



# Information Leaflet No. 1: CT Scanner Acceptance Testing

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## 1. Scope of leaflet

This leaflet is intended as a practical guide to the tests required at the acceptance and commissioning of a CT scanner. It assumes some basic knowledge of CT performance testing but provides additional information, where relevant, regarding multi-slice CT systems. Since there is broad overlap between tests performed at acceptance and commissioning, they are covered jointly here.

The list of tests described here is neither prescriptive nor exhaustive, as less or more could potentially be performed during the acceptance and commissioning of a new scanner. The intention has been to provide an adequate set of measurements to carry out for a routine diagnostic scanner. Some applications, particularly radiotherapy, have specialised requirements from a scanner, and need additional tests to verify them.

The leaflet is intended for direct use within the ionising radiation legislative framework that exists in the UK [1,2], although similar tests are likely to be applicable internationally.

For more detail on all measurement methods discussed here, the reader should refer to [3].

## 2. General principles of acceptance and commissioning

Acceptance and commissioning tests are performed following the installation of a scanner and after the critical examination has taken place.

Definitions of acceptance and commissioning used here are those given in [4]. In summary, acceptance constitutes the set of tests necessary to demonstrate that the specified requirements in the contract have been met. These include mechanical, electrical and radiation safety tests. Commissioning has two purposes. Firstly, to ensure that the equipment is suitable for clinical use and, secondly, to establish baseline values against which subsequent routine quality control results are to be compared.

Although acceptance and commissioning tests are often performed together, two sets of phantoms and exposure parameters may need to be used, for the reasons given in section 2.1.

## 2.1 Phantoms

Some parameters, such as noise, dose and low contrast resolution, are dependent on the type of phantom used to make the measurements. In these cases, phantom selection is important and depends on the purpose of the tests.

For acceptance testing, where comparison with manufacturers' specifications is required, the phantoms should match those used by the manufacturer in their specification documentation. One option is to ask the manufacturer to supply appropriate phantoms for the duration of acceptance testing.

When establishing baseline values, the types of phantoms used should be the same as those that will be available for the subsequent routine quality control tests.

## 2.2 Exposure and reconstruction parameters

Again, these must be considered carefully. At acceptance, it is important to use the same scan settings as those selected by the manufacturer in their documentation.

For commissioning, the most relevant scan settings to select are those that will be used clinically. For example, these could cover local clinical settings for a standard brain scan, a high resolution inner ear scan, and a standard helical abdomen scan.

## 3. Recommended tests

### 3.1 Electrical safety

Electrical safety features, for all components of a scanner system, should be checked at acceptance and appropriate guidance is provided in [5,6].

### 3.2 Mechanical safety

Mechanical safety features such as devices designed to reduce the risk of collision with the patient, patient release devices and emergency stop controls or switches should be tested as part of an acceptance test. Relevant guidance can be found in IEC standards [5,7].

### 3.3 Laser safety

Manufacturers' documentation, guidance notes and warning notices, regarding the use of any laser alignment lights installed on the system, should be checked at acceptance. The person accepting the scanner should be satisfied that the necessary information has been provided and that warning notices are displayed in appropriate locations. He/she should be satisfied that any safety precautions are well documented. Relevant guidance on laser safety may be found in [8].

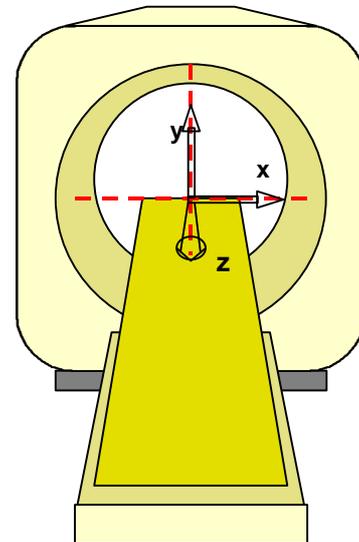
### 3.4 Radiation safety

The person accepting the scanner must be satisfied that the scanner system and x-ray room comply with current radiation safety legislation and guidance [1,2]. The relevant radiation safety tests, however, should already

have been performed as part of the Critical Examination. These are discussed for x-ray equipment in general in [9].

