image counts beyond the geometrical boundaries of the object. This effect becomes more important as the object size decreases. The RECOVERY COEFFICIENT provides an assessment of the ability of the tomograph to quantify the ACTIVITY concentration as a function of the object size.

3.2.2 Purpose

The objective of the following procedures is to quantify the apparent decrease in tracer concentration in a region of interest (ROI) of an image of spherical sources of different diameters.

3.2.3 Method

A number of hollow spheres, filled with an ACTIVITY concentration of ^{18}F from a stock solution, are placed in the water-filled head phantom (see figures 1 and 4) which is in turn placed in the centre of the TRANSVERSE FIELD OF VIEW. The phantom shall be held in position without introducing additional attenuating material. At least two samples from this solution are counted in a well counter. The spheres are arranged to be coplanar.

For discrete ring systems, utilizing TWO-DIMENSIONAL RECONSTRUCTION, separate measurements shall be made with the spheres centred over each representative type of slice derived from different ring combinations (e.g. direct and cross, or odd and even). A measurement shall also be taken halfway in between slices in order to see the worst case of recovery in addition to the best case. The measurements are taken near the axial centre of the tomograph.

For systems utilizing THREE-DIMENSIONAL RECONSTRUCTION, the measurements shall be done at the axial centre of the tomograph and halfway between the axial centre and the edge of the AXIAL FIELD OF VIEW.

After data acquisition, the spheres are removed and the cylinder filled with a uniform solution of ^{18}F from which at least two samples are taken for well counting.

3.2.4 Data collection

The data collection shall be carried out at low COUNT RATES such that the COUNT LOSS is less than 10 % and the RANDOM COINCIDENCE rate is less than 10 % of the TOTAL COINCIDENCE rate. Care should be taken to acquire sufficient counts so that statistical variations do not significantly affect the result**.** So, for the slice containing the spheres, at least 2 000 000 counts shall be acquired. COUNT RATES and scanning times shall be stated.

3.2.5 Data processing and analysis

Reconstruction shall be performed using a ramp filter with a cut-off at the Nyquist frequency and with all corrections applied. The method of ATTENUATION correction shall be by an analytical calculation. The ATTENUATION coefficient used shall be reported. The scatter correction method used shall be clearly described.

Circular ROIs of diameter as close as possible to the FWHM as measured in section 3.1.3.2.1 are defined centrally on the image of each sphere. The precise ROI diameter should be stated.

A large ROI (diameter: 150 mm) is centred on the image of the uniform cylinder. Calculation of the RECOVERY COEFFICIENT (RC_{si}) for each sphere is obtained from the equation:

$$RC_{si} = \left(\frac{\frac{C_{si}}{SM_s}}{\frac{C_u}{SM_u}} \right)$$

where

C_{si} are the ROI counts/pixel/s for sphere i;

SM_s are the sample counts/s/cm^3 (stock solution spheres);

C_u are the ROI counts/pixel/s (head phantom);

SM_u are the sample counts/s/cm^3 (head phantom);

C_u/SM_u represents a calibration factor for a large reference object.

Care shall be taken to correct for any dead-time and sample volume effects in the well counter. RC_{si} is then plotted against sphere diameter to give recovery curves.

3.2.6 Report

Graphs of RECOVERY COEFFICIENTS for each axial position described in 3.2.3 shall be reported. The scatter correction method used shall be clearly described, as well as the attenuation coefficient used.

3.3 Tomographic sensitivity

3.3.1 General

Tomographic sensitivity is a parameter that characterizes the rate at which coincidence events are detected in the presence of a RADIOACTIVE SOURCE in the limit of low ACTIVITY where COUNT LOSSES and RANDOM COINCIDENCES are negligible. The measured rate of TRUE COINCIDENCE EVENTS for a given distribution of the RADIOACTIVE SOURCE depends upon many factors, including the detector material, size, and packing fraction, tomograph ring diameter, axial acceptance window and septa geometry, ATTENUATION, scatter, dead-time, and energy thresholds.

3.3.2 Purpose

The purpose of this measurement is to determine the detected rate of TRUE COINCIDENCE events per unit of ACTIVITY concentration for a standard volume source, i.e. a cylindrical phantom of given dimensions.

3.3.3 Method

The tomographic sensitivity test places a specified volume of radioactive solution of known ACTIVITY concentration in the TOTAL FIELD OF VIEW of the POSITRON EMISSION TOMOGRAPH and observes the resulting COUNT RATE. The systems sensitivity is calculated from these values.

The test is critically dependent upon accurate assays of radioactivity as measured in a dose calibrator or well counter. It is difficult to maintain an absolute calibration with such devices to accuracies finer than 10 %. Absolute reference standards using positron emitters should be considered if higher degrees of accuracy are required.

3.3.3.1 RADIONUCLIDE

The RADIONUCLIDE used for these measurements shall be ^{18}F. The amount of ACTIVITY used shall be such that the percentage of COUNT LOSSES is less than 2 % and the RANDOM COINCIDENCE rate is less than 2 % of the TOTAL COINCIDENCE rate.

3.3.3.2 RADIOACTIVE SOURCE distribution

The head phantom (figure 1) shall be filled with a homogeneous solution of known ACTIVITY concentration. The phantom shall be held in position without introducing additional attenuating material. It shall be centred both axially and transaxially in the TOTAL FIELD OF VIEW.

3.3.3.3 Data collection

Each coincident event between individual detectors shall be taken into account only once. Data shall be assembled into SINOGRAMS. All events will be assigned to the transverse slice passing the midpoint of the corresponding LINE OF RESPONSE.

At least 200 000 counts shall be acquired for each slice within the lesser of the AXIAL FIELD OF VIEW or the central 16,5 cm where the phantom was placed.

3.3.3.4 Data processing

The ACTIVITY concentration in the phantom shall be corrected for decay to determine the average ACTIVITY concentration, a_{ave}, during the data acquisition time, T_{acq}, by the following equation:

$$a_{ave} = \frac{A_{cal}}{V} \frac{1}{\ln 2} \frac{T_{1/2}}{T_{acq}} \exp\left[\frac{T_{cal} - T_0}{T_{1/2}} \ln 2\right] \left[1 - \exp\left(-\frac{T_{acq}}{T_{1/2}} \ln 2\right)\right]$$

where

V is the volume of the phantom;

A_{cal} is the ACTIVITY times branching ratio ("positron activity") measured at time T_{cal};

T_0 is the acquisition start time;

$T_{1/2}$ is the HALF LIFE of the RADIONUCLIDE.

It is not necessary to reconstruct these data. No corrections for detector normalization, COUNT LOSS, scatter, and ATTENUATION shall be applied. The data shall be corrected for RANDOM COINCIDENCES.

3.3.4 Analysis

The total counts $C_{i,tot,120mm}$ on each slice i shall be obtained by summing all PIXELS in the corresponding SINOGRAM within a radius of 120 mm. The SLICE SENSITIVITY S_i for unscattered events shall be found by the following:

$$S_i = \frac{C_{i,tot,120mm}}{T_{acq}} \frac{(1 - SF_i)}{a_{ave}}$$

where SF_i is the corresponding SCATTER FRACTION (see 3.6).

