

**INSTRUCTION MANUAL FOR TESTING THE ACR CT PHANTOM**

*Please follow these instructions carefully for submission of test materials.*

**INTRODUCTION**

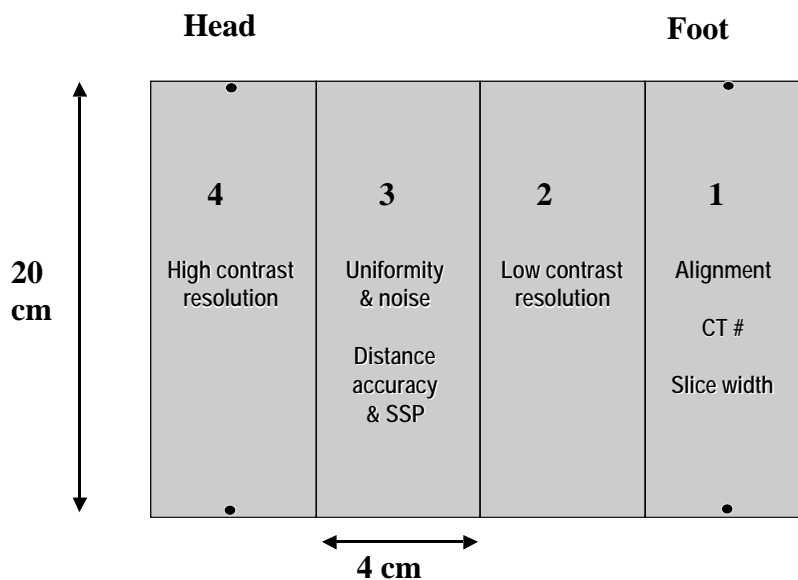
The ACR CT accreditation phantom has been designed to examine a broad range of scanner parameters. These include:

- Positioning accuracy
- CT # accuracy
- Slice width
- Low contrast resolution
- High contrast (spatial) resolution
- CT number uniformity
- Image noise

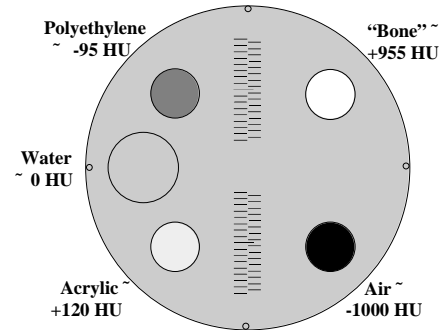
This document describes the test procedures in sufficient detail to allow a CT technologist or medical physicist to acquire the desired images and perform the necessary analysis and calculations. A medical physicist, however, is required to obtain the necessary dosimetric data.

**THE PHANTOM**

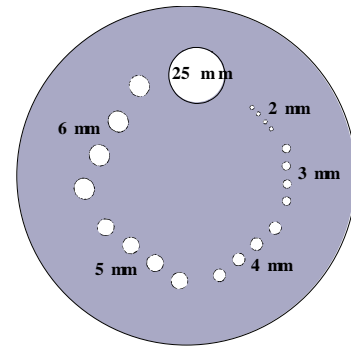
The ACR CT accreditation phantom is a solid phantom containing four modules, and is constructed primarily from a water-equivalent material. Each module is 4 cm in depth and 20 cm in diameter. There are external alignment markings scribed and painted white (to reflect alignment lights) on EACH module to allow centering of the phantom in the axial (z-axis, cranial/caudal), coronal (y-axis, anterior/posterior), and sagittal (x-axis, left/right) directions. There are also “HEAD”, “FOOT”, and “TOP” markings on the phantom to assist with alignment.



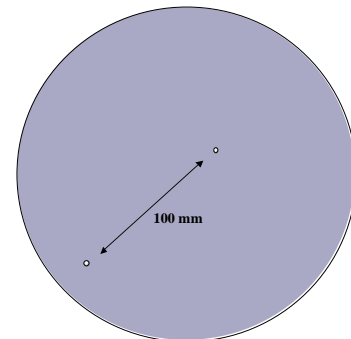
Module 1 is used to assess positioning and alignment, CT number accuracy, and slice thickness. The background material is water equivalent. For positioning, the module has 1-mm diameter steel BBs embedded at the longitudinal (z-axis) center of the module, with the outer surface of the BB at the phantom surface at 3, 6, 9, and 12 o'clock positions within the field of view (19.9cm center to center). To assess CT number accuracy, there are cylinders of different materials: bone-mimicking material ("Bone"), polyethylene, water equivalent material, acrylic, and air. Each cylinder, except the water cylinder, has a diameter of 25 mm and a depth of 4 cm. The water cylinder has a diameter of 50 mm and a depth of 4 cm. To assess slice thickness, two ramps are included which consist of a series of wires that are visible in 0.5-mm z-axis increments.