## 3.5 Mechanical accuracy

### 3.5.1 Alignment of indicating lights with scan, coronal and sagittal planes



x-y: scan (transaxial) plane  
x-z: coronal plane  
y-z: sagittal plane

Figure 1: Alignment of indicating lights to planes

There are a number of methods that can be used to perform these tests. The techniques described here are straightforward to implement and require little specialist test equipment.

#### 3.5.1.1 Scan plane lights

##### 3.5.1.1.(i) Agreement between internal and external scan plane lights

This test is performed to check that the correct distance separates the internal and external scan plane lights. When performing the test immediately prior to 3.5.1.1(ii), it is easiest to use the envelope-wrapped film recommended for that measurement, however, a piece of paper or card can also be used. The wrapped film is placed flat on the table and illuminated by the external scan plane light. The position of the light is marked on the film envelope and the table is moved automatically to the scan plane. If the distance between the internal and external lights is correct, the internal light should now coincide with the mark on the film envelope.

##### 3.5.1.1.(ii) Co-incidence of internal scan plane lights and scan plane

Pin pricks are made in a piece of therapy verification film (or similar) along the line of the internal scan plane light, and the film is exposed to a narrow axial scan and developed (figure 2). Coincidence between the pin pricks and the x-ray beam exposure indicates alignment between the internal lights and the scan plane.

For multi-slice scanners, pin pricks (and, thus, the internal alignment light) are usually found to coincide with the centre of the four slices. To plan a scan so that the x-ray beam is centred over the internal scan plane lights at zero, it will be necessary to centre the first and last slices symmetrically around zero (e.g. four slices from  $-7.5$  mm to  $+7.5$  mm on a  $4 \times 5$  mm scan).

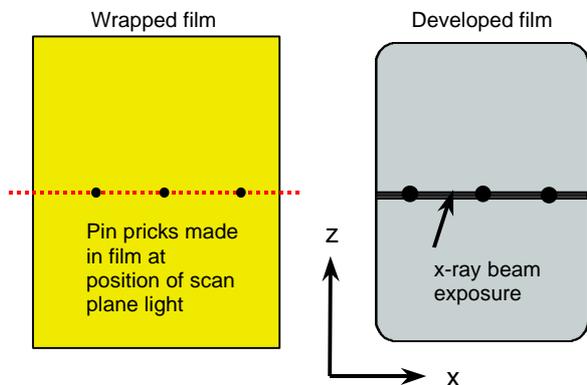


Figure 2: Technique for assessing alignment of internal scan plane light to scan plane

### 3.5.1.2 Coronal and Saggital plane lights

A long, thin object, with a high CT number relative to air, such as the 'lead' in a pencil or a straightened paper clip, can be used as a marker to perform this test. The marker is supported above the patient table and aligned, using the indicating lights, so that it is positioned at the isocentre, parallel to the z-axis and perpendicular to the scan plane. If indicating lights are accurately aligned to the coronal and sagittal planes, the marker should appear as a dot at exactly  $x=0$ ,  $y=0$  on the axial image.

Alignment light accuracy is often assessed at the isocentre. However, in practice, the lights are more likely to be used for positioning at the surface of the patient. Therefore, it may also be useful to perform tests 3.5.1.1 and 3.5.1.2 with marker displaced by e.g. 10cm from the isocentre. This could be achieved by placing it on the surface of a phantom.