The NORMALIZED SLICE SENSITIVITY for each slice nS_i shall be calculated as follows:

$$nS_i = \frac{S_i}{\mathrm{EW}_{a,i}}$$

where $\mathrm{EW}_{a,i}$ is the AXIAL SLICE WIDTH for slice i (see 3.1.4).

NOTE – The NORMALIZED SLICE SENSITIVITY allows for comparison of tomographs with different AXIAL SLICE WIDTH.

The VOLUME SENSITIVITY, S_{tot}, shall be the sum of S_i over all slices of the tomograph within the central 16,5 cm or the AXIAL FIELD OF VIEW, whichever is smaller.

NOTE – This will yield only the VOLUME SENSITIVITY for the central part of the tomograph, if the AXIAL FIELD OF VIEW is greater than 16,5 cm.

3.3.5 Report

For each slice i, tabulate the values of S_i and nS_i. The VOLUME SENSITIVITY S_{tot} shall also be reported.

3.4 Uniformity

No test has been specified to characterize the uniformity of reconstructed images, because all methods known so far will mostly reflect the noise in the image.

3.5 COUNT RATE CHARACTERISTIC

3.5.1 General

PET COUNT RATE performance depends in a complex manner on the spatial distribution of ACTIVITY and scattering materials, which we will refer to as the different scatter conditions (see 3.5.3.1). The COUNT RATE CHARACTERISTIC of the TRUE COINCIDENCE COUNT RATE is highly dependent on the trues-to-singles ratio and on the COUNT RATE CHARACTERISTIC of the SINGLES RATE and consequently on the set up of the measurements conditions, which therefore should simulate the range of clinical imaging situations. In addition, COUNT RATE performance is strongly influenced by the amount of RANDOM COINCIDENCES and by the accuracy of the subtraction of these events.

NOTE – As the TRUE COINCIDENCE COUNT RATE includes scattered events, the relative SCATTER FRACTION must be considered when comparing tomographs with different design.

3.5.2 Purpose

The procedure described here is designed to evaluate deviations from the linear relationship between TRUE COINCIDENCE COUNT RATE and ACTIVITY, caused by COUNT LOSSES, and the evaluation of image distortions at high COUNT RATES, especially those leading to spatially misplaced events by ADDRESS PILE UP. As modern PET tomographs are operated with COUNT LOSS correction schemes, the accuracy of these correction algorithms is tested.

PET COUNT RATE performance means:

a) the relationship between measured TRUE COINCIDENCES (UNSCATTERED plus SCATTERED TRUE COINCIDENCES) and ACTIVITY, i.e. the COUNT RATE CHARACTERISTIC of TRUE COINCIDENCE COUNT RATE;
b) a test to determine address errors caused by ADDRESS PILE UP;
c) the evaluation of the accuracy of the COUNT LOSS correction scheme.

3.5.3 Method

For dedicated brain tomographs, only the scatter condition described in 3.5.3.1.1 applies, whereas for all other tomographs the scatter conditions described in 3.5.3.1.1 to 3.5.3.1.3 apply. For all tests the only correction to be applied is the subtraction of the multiple and the RANDOM COINCIDENCES (to calculate TRUE COINCIDENCE counts). No correction is made for COUNT LOSSES, ATTENUATION, and scatter, unless otherwise stated. The ACTIVITY shall generally be specified as the total amount of ACTIVITY within the phantom as specified in 3.5.3.1. As the variation of ACTIVITY is normally achieved by radioactive decay, care should be taken with respect to the radiochemical purity of the ACTIVITY used.

3.5.3.1 RADIOACTIVE SOURCE distribution

To describe various scatter conditions, three different experimental set-ups are to be used.

3.5.3.1.1 Head imaging

The head phantom (figure 1) filled homogeneously with ACTIVITY.

3.5.3.1.2 Cardiac imaging

The body phantom, figure 2, (head phantom inserted) with outer section and arms (figure 3) of the phantom filled with water, inner section (head phantom, figure 1) filled with air, a rod source (130 mm inside length × 21 mm inside diameter) containing the ACTIVITY and placed eccentrically as indicated in figure 7. The centre of the phantom shall be centred to the SYSTEM AXIS, see figures 2 and 7.

3.5.3.1.3 Abdominal imaging

The procedure described in 3.5.3.1.2 is followed but the head phantom is also filled with water. This configuration is used to mimic the worst case scattering condition encountered in PET imaging.

3.5.4 Data acquisition and analysis

Each coincident event between individual detectors shall be taken into account only once.

3.5.4.1 Test of the TRUE COINCIDENCE COUNT RATE CHARACTERISTIC

For all scatter conditions, a COUNT RATE CHARACTERISTIC (measured TRUE COINCIDENCE COUNT RATE versus incident TRUE COINCIDENCE COUNT RATE or ACTIVITY within the TOTAL FIELD OF VIEW of the tomograph) is to be measured. The variation of ACTIVITY is accomplished by radioactive decay; ^{18}F or ^{11}C with continuous measurements over approximately 10 HALF LIVES can be used. The time per frame shall be less than one-half of the HALF LIFE with the exception of the last three frames, which can be longer. The initial amount of ACTIVITY shall be chosen so that COUNT RATE saturation is exceeded, and the last frame shall be acquired with a COUNT LOSS of less than 1 %.

Data shall be assembled into SINOGRAMS. All events will be assigned to the transverse slice passing the midpoint of the corresponding LINE OF RESPONSE. The data to be inspected are for the TRANSVERSE FIELD OF VIEW restricted to 520 mm in diameter and without COUNT LOSS correction. For the sake of comparison with data published elsewhere, a second scale (kBq/cm^3) shall be added to the abscissa for scatter condition of 3.5.3.1.1.

The average of the decaying activity, $A_{ave,i}$, during the data acquisition interval for time frame i, $T_{acq,i}$, shall be determined by the following equation:

$$A_{\text{ave},i} = A_{\text{cal}} \frac{1}{\ln 2} \frac{T_{1/2}}{T_{\text{acq},i}} \exp\left[\frac{T_{\text{cal}} - T_{0,i}}{T_{1/2}} \ln 2\right]\left[1 - \exp\left(-\frac{T_{\text{acq},i}}{T_{1/2}} \ln 2\right)\right]$$

where

A_{cal} is the ACTIVITY measured at time T_{cal}, corrected for branching ratio (see 3.3.3.4);

$T_{0,i}$ is the acquisition start-time of the time frame i;

$T_{1/2}$ is the HALF LIFE of ^{18}F or ^{11}C, respectively.

From the above measurements, plot the COUNT RATE CHARACTERISTIC (e.g. measured TRUE COINCIDENCE COUNT RATE versus ACTIVITY) and the characteristic of the RANDOM COINCIDENCE rate (all data without ATTENUATION correction and normalization) for the total system (data for the TOTAL FIELD OF VIEW).