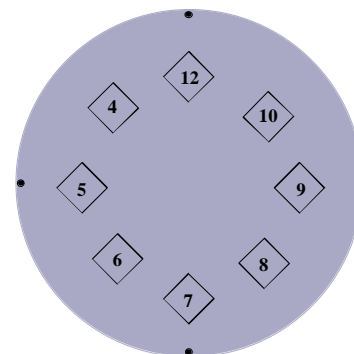
Module 2 is used to assess low contrast resolution. This module consists of a series of cylinders of different diameters, all at 0.6% (6 HU) difference from a background material having a mean CT number of approximately 90 HU. The cylinder-to-background contrast is energy-independent. There are four cylinders for each of the following diameters: 2 mm, 3 mm, 4 mm, 5 mm, and 6 mm. The space between each cylinder is equal to the diameter of the cylinder. A 25-mm cylinder is included to verify the cylinder-to-background contrast level.



Module 3 consists of a uniform, tissue-equivalent material to assess CT number uniformity. Two very small BBs (0.28 mm each) are included for optional use in assessing the accuracy of in-plane distance measurements. They may also be used to assess section sensitivity profiles.



Module 4 is used to assess high contrast (spatial) resolution. It contains eight bar resolution patterns: 4, 5, 6, 7, 8, 9, 10 and 12 lp/cm, each fitting into a 15-mm x 15-mm square region. The z-axis depth of each bar pattern is 3.8 cm, beginning at the Module 3 interface. The aluminum bar patterns provide very high object contrast relative to the background material. Module 4 also has four 1mm steel beads, as described for Module 1.



## INSTRUCTIONS

Note: Sections 1 through 8 can be done either by a technologist or medical physicist. A medical physicist must do sections 9 through 11. If the first 8 sections are done before you schedule your medical physicist to come in and perform the last sections, then you will need to save your data so you can film all (1 through 11) sections at the same time.

1. Fill out the first two pages of the Phantom Scanning Data Form: This will entail listing information about the CT scanner and the acquisition parameters typically used for several types of clinical scans. These parameters will be used for imaging the phantom and should be consistent with the acquisition parameters used for the clinical exams submitted as part of the accreditation process. If your site does not perform one of the requested exam types, provide the manufacturer-recommended technique and use it for the phantom scans.

### Important definitions:

*z-axis collimation (T)* = the width of the tomographic section along the z-axis imaged by one data channel. In multi-detector row (multi-slice) CT scanners, several detector elements may be grouped together to form one data channel.

*Number of data channels (N)* = the number of tomographic sections imaged in a single axial scan.

*Maximum number of data channels (Nmax)* = the maximum number of tomographic sections for a single axial scan.

*Increment (I)* = the table increment per axial scan or the table increment per rotation of the x-ray tube in a helical scan.

2. Calibrate Scanner: Prior to scanning the ACR CT accreditation phantom, perform tube warm-up and any necessary daily *calibration* scans (air scans, water scans) as recommended by the manufacturer. It is recommended that the site's water phantom be scanned and tested for accuracy of the CT number of water, absence of artifacts, and uniformity across the field of view prior to proceeding.
3. Ensure proper calibration of your laser imager (hard-copy device): Prior to filming any images, a SMPTE test pattern created by the Society of Motion Picture and Television Engineers, should be printed using the appropriate window width (WW) and window level (WL). If you are unfamiliar with this procedure, you should review Gray et al., "Test pattern for video display and hard-copy camera," *Radiology* 145:519- 527 (1985), and then contact your local service engineer for assistance.
  - 3.1 When printed, the 95% density patch within the 100% square and the 5% density patch within the 0% square should be visible, and there should be no notable distortions or artifacts present. If these criteria are not met, contact your service engineer for laser camera calibration before proceeding with any filming.
  - 3.2 It is essential that a video test pattern be included on both films. If a SMPTE pattern is not available on your scanner, print the scanner's own video test pattern. The system manufacturer should be contacted to obtain a SMPTE image for future accreditation testing.
  - 3.3 All images should be recorded on film using the following location map:

### Film Page:

|                                       |        |        |
|---------------------------------------|--------|--------|
| Box 1 - SMPTE<br>(on both film pages) | Box 2  | Box 3  |
| Box 4                                 | Box 5  | Box 6  |
| Box 7                                 | Box 8  | Box 9  |
| Box 10                                | Box 11 | Box 12 |

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This manual has been written to guide the user through the data acquisition and analysis process in a step-by-step fashion. It is essential that scan acquisition parameters match those given in Table 1 (and used clinically). To facilitate this, and to speed data acquisition, use the appropriate clinical protocol as the starting point for all data acquisitions. Otherwise, some important acquisition parameters (such as use of bowtie filters and special image processing) may be overlooked.

### Important notes regarding helical and multi-slice CT (MSCT) systems:

For multi-slice CT scanners, the term  $N_{max}$  will mean the *Maximum* number of axial images able to be acquired simultaneously in one rotation (e.g., the maximum number of data channels along the z-axis). The term  $N$  will refer to the actual number of channels *used* during the acquisition. For a given protocol,  $N$  may be less than or equal to  $N_{max}$ . For single-slice scanners,  $N=N_{max} = 1$ .

In sections 4 – 5, axial images will be requested.

- If the site's clinical protocol is already axial, it should be used without modification.
- If the site's clinical protocol is helical, but axial images are requested (e.g. sections 4.2, 4.6, 5.2, 5.4 and 5.7), the user should choose the axial multi-slice (MS) mode that reconstructs  $N_{max}$  simultaneous axial images per rotation. That is, for a four-data-channel system ( $N_{max}=4$ ), axial scans should be prescribed such that four images are created per tube rotation. The set of  $N_{max}$  images should be positioned such that one of the images is centered at the location requested. Each of the  $N_{max}$  scans should be viewed; however, only the image centered at the location requested is to be filmed for accreditation purposes. (*For the site's regular quality assurance program, each of the  $N_{max}$  images should be evaluated.*) In sections 5.2 and 5.4, only the one axial technique that produces  $N_{max}$  images of a given slice width is to be acquired. That is, for a 5-mm slice width, acquire four axial 5-mm scans.

In sections 9 – 11, CTDI information must be acquired using axial scan acquisitions. In multi-slice CT, CTDI is a function of detector configuration. Thus, it is imperative that the same detector configuration used in a site's helical exam protocol ( $N \cdot T$ , where  $N$  may be less than or equal to  $N_{max}$ ) be used during the axial dose measurements. As some systems do not explicitly note the value of detector configuration, the physicist may need to consult the operator's manual, literature, or manufacturer to determine the correct value of  $N \cdot T$  for a given helical scan protocol.

## 4. Module 1 - Phantom and Scanner Alignment (Boxes 1:2, 1:3)

- 4.1 Pull back the table padding and position the ACR CT accreditation phantom so that it is "HEAD" first into the gantry. (Be sure to choose a patient orientation of "head first" on the scanner.) *Carefully* position the phantom so that the CT scanner's *alignment lights* are accurately positioned over the scribe line corresponding to the center of Module 1 (FOOT END of the phantom). Use the set of alignment lights, internal or external, that are used clinically. On the data form, circle which set of lights was used. Align the phantom in the sagittal, coronal, and axial planes. Zero (or landmark) the table at this point (or be sure to note the table location, as all scans will be acquired in reference to this location). While maintaining careful alignment, secure the phantom using clear tape (Figure 1). Do not use the thick white tape that is embedded with barium, as it may cause streaks in the image.