## 3.5.2 Couch travel accuracy

### 3.5.2.1 Accuracy of distance indicator on gantry

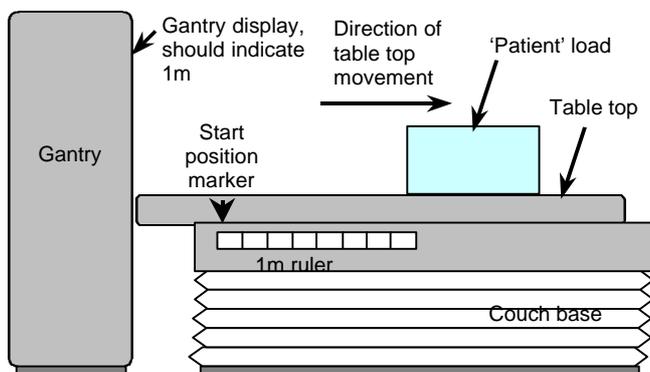


Figure 3: Assessment of distance indicator accuracy

A ruler or tape measure placed alongside the table, as shown in figure 3, can be used to check that the degree of couch movement indicated on the gantry agrees with the actual distance moved. A load of approximately 70-80 kg should be placed on the table in order to simulate the weight of a patient. The test should be performed twice: by driving the table top both away from and towards the gantry.

### 3.5.2.2 Axial scan incrementation accuracy

Verification of incrementation accuracy between successive axial slices can be achieved by placing envelope-wrapped film on the couch (in the isocentre plane) and exposing it to an axial scan sequence. Narrow slices separated by a couch increment greater than 1 slice width can be used, and the distance between the lines on the film measured.

### 3.5.2.3 Couch travel accuracy for helical scans

In helical scanning, it is not sufficient to use a simple mechanical test such as in 3.5.2.1 because the distance imaged depends on couch speed and scanner software. One method of assessing imaged distance accuracy is to use a Perspex test object containing two small radio-opaque markers, separated by a fixed distance (e.g. 20 cm), as shown in figure 4.

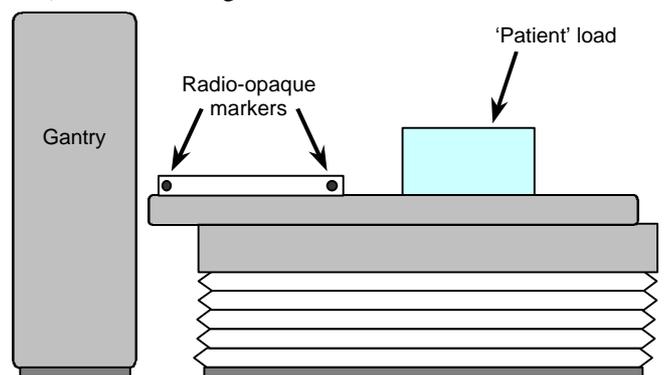


Figure 4: Assessment of couch travel accuracy for helical scans

The test object is scanned in Scan Projection Radiography (SPR) mode and a helical run is planned to start at the first marker and to end at a distance  $x$  from the first marker. If couch travel is accurate during the helical scan, the markers should be clearly seen on the first and final images of the series.

### 3.5.4 Gantry Tilt

The accuracy of displayed gantry tilt can be assessed by supporting envelope-wrapped x-ray film at the gantry end of the patient table. The film must be held vertically (e.g. by taping to a Perspex block), so that it is parallel to the sagittal plane and intersects scan and coronal planes at right angles. Three axial exposures are made using the same film: one for the maximum superior gantry tilt, one for the maximum inferior gantry tilt and a third at  $0^\circ$  gantry tilt. The three scan planes should then be visible on the developed film (figure 5). The angles  $\theta_+$  and  $\theta_-$  between scan planes at maximum tilt relative to that at  $0^\circ$  tilt should equal tilt angles displayed on the gantry.

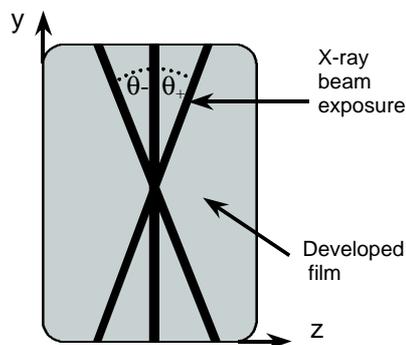


Figure 5: Assessment of accuracy of gantry tilt angles displayed on the gantry

### 3.6 Dosimetry

#### 3.6.1 Computed Tomography Dose Index in air

The Computed Tomography Dose Index (CTDI) in air [10] can be measured using a 10cm pencil ionisation chamber, bisected by the scan plane at the isocentre, supported from the patient table (as shown in figure 6). The ion chamber can be supported using a retort stand and clamp, if a dedicated holder is not available.