For the head phantom, the random rate shall be evaluated only for a circular region, with diameter of 24 cm, centred at the position of the phantom.

The conversion factor between ACTIVITY and TRUE COINCIDENCE COUNT RATE without COUNT LOSS shall be determined from each of the three frames with lowest ACTIVITY and averaged. Care shall be taken to acquire enough counts in these frames to ensure sufficient statistical precision.

From the data set, for each slice and for the total system, determine the ACTIVITY at which the measured TRUE COINCIDENCE COUNT RATE reaches 20 % COUNT LOSS and plot these ACTIVITY levels versus slice number. Repeat this evaluation for 50 % COUNT LOSS. For the total system specify the measured TRUE COINCIDENCE COUNT RATE for 20 % COUNT LOSS and for 50 % COUNT LOSS.

From the data set measured (from the SINOGRAMS as described above when using TWO-DIMENSIONAL RECONSTRUCTION, from the full data set when using THREE-DIMENSIONAL RECONSTRUCTION) reconstruct a full set of slices for all time frames. For a region containing the ACTIVITY (21 mm in diameter for the rod source, 194 mm in diameter for the cylinder), plot ROI counts divided by measured TRUE COINCIDENCES for the whole slice versus ACTIVITY, as an indicator of image distortion at high COUNT RATES (ideally, this plot should yield a constant value).

3.5.4.2 Test of ADDRESS PILE UP

The ADDRESS PILE UP in the axial direction shall be checked from the set of reconstructed images according to 3.5.4.1. For a region just containing the source, calculate the ratio of ROI counts per slice at each COUNT RATE, normalized to the corresponding value at the lowest rate.

$$R_{i,j} = \frac{C_{i,j}}{C_{i,\text{low}}}$$

where

$R_{i,j}$ is the ratio of ROI counts for slice i and time frame j.

$C_{i,j}$ are the ROI counts for slice i at time frame j.

$C_{i,\text{low}}$ are the average ROI counts for slice i at the three time frames with lowest ACTIVITY, see 3.5.4.1.

By the above division, all normalizing factors with respect to different efficiencies per slice cancel out. Plot this ratio versus the slice number. In this graph, all deviations from a line parallel to the abscissa and positioned at the mean value are a measure of ADDRESS PILE UP in the axial direction. Determine the ACTIVITY in the phantom within the TOTAL FIELD OF VIEW corresponding to a 5 % deviation for any slice.

NOTE – Axial variations at high count rates are most often caused by address pile up, but may also result from other factors depending on the design of the tomograph.

For systems utilizing THREE-DIMENSIONAL RECONSTRUCTION, this test does not apply, because the complex relationship between a reconstructed slice and an axial crystal ring obscures meaningful results from this test.

3.5.4.3 Test of COUNT LOSS correction scheme

From the set of reconstructed images according to 3.5.4.1 (and for each slice) plot a graph (see figure 8) of:

a) TRUE COINCIDENCE counts measured;

b) TRUE COINCIDENCE counts corrected for COUNT LOSS;

c) TRUE COINCIDENCE counts corrected for COUNT LOSS and decay.

The decay correction shall be done with the same HALF LIFE according to table 1 for all slices and for all scatter conditions. This HALF LIFE should yield, in the low COUNT LOSS range (low COUNT LOSSes but high decay correction factor), a line parallel to the abscissa. All deviations from this parallel line are indicative of errors in the COUNT LOSS correction.

3.5.5 Report

3.5.5.1 TRUE COINCIDENCE COUNT RATE CHARACTERISTIC (see 3.5.4.1)

From the measurements according to 3.5.4.1, report the graphs showing the COUNT RATE CHARACTERISTIC (including the characteristic of the RANDOM COINCIDENCE rate) for the total system, and the ACTIVITY levels at 20 % COUNT LOSS and at 50 % COUNT LOSS (without ATTENUATION correction and normalization) for each slice. For the total system, report the measured TRUE COINCIDENCE COUNT RATE at 20 % COUNT LOSS and at 50 % COUNT LOSS.

Report a plot of ROI counts (21 mm in diameter for the rod source, 194 mm in diameter for the cylinder) divided by measured TRUE COINCIDENCES for the whole slice versus ACTIVITY for each slice.

3.5.5.2 ADDRESS PILE UP (see 3.5.4.2)

Report a plot of normalized ROI counts according to 3.5.4.2. Report the observed ACTIVITY in the phantom within the TOTAL FIELD OF VIEW causing a 5 % deviation in the axial profile according to 3.5.4.2.

3.5.5.3 Accuracy of COUNT LOSS correction (see 3.5.4.3)

Report the plots according to 3.5.4.3. Report the maximum deviation from linearity up to the saturation point and the corresponding ACTIVITY for any slice for the three scatter conditions described in 3.5.3.1.1 to 3.5.3.1.3.

3.6 Scatter measurement

3.6.1 General

The scattering of primary gamma rays created in the annihilation of positrons results in coincidence events with false information for radiation source localization. Variations in design and implementation cause POSITRON EMISSION TOMOGRAPHS to have different sensitivities to scattered radiation.

3.6.2 Purpose

The purpose of this procedure is to measure the relative system sensitivity to scattered radiation, expressed by the SCATTER FRACTION (SF) as well as the values of the SCATTER FRACTION in each slice.

3.6.3 Method

The measurement shall be performed by imaging a single LINE SOURCE at three different radial positions within the water-filled head phantom (see figures 1 and 5).

Unscattered events are assumed to lie within a 4 × FWHM wide strip centred on the image of the LINE SOURCE in each SINOGRAM. This width region is chosen because the scatter value is insensitive to the exact width of the region, and negligible unscattered events lie more than 2 × FWHM from the line image in POSITRON EMISSION TOMOGRAPHS (see figure 10).

The width of the scatter response function allows a simplified method of analysis. A linear interpolation across the strip from the points of intersection of the scatter tails and the edges of the 4 × FWHM wide strip is used to estimate the amount of scatter present in the strip. The area under the line of interpolation, plus the contributions outside of the strip constitute the estimated scatter.

Estimates of SCATTER FRACTION for uniform source distributions are made under the assumption of slow radial dependence. The SCATTER FRACTION for a LINE SOURCE on-axis is assumed to be constant over a cross-sectional area out to a radius of 22,5 mm, the SCATTER FRACTION for a LINE SOURCE 45 mm off-axis is assumed to be constant within an annulus between 22,5 mm and 67,5 mm, and the SCATTER FRACTION for a LINE SOURCE 90 mm off-axis is assumed to be constant within an annulus between 67,5 mm and 100 mm (see figure 5). The three values for SCATTER FRACTION are weighted by the areas to which they are applied, yielding a weighted average. The annular areas are in the ratios of 1:8:10,75, respectively.