Figure 6: Measurement of CTDI in air

When commissioning a CT scanner, it is valuable to measure the CTDI in air under the following conditions:

- For all beam shaping filters
- For all nominal slice widths
- For all clinical kV settings
- For a range of scan times
- For a range of mA settings

An additional test is to compare the dose from a helical scan with that from an axial scan. However, a helical CTDI value cannot be measured directly, as CTDI is a single slice measurement. To obtain a relative dose for helical scanning, the entire length of the chamber can be scanned firstly in axial mode (contiguous slices) and secondly in helical mode, at pitch 1 (figure 7). The ratio of the 2 doses provides a correction factor, which can then be used to convert axial CTDIs into 'helical CTDI's.

Scanning the chamber length with different pitches allows assessment of the variation of dose with pitch.

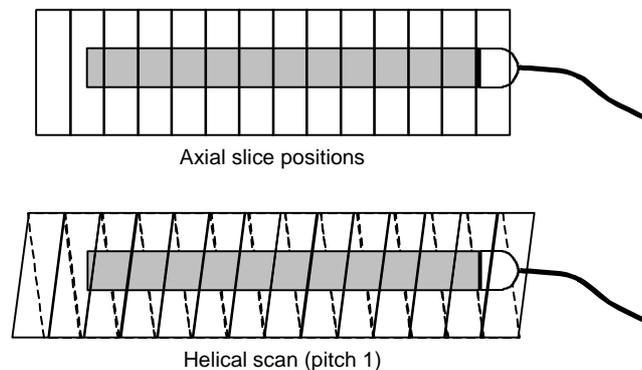


Figure 7: Technique to obtain a helical 'CTDI'

#### 3.6.2 Computed Tomography Dose Index in Perspex CTDI Phantoms

In their specification documentation, manufacturers often quote CTDI measurements at the centre and periphery of standard Perspex (PMMA) phantoms (illustrated in figure 8). To make corresponding measurements at acceptance take care to make any appropriate conversions between methods, e.g.  $CTDI_{FDA}$  to  $CTDI_{air}$ : refer to [3] for more details.

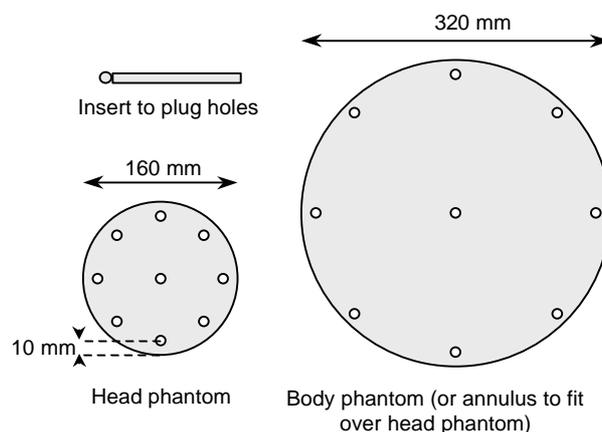


Figure 8: Perspex (PMMA) Head and body phantoms for measurement of CTDI. Both phantoms are  $\geq 140$  mm in z-axis length.

The body phantom placed on the patient table and the head phantom is supported in the head rest. Phantoms are aligned centred at the scan isocentre. The ion chamber is inserted into either the central or one of the peripheral cavities of the phantom (all other cavities being filled with Perspex rods). Dose measurements at the centre are used to calculate the central CTDI. To obtain the periphery CTDI it is necessary to measure dose in at least four positions around the phantom, so as to achieve a true average. If gantry rotation is initiated from different angular positions for successive scans it may be necessary to take a number of measurements at each position in order to get a representative mean dose.