3.6.3.1 RADIONUCLIDE

The RADIONUCLIDE for the measurement shall be ^{18}F, with an ACTIVITY such that the percentage of COUNT LOSSES is less than 5 % and the RANDOM COINCIDENCE rate is less than 5 % of the TOTAL COINCIDENCE rate.

3.6.3.2 RADIOACTIVE SOURCE distribution

The head phantom (figure 1) shall be filled with non-radioactive water as a scatter medium. The test phantom LINE SOURCE shall be inserted parallel to the axis of the cylinder sequentially at radii of 0 mm, 45 mm, and 90 mm, see figure 5. The phantom shall be centred transaxially and axially in the field of view.

3.6.3.3 Data collection

Each coincident event between individual detectors shall be taken into account only once. Data shall be assembled into SINOGRAMS. All events will be assigned to the slice at the midpoint of the corresponding LINE OF RESPONSE. With the source at the specified positions, at least 200 000 counts shall be acquired for each slice within:

a) the AXIAL FIELD OF VIEW:

b) the central 16,5 cm, where the phantom was placed;

whichever is the smaller.

3.6.3.4 Data processing

Data shall be corrected for RANDOM COINCIDENCES and COUNT LOSSES, but not for scatter or ATTENUATION.

3.6.4 Analysis

All SINOGRAMS corresponding to slices at least 1 cm from either end of the phantom shall be processed. Thus for tomographs with an AXIAL FIELD OF VIEW less than 16,5 cm, all slices shall be processed.

All PIXELS in each SINOGRAM *i* which are located further than 12 cm from the centre shall be set to zero. For each PROJECTION ANGLE within the SINOGRAM, the location of the centre of the LINE SOURCE shall be determined by finding the PIXEL with the largest value. Each PROJECTION shall be shifted so that the PIXEL containing the maximum value aligns with the central PIXEL column of the SINOGRAM. After realignment, a sum PROJECTION shall be produced.

The FWHM to be used for the analysis is the average of the RADIAL RESOLUTION and the TANGENTIAL RESOLUTION at radial position 10 cm off centre (see 3.1.5). The counts in the PIXELS at the left and right edges of the 4 × FWHM wide strip, $C_{L,i,k}$ and $C_{R,i,k}$, respectively shall be obtained from the sum PROJECTION (see figure 10). Linear interpolation shall be used to find the PIXEL intensities at ±2 × FWHM from the central PIXEL of the PROJECTION. The average of the two count levels $C_{L,i,k}$ and $C_{R,i,k}$ shall be multiplied by the fractional number of PIXELS between the edges of the 4 × FWHM wide strip, with the product added to the counts in the PIXELS outside the strip, to yield the number of SCATTERED TRUE COINCIDENCE counts $C_{s,i,k}$, for the slice *i* and the source position *k*. The TRUE COINCIDENCE counts (scattered plus unscattered) $C_{\mathrm{tot},i,k}$ is the sum of all PIXELS in the sum PROJECTION.

The average ACTIVITY $A_{\mathrm{ave},k}$ during data acquisition over the time interval $T_{\mathrm{acq},k}$ for the LINE SOURCE at position *k*, shall be calculated (see 3.3.3.4).

The SCATTER FRACTION SF_i for each slice, due to a uniform source distribution is calculated as follows:

$$SF_i = \frac{\left[\frac{C_{s,i,1}}{A_{\mathrm{ave},1}}\right] + 8\left[\frac{C_{s,i,2}}{A_{\mathrm{ave},2}}\right] + 10{,}75\left[\frac{C_{s,i,3}}{A_{\mathrm{ave},3}}\right]}{\left[\frac{C_{\mathrm{tot},i,1}}{A_{\mathrm{ave},1}}\right] + 8\left[\frac{C_{\mathrm{tot},i,2}}{A_{\mathrm{ave},2}}\right] + 10{,}75\left[\frac{C_{\mathrm{tot},i,3}}{A_{\mathrm{ave},3}}\right]}$$

where the subscripts 1, 2 and 3 refer to LINE SOURCES at radii 0 mm, 45 mm and 90 mm, respectively.

3.6.5 Report

For each slice that was processed, tabulate the value of SF_i. The average *SF* of the SF_i shall also be reported as the system SCATTER FRACTION.

3.7 ATTENUATION correction

3.7.1 General

POSITRON EMISSION TOMOGRAPHY has a valid theoretical basis for ATTENUATION correction for arbitrary attenuating media within the TOMOGRAPHIC VOLUME of a tomograph. The basis for the correction is a measurement of the transmission of ANNIHILATION RADIATION through the object within the TOTAL FIELD OF VIEW. The accuracy with which this is achieved in practice is an important measure of its quantitative ability.

3.7.2 Purpose

The purpose of this procedure is to measure the accuracy of the transmission method of ATTENUATION correction.

NOTE – The outcome of this test is influenced also by scatter.

3.7.3 Method

Transmission of external radiation through a non-uniform attenuating medium is processed to give ATTENUATION correction matrices which are applied to emission PROJECTION data as a part of the reconstruction process. Conformity of reconstructed emission values with true values is an indicator of the accuracy of ATTENUATION correction.

3.7.3.1 RADIONUCLIDE

The RADIONUCLIDE for the emission measurement shall be ^{18}F, with an ACTIVITY such that the percentage of COUNT LOSSES is less than 5 % and the RANDOM COINCIDENCE rate is less than 5 % of the TOTAL COINCIDENCE rate.

3.7.3.2 RADIOACTIVE SOURCE distribution

The head phantom (figure 1) shall be centred in the AXIAL FIELD OF VIEW but (vertically) displaced 25 mm off-axis. It shall be used with the three 50 mm diameter cylinder inserts placed 60 mm from the axis of the phantom at 120° angular increments, arranged as in figure 6. For the transmission measurement, the phantom shall be filled with non-radioactive water. One of the hollow inserts shall be filled with non-radioactive air and the other with non-radioactive water. The third insert is solid and made of polytetrafluoroethylene. For the emission measurement, a measured amount of ACTIVITY shall be added to the background of the test phantom and thoroughly mixed with the water.

3.7.3.3 Data collection

Transmission measurement of the head phantom shall be carried out by the method recommended by the manufacturer of the tomograph and shall be stated. For the emission measurement, the ACTIVITY shall be added to the head phantom and a standard image acquisition shall be performed, obtaining at least five million counts per slice.

The transmission and emission measurements can be performed in either order provided proper procedures are followed. If the head phantom must be removed between measurements, it should be precisely repositioned as before. If the emission scan is performed first, then at least ten HALF-LIVES shall elapse before transmission data are acquired. Because the images are summed over slices in the analysis, it is important that the phantom axis be parallel to the axial direction (SYSTEM AXIS) of the tomograph.

3.7.3.4 Data processing

For tomographs with an AXIAL FIELD OF VIEW of 16,5 cm or less, all slices shall be reconstructed. For tomographs with an AXIAL FIELD OF VIEW greater than 16,5 cm, only slices in that part of the AXIAL FIELD OF VIEW, where the phantom was placed, shall be reconstructed. Images shall be reconstructed using the standard IMAGE MATRIX and TRIXEL size and using a ramp filter with cutoff at the Nyquist frequency of the PROJECTION data. The emission data shall be reconstructed applying all corrections including ATTENUATION correction as obtained from the transmission measurement. Transmission processing shall be done according to the method recommended by the manufacturer and shall be stated.

3.7.4 Analysis

The emission images shall be summed axially. In the summed emission image, define three circular ROIs having 30 mm diameters centred on the air, solid, and water insert images, and nine circular ROIs having 30 mm diameters in the uniform ACTIVITY area, as shown in figure 9. The radial distance to the outer six 30 mm ROIs from the axis of the phantom shall equal 60 mm. Record the total counts in each of the ROIs as:

$$C_{air},\ C_{solid},\ C_{water},\ C_1,\ \ldots C_9$$

respectively, where the numerical index corresponds to the nine ROIs in the uniform ACTIVITY areas.

Calculate the normalized counts C_N in the uniform region according to the following:

$$C_N = \frac{1}{9}\sum_{i=1}^{9} C_i$$

The relative errors ΔC_{insert} , i.e. the deviation between measured activity concentration C_{insert} and true concentration 0 in the object, in percentage units for each of the inserts in the summed image shall be calculated as follows:

$$\Delta C_{\text{insert}} = 100\,\frac{C_{\text{insert}}}{C_N} \quad \%$$

The non-uniformity of the ATTENUATION correction shall be calculated as follows:

$$NU_A = \begin{cases} +100\,\dfrac{\text{Max}C_i - C_N}{C_N} & \% \\ -100\,\dfrac{C_N - \text{Min}C_i}{C_N} & \% \end{cases}$$

$$i = 1, 2, \ldots 9$$

In addition to the ROI analysis, for each insert a 10 mm wide profile shall be drawn in the image, passing through the centre of the head phantom and through the centre of the insert.

3.7.5 Report

For the summed image, tabulate the values of ΔC_{air}, ΔC_{solid}, and ΔC_{water}. Also tabulate the values of NU_A. Graphs of the profiles through the three inserts shall also be reported.

4 ACCOMPANYING DOCUMENTS

A document shall accompany each POSITRON EMISSION TOMOGRAPH and shall include the following information.

4.1 Design parameters

- detector element dimensions and number of elements
- detector material
- number and configuration of detector elements per block, if applicable
- number of detector blocks per ring, if applicable
- COINCIDENCE WINDOW
- detector ring diameter
- patient port diameter
- TRANSVERSE FIELD OF VIEW
- AXIAL FIELD OF VIEW
- SINOGRAM sampling (linear and angular)
- axial sampling
- septal length
- septal thickness

– length of side shields
– type of transmission source and source ACTIVITY (nominal and recommended range)
– detector movement (e.g. rotational speed, angular range), if any

4.2 Configuration of the tomograph

– energy threshold
– axial acceptance angle (2D-mode, 3D-mode)
– reconstruction algorithm
– method of RANDOM COINCIDENCE estimation
– any additional information being considered essential by the manufacturer to characterize normal operation

4.3 SPATIAL RESOLUTION

– TRANSVERSE RESOLUTION (radial and tangential) according to 3.1.5
– AXIAL SLICE WIDTH according to 3.1.5
– AXIAL RESOLUTION according to 3.1.5
– axial PIXEL dimension according to 3.1.5
– transverse PIXEL dimensions according to 3.1.5
– axial step size according to 3.1.5

4.4 RECOVERY COEFFICIENT

– graphs of RECOVERY COEFFICIENTS according to 3.2.6

4.5 Sensitivity

– SLICE SENSITIVITY according to 3.3.5
– NORMALIZED SLICE SENSITIVITY according to 3.3.5
– VOLUME SENSITIVITY according to 3.3.5

4.6 COUNT RATE performance

– COUNT RATE CHARACTERISTIC according to 3.5.5
– ACTIVITY levels at 20 % and 50 % COUNT LOSS according to 3.5.5
– measured TRUE COINCIDENCE COUNT RATE at 20 % COUNT LOSS and 50 % COUNT LOSS according to 3.5.5
– plots of normalized ROI counts versus ACTIVITY according to 3.5.5
– ADDRESS PILE UP according to 3.5.5
– accuracy of COUNT LOSS correction and associated plots according to 3.5.5

4.7 SCATTER FRACTION

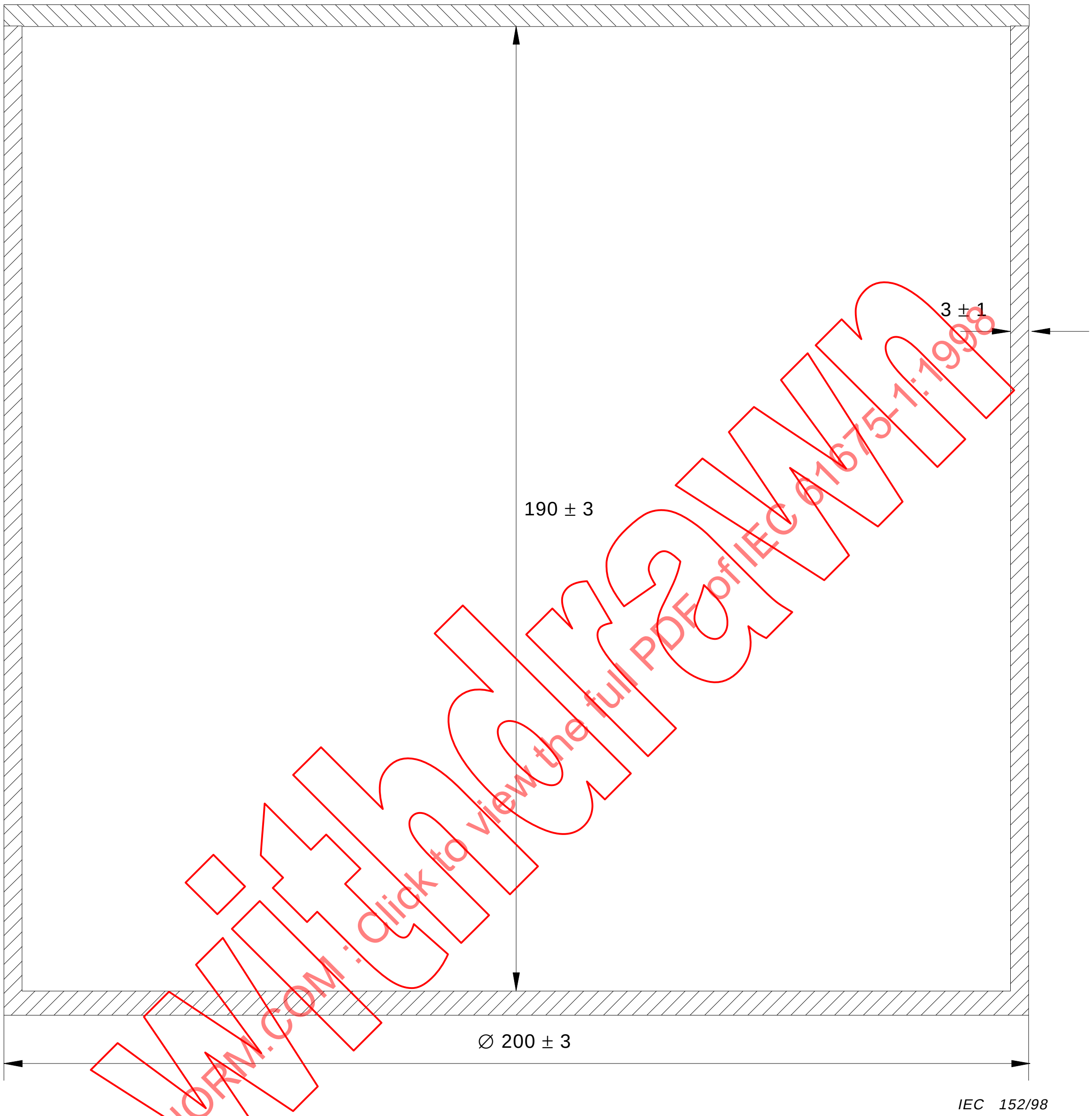
– SCATTER FRACTIONS SF_i and SF according to 3.6.6