Central and peripheral CTDI's are used to calculate weighted CTDI,  $CTDI_w$ :

$$CTDI_w = \frac{CTDI_{centre} + 2 \times CTDI_{periphery}}{3} \text{ mGy}$$

CTDI<sub>w,s</sub> can be compared against diagnostic reference levels for standard head and abdomen scans, quoted in [10].

### 3.6.3 Dose Profiles (Irradiated slice width)

Measurement of irradiated slice widths, for all nominal slice width settings, provides a direct test of pre-patient beam collimation functionality and allows geometric efficiencies to be calculated for the scanner.

Geometric efficiency is defined as:

$$\text{Geometric Efficiency} = \frac{\text{imaged slice width}}{\text{irradiated slice width}} \times 100\%$$

It is recommended that the geometric efficiency is displayed on the console if it is less than 70% [11]. Refer to section 3.7.6.1 for measurement of imaged slice width.

One method of obtaining irradiated slice width measurements is to expose envelope-wrapped x-ray film, supported in air at the isocentre, at each of the slice width settings (figure 9). Once developed, optical density profiles may be plotted using a scanning microdensitometer or the width measured using a ruler. To provide an accurate dose profile, a calibration curve can be applied to convert optical density profiles into dose profiles, from which irradiated slice widths (FWHM of dose profiles) may be derived. An alternative technique is to measure dose profiles using TLD's.

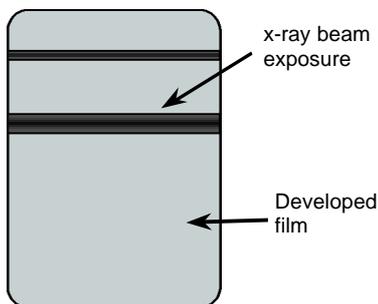


Figure 9: Measurement of irradiated slice widths for a range of nominal slice width settings

## 3.7 Imaging performance

### 3.7.1 Noise

Noise is generally assessed using cylindrical phantoms, which are either filled with water or made of a tissue equivalent material. Once an axial image of the phantom has been acquired, noise is obtained from the standard deviation in CT number in a region of interest placed centrally within the image (figure 10).

Noise figures given in manufacturers' specifications are quoted for a specific phantom (e.g. manufacturer's QA phantom) and for specified scan parameters. These conditions must be matched exactly for the purposes of the acceptance test. Manufacturers often quote noise at a particular surface dose. If this is the case, dose for axial scans can be measured by taping an ion chamber to the surface of the phantom. (When selecting the position of

the chamber, care must be taken with regard to any non-uniformity in dose around the phantom.) Dose for helical scans can be calculated from the axial dose by applying the axial CTDI: helical CTDI correction factor (derived from in air dose measurements – see section 3.6.1), divided by the pitch.

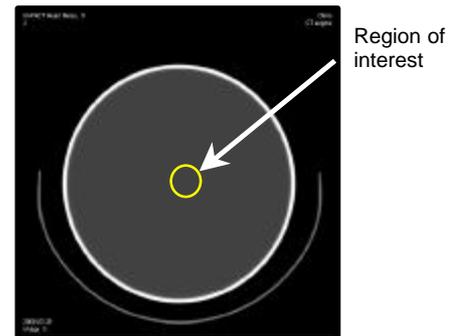


Figure 10: Axial image of a homogenous phantom used for the assessment of noise

Baseline noise values should be obtained for several scan protocols that will be used clinically, using the routine QC noise phantom.

To ensure that noise figures are both accurate and representative, it is essential to find the mean value from several scans. (ImPACT calculates the mean noise from 10 scans.)