4.8 Accuracy of ATTENUATION correction

– ΔC_{air}, ΔC_{solid}, ΔC_{water}, and NU_A according to 3.7.5
– profiles across inserts according to 3.7.5

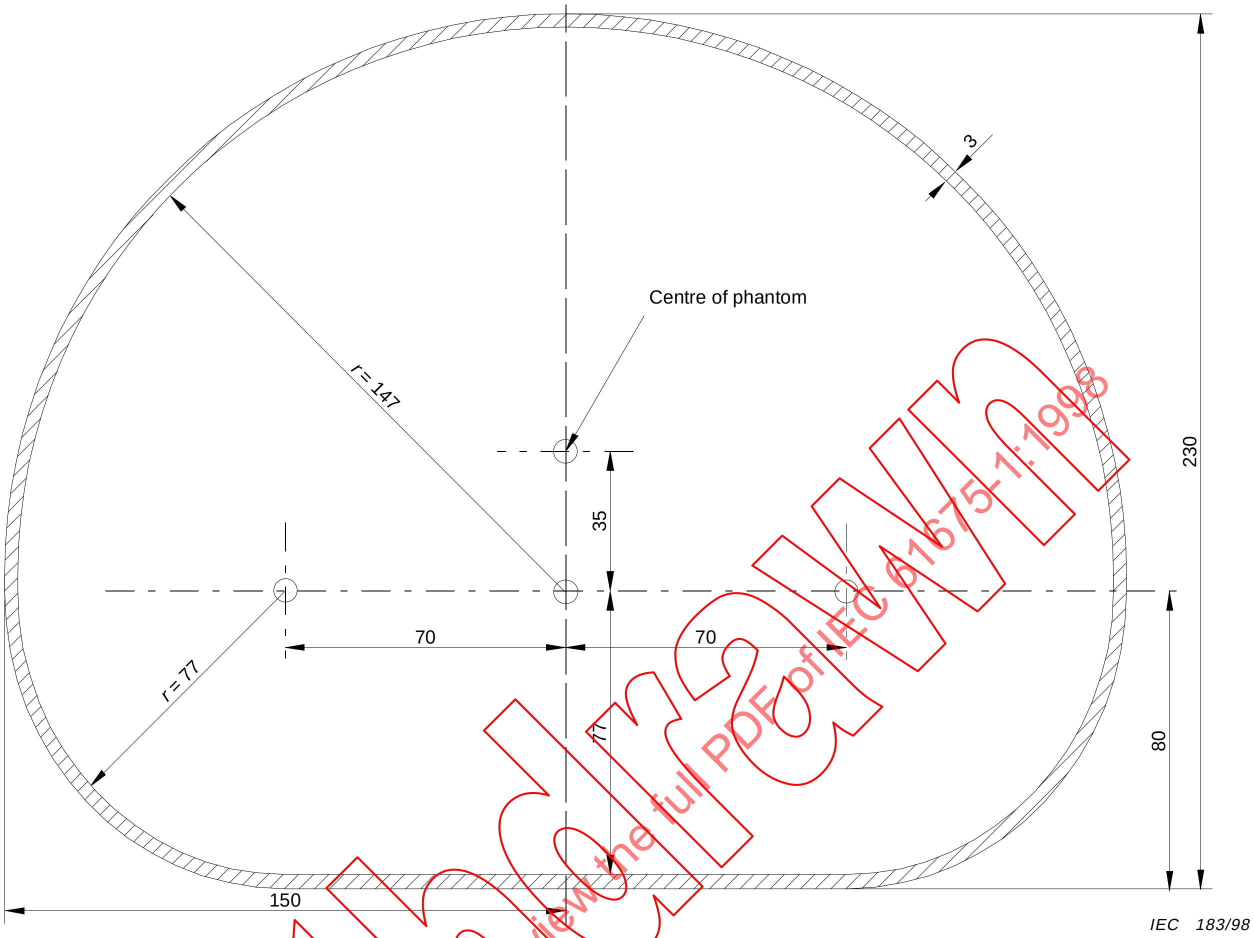
Table 1 – RADIONUCLIDES to be used in performance measurements

RADIONUCLIDE	HALF LIFE min	Branching ratio
^{18}F	109,70 ± 0,11	0,971 ± 0,002
^{11}C	20,375	0,998



Dimensions in millimetres *Material: polymethylmethacrylate*

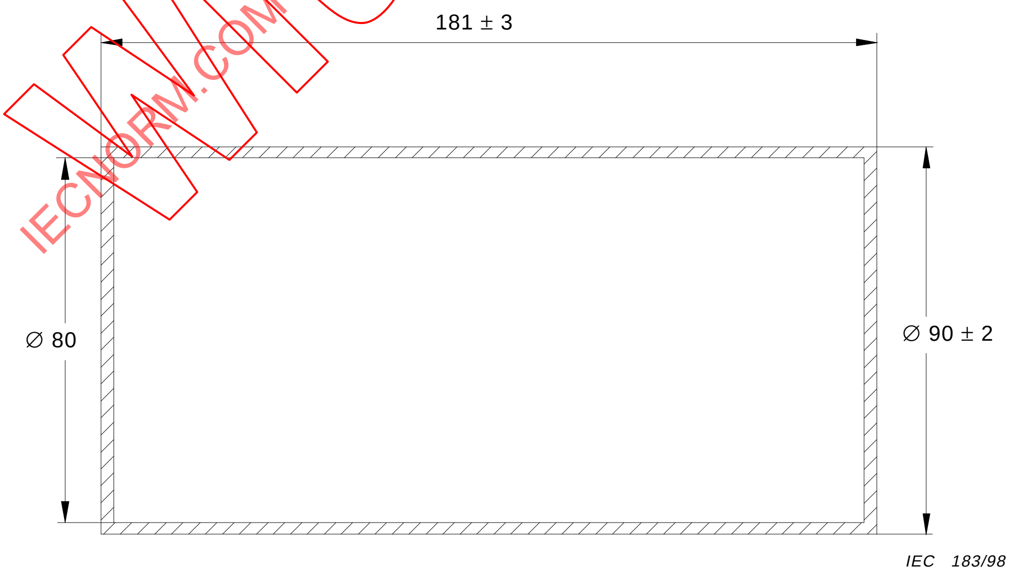
Figure 1 – Cylindrical head phantom



Dimensions are in millimetres and are given within ±1 mm *Material: polymethylmethacrylate*

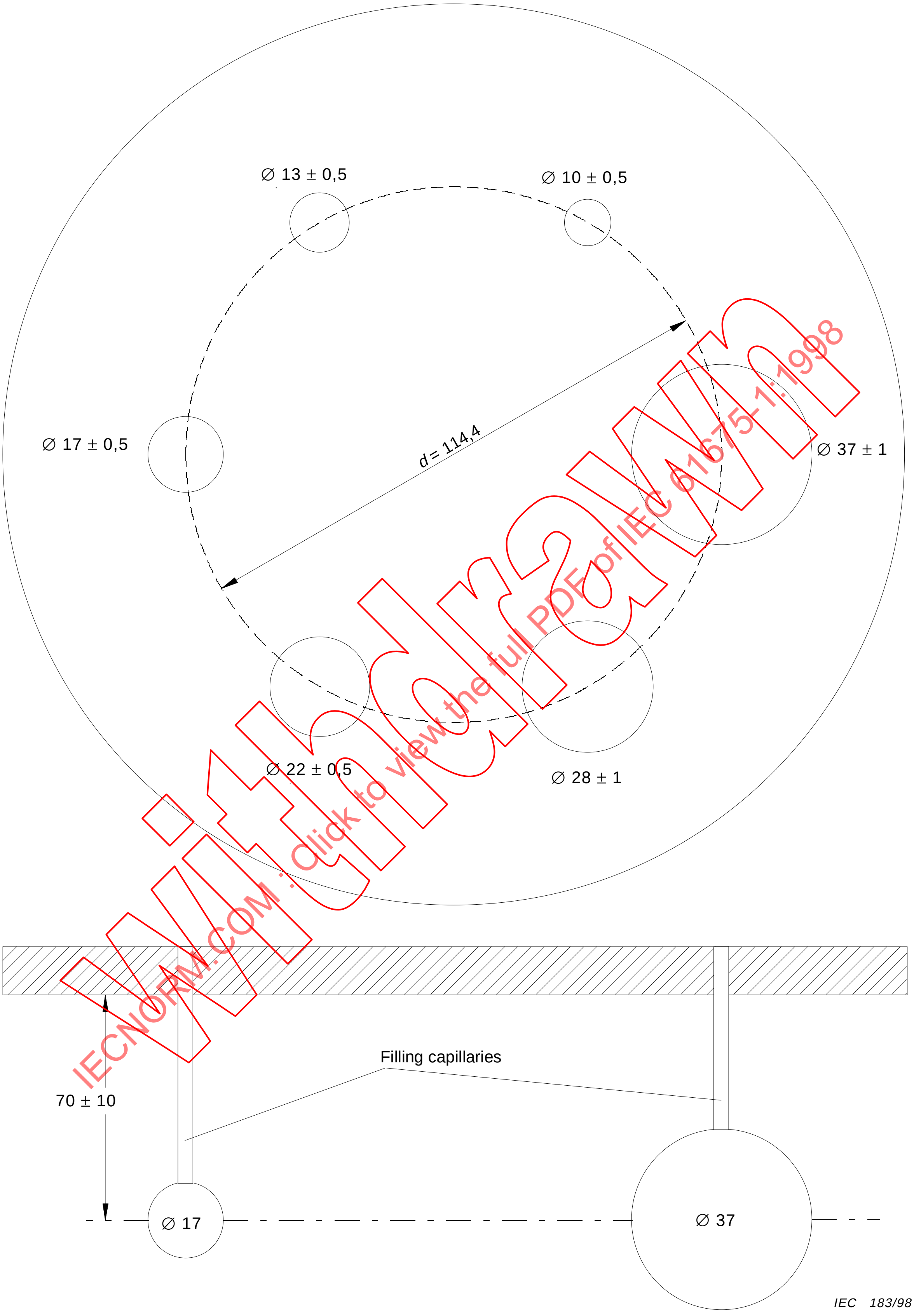
NOTE – The phantom length shall be chosen to allow fitting of the head phantom and shall be at least 180 mm ± 5 mm.