An additional test for multi-slice scanners is to compare the noise for each of the images acquired in a single axial rotation. Differences in noise between images could indicate some degree of misalignment within the x-ray target / collimation / detector array system and / or differences in sensitivity of the parallel banks of detectors

### 3.7.2 CT Number Uniformity

CT number uniformity can be assessed at the same time as measuring noise, by placing four additional regions of interest (N, E, S and W) at positions near the edge of the image of a uniform phantom (figure 11). Mean CT number is then noted for these four regions, as well as the central one. The deviation from the central value should be calculated. It can be valuable to check CT number uniformity for large fields of view

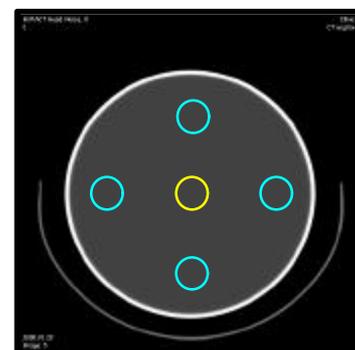


Figure 11: Axial image of a homogenous phantom used for the assessment of CT number uniformity

### 3.7.3 CT Number Linearity

CT number linearity is assessed using a phantom containing inserts of a number of different materials. For a comprehensive linearity test, insert materials should cover a wide range of CT numbers. One example of a suitable phantom to use at acceptance is the Catphan (The Phantom Laboratory, Salem, NY, [www.phantomlab.com](http://www.phantomlab.com)), which contains four inserts with CT numbers ranging from approximately -1000HU to +1000HU (figure 12). For commissioning tests, it is important to use the same phantom as that available for subsequent routine QC.

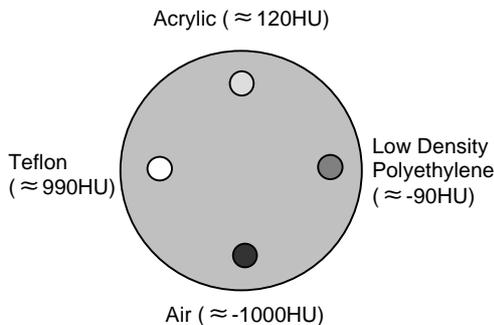


Figure 12: Phantom for the assessment of CT number linearity

### 3.7.4 Low contrast resolution

Low contrast resolution (or low contrast detectability) is often quoted in specification documentation, as the smallest visible object at a given contrast for a given dose. Since this measurement relates directly to imaging performance, it is an important parameter to verify at acceptance.

The phantom and scan settings selected for the acceptance test will depend on those used by the manufacturer in the scanner specification. Common phantoms are the low contrast resolution (LCR) insert in the Catphan and the ATS insert of the AAPM phantom. Figure 13 shows a typical image of the Catphan LCR insert.

At least 20 images of the low contrast insert should be acquired and then viewed by at least 3 observers under optimal viewing conditions, so as to obtain an average. The dose should be measured using an equivalent technique to that quoted in the manufacturer's specification

During commissioning, it may be useful to assess low contrast resolution for a number of clinical scan protocols, but only if further assessment of this parameter is planned for routine QC. It could be argued that low contrast measurements on a routine basis are not necessary since they are limited largely by random noise, which is assessed independently. specification, e.g. by placing the ion chamber on the surface of the phantom (taking care to consider any non-uniformity in dose around the phantom).

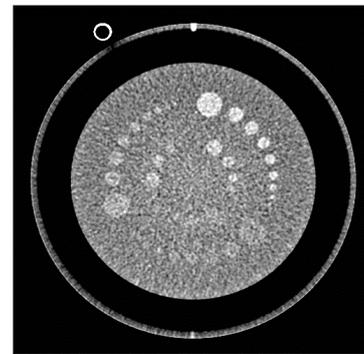


Figure 13: Typical image of the Catphan LCR insert

### 3.7.5 Spatial resolution

High contrast spatial resolution can be measured using a number of techniques. These can be broadly split into two categories: those involving analysis of the point spread function, usually by calculation of the modulation transfer function (MTF), and those involving either objective analysis or visual assessment of images of a resolution bar phantom.

The resolution is quoted as the spatial frequency (in line pairs / cm) at which the modulation falls to 50%, 10% or 2% MTF. They also quote the limiting resolution (calculated from the 0% MTF) in mm. These figures are often given for more than one reconstruction algorithm, e.g. for standard and high-resolution scans.