Figure 2 – Cross-section of body phantom



Dimensions in millimetres *Material: polymethylmethacrylate*

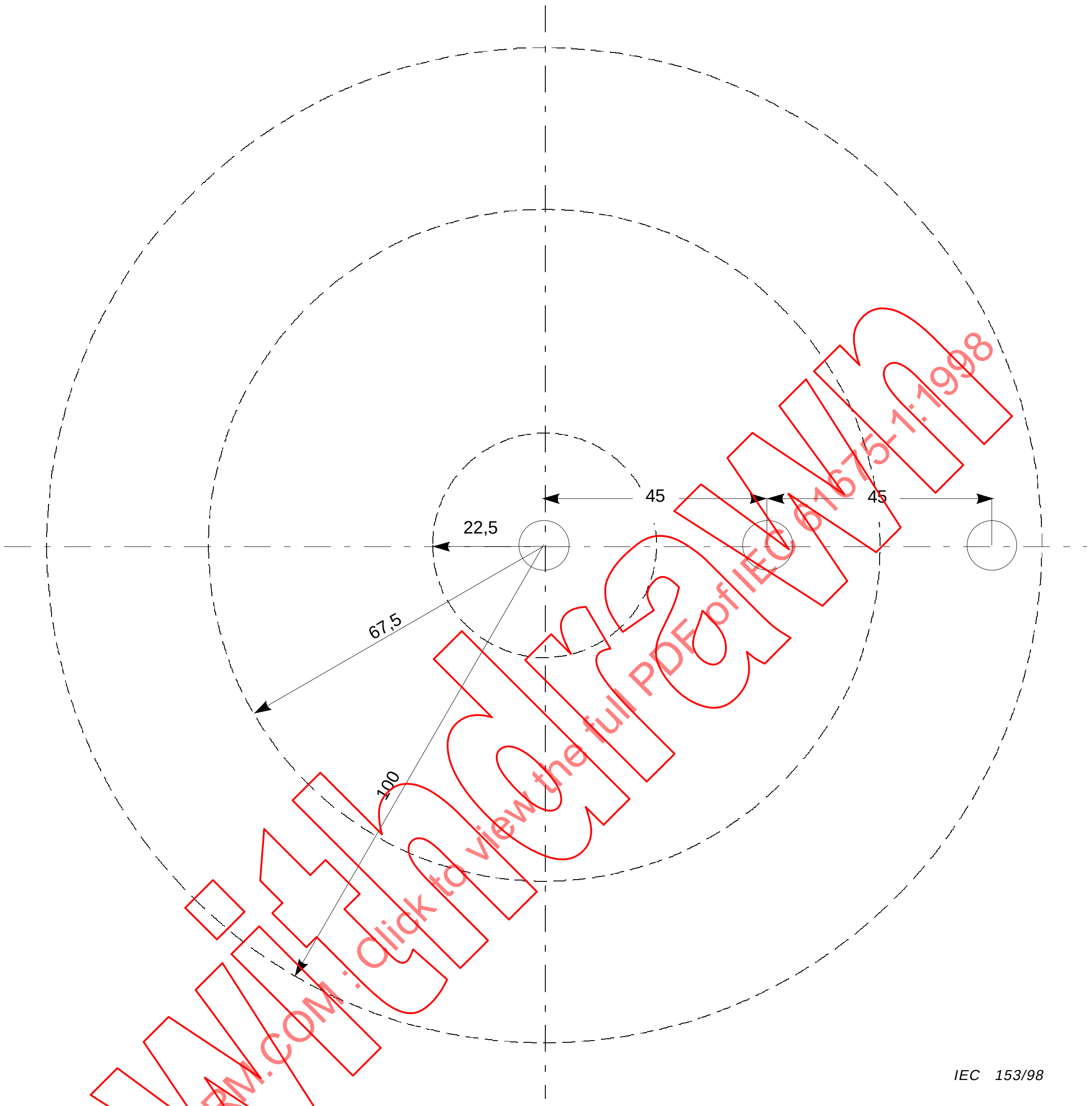
Figure 3 – Arm phantom



Dimensions in millimetres *Material: polymethylmethacrylate*

NOTE – All diameters given are inside diameters.
The wall thickness of the spheres shall be ≤1 mm.
The centres of the spheres shall be at the same distance from the surface of the mounting plate.
The mounting plate replaces the cover of the head phantom.
The spheres can also be made from glass.

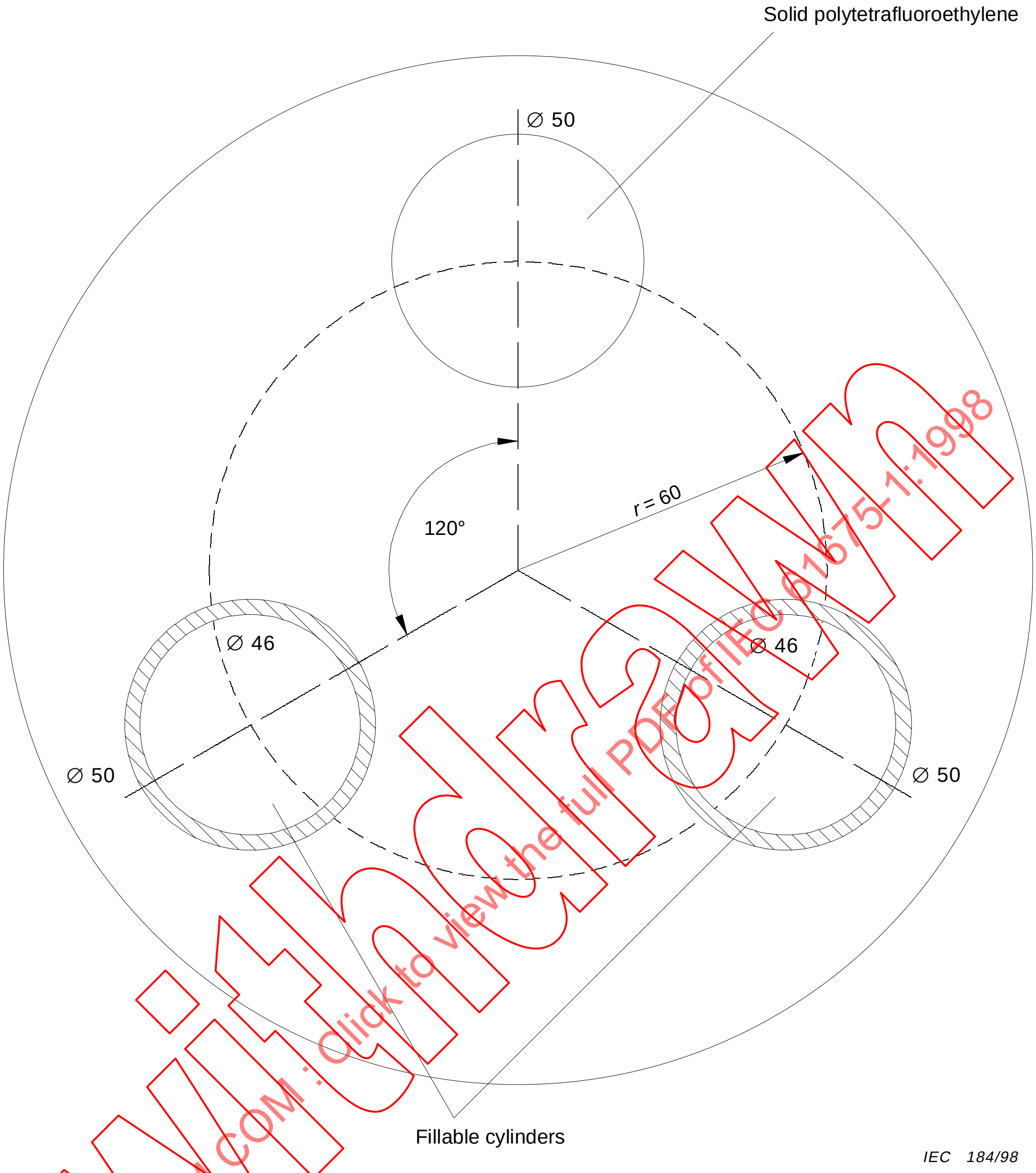
Figure 4 – Phantom insert with hollow spheres



Dimensions in millimetres *Material: polymethylmethacrylate*

NOTE – The mounting plate replaces the cover of the head phantom.
The source holders consist of tubes of lengths sufficient to fill the inside length of the head phantom.
In addition, the drawing shows the weighting areas (bounded by the dashed lines) for the scatter measurement.

Figure 5 – Phantom insert with holders for the scatter source



Dimensions in millimetres

NOTE – The mounting plate replaces the cover of the head phantom.
The fillable cylinders made of polymethylmethacrylate have outer dimensions of 50 mm diameter × 185 mm length, the inside dimensions are 46 mm diameter × 182 mm length.
The solid cylinder made of polytetrafluoroethylene is 50 mm in diameter × 185 mm length.

Figure 6 – Phantom insert for the evaluation of ATTENUATION correction