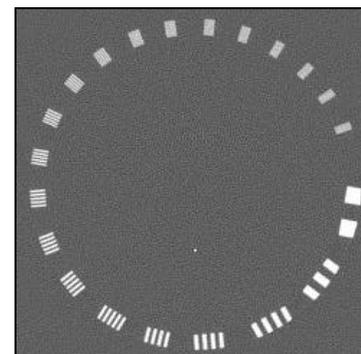


Figure 14: Bar phantom image from the Catphan

When performing acceptance or commissioning tests, visual assessment of bar phantom images, such as that shown in figure 14, is often sufficient. The number of line pairs per cm just visible in the image is approximately equivalent to the 2% value of the MTF. This result can then be compared with the 2% MTF, if this is quoted in the manufacturer's specification. To fulfil the requirements of acceptance, resolution should be measured for all scan settings and reconstruction algorithms quoted in the specification. For commissioning, it should be evaluated for a range of local clinical scan protocols.

### 3.7.6 Z-sensitivity (imaged slice width)

#### 3.7.6.1 Axial mode measurements

Phantoms used for axial measurements may contain thin metal plates (figure 15), wires or arrays of air holes, inclined at an angle to the image plane.

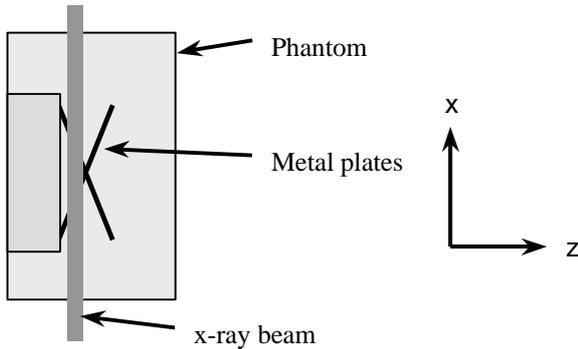


Figure 15: Plan view of a test object used to measure imaged slice widths for axial scans

Manufacturers should be able to supply an appropriate phantom or, alternatively, the Catphan contains an insert suitable for this test. A point to note here is that, in order to obtain meaningful measurements, the thickness of the plates, wires or holes cannot be greater than the nominal slice width concerned. This criterion may pose problems for the sub-millimetre slice widths offered on multi-slice scanners. ImPACT has developed a test object with thin plates for measuring sub-millimetre slices.

Manufacturers may quote the tolerance for each nominal slice width setting in their specification documentation. Z-sensitivity measurements in axial mode can be used to check that imaged slice widths are within the tolerances given. They can also be used in conjunction with irradiated slice width measurements to assess the accuracy of post patient collimation and to calculate the geometric efficiency for the scanner (see section 3.6.3 Dose Profiles).

Z-sensitivity profiles for each of the images acquired in a single axial rotation for multi-slice scanners can be compared. Differences in these profiles between images could indicate misalignment within the x-ray target / collimation / detector array system and/or differences in sensitivity of the parallel banks of detectors

#### 3.7.6.2 Helical mode measurements

Appropriate phantoms for helical measurements contain either a high contrast bead of sub-millimetre diameter or a high contrast disc of sub-millimetre thickness. Manufacturers' phantoms may include a suitable insert. ImPACT's phantom for helical scans (figure 16) contains a tungsten disc (6mm diameter, 0.05mm thick) sandwiched within a Perspex rod.

Axial images are reconstructed at suitable intervals (e.g. one-tenth of the nominal slice width) along a helical scan of the test object and the CT number in a central region of each image is recorded. CT number is plotted against z-axis position to obtain a CT number profile,

and the FWHM of the profile is measured to obtain the imaged slice width.

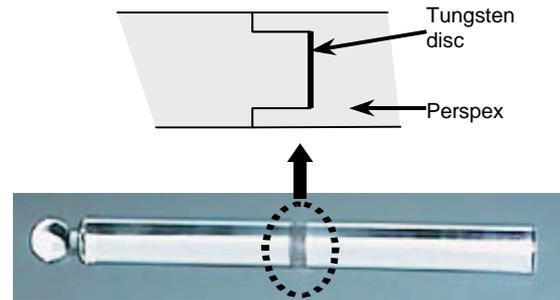


Figure 16: ImPACT's helical z-sensitivity phantom

Helical imaged slice widths could potentially be affected by software changes to the system and changes to the table speed. They should be measured at acceptance, but need only be re-measured after software upgrades. A typical set of measurements could use a set slice width (e.g. 5mm), for a range of pitch and interpolation algorithm combinations.

### 3.7.7 Artefacts

Although a potentially important area to test, there are currently no phantoms generally available that are dedicated to the assessment of artefacts.

The presence of artefacts can be assessed subjectively throughout an acceptance test. Ring artefacts, for example, should be apparent on noise images when using a narrow window width. Use of the largest noise phantom, with a body FOV, allows a greater number of detectors to be evaluated.

### 3.7.8 Accuracy of distance measurements

#### 3.7.8.1 Axial scans

The accuracy of distance measurements made on axial images can be assessed using a phantom that contains high contrast markers separated by known distances in x and y (Lateral and PA/AP) directions. The phantom alignment insert of the Catphan is one test object that is suitable for this test. This insert contains four rods, oriented along the z-axis, separated by 50mm, which should appear in the image as shown in figure 17. Measured distances between pairs of rods in the image should equal 50mm.

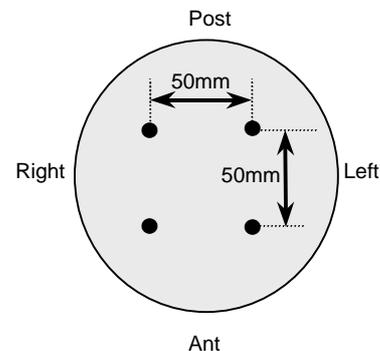


Figure 17: Image of the Catphan phantom alignment insert

### 3.7.8.2 Scan Projection Radiography (SPR) mode

The accuracy of distance measurements in SPR mode can be assessed using any phantom that contains high contrast markers separated by a known distance in the x and z-directions. Leeds test object M1, which contains a wire grid, is one example of a suitable phantom for this test (figure 18). By supporting this test object flat on the patient table at the isocentre and performing a PA or AP SPR scan, the following type of image is obtained:

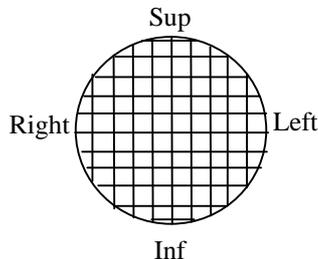


Figure 18: Leeds test object M1

The distances between the outermost wires visible on the image are measured in both superior-inferior and lateral dimensions. These distances should equal the actual separations of the wires within the phantom.

### 3.7 Other measurements

Fundamental scanner features, such as focal spot size, half value layer (HVL) and kV accuracy should ideally be evaluated when commissioning a scanner, since the baseline data acquired can aid later fault diagnosis during routine Quality Control. For example, if there are discrepancies between measured and specified CTDI values, HVL measurements may be helpful in explaining the reason for the discrepancy. Methods for measurement of these parameters are covered in [3].

As part of acceptance testing, it could be argued that assessment of these parameters is low priority, certainly in the first instance, since any problems with them should be apparent in other measurements, such as CTDI and spatial resolution.

Testing of scanner software packages is another area that should be considered – as software becomes more advanced and specialised, the potential for errors in

measurements provided by that software increases. This area is beyond the scope of this leaflet, but should not be ignored.

## 4. References

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ImPACT is the UK's national CT evaluation centre, providing publications, information and advice on all aspects of CT scanning. Funded by the Medical Devices Agency, it is part of a comprehensive medical imaging device evaluation programme.

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