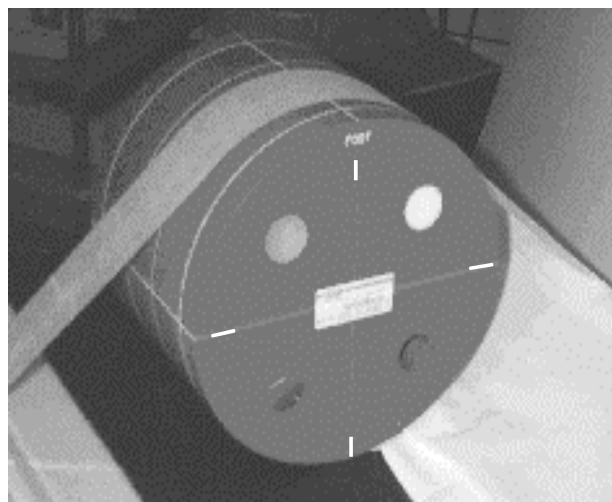


Figure 1

- 4.2 Use your site's high resolution chest technique to acquire a single axial scan at the landmark location (0 or S0), as well as at 1 mm inferior and 1 mm superior (I1 and S1). Even if your site's HRC protocol does not use a scan width of less than 2 mm, you must use a scan width of less than 2 mm for phantom alignment. Use a display field of view (reconstructed image diameter) as close to, but not smaller than, 21 cm.
- 4.3 Examine all three images to determine whether all four BBs are visible in at least one of the images. Use WW = 1000 and WL = 0. In one of the three images, all four BBs should be visible. Additionally, the central wire of the slice width ramps (the center of the group of visible wires that is longer than the rest) should be in the center of the other visible wires ( $\pm 1$  wire) for both the 12 o'clock (top) and 6 o'clock (bottom) ramps (Figure 2).

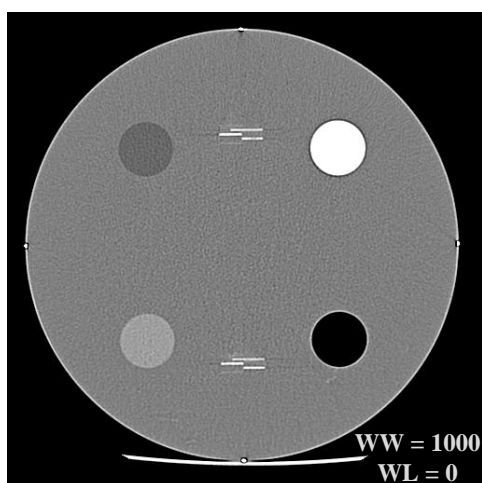


Figure 2: All four BBs are visible *and* the central wires are symmetrically located ( $\pm 1$  wire) in the center of the ramps

- 4.4 If there is at least one image in which all four BBs are visible and the central wires are symmetrically located in the center of the ramps, record PASS for Module 1 BB alignment. Film (Film Page 1, Box 2) the one image in which all four BBs are visible *and* the central wires are symmetrically located in the center of the ramps.
- 4.5 If there is NOT at least one image in which all four BBs are visible *and* the central wires are symmetrically located in the center of the ramps, recheck phantom positioning and repeat steps 4.1 through 4.4. Do not proceed until the criteria of 4.4 are met. If after several attempts at careful phantom positioning the criteria of 4.4 can still not be met, stop testing and ask a field service engineer to check laser alignment and gantry tilt.
- 4.6 Prescribe a scan at the center of Module 4 (S120 or 120 mm superior to the reference location) and repeat the scans from step 4.2 at the new location, as well as 1 mm superior and inferior to the new location (e.g., S119 and S121).
- 4.7 Examine all three images to determine whether all four BBs are visible in at least one of the images. Use WW = 1000 and WL = 0.
- 4.8 If there is at least one image in which all four BBs are visible, record PASS for Module 4 BB Alignment. Film (Film Page 1, Box 3) the one image in which all four BBs are visible.
- 4.9 If there is NOT at least one image in which all four BBs are visible, recheck phantom positioning and repeat steps 4.1 through 4.8. Do not proceed until the criteria of 4.4 and 4.8 are met. If after several attempts at careful phantom positioning the criteria of 4.4 and 4.8 can still not be met, stop testing and ask a field service engineer to check laser alignment, gantry tilt, and table motion accuracy.

## 5. Module 1 - CT Number Calibration and Slice Thickness (Boxes 1:4 to 1:12)

- 5.1 Move the table so that the alignment light is again carefully centered over Module 1. Record the position of the center of Module 1 (SO, reference location, or landmark location). Prescribe an axial single scan (without table increment) at this reference location using the technique factors listed for the Adult Abdomen technique. If your Adult Abdomen protocol is a spiral acquisition, perform an axial scan instead while keeping the remaining technical parameters unchanged. If using a multi-slice CT scanner, choose the axial multi-slice mode that reconstructs Nmax images. The set of Nmax images should be positioned such that one of the images is centered at the location requested. Use a display field of view (reconstructed image diameter) as close to, but not smaller than, 21 cm.
- 5.2 Place a circular region of interest (ROI, approximately 200 mm<sup>2</sup>) within each cylinder (Figure 3) and record the mean CT number for each material on the data sheet. It is important to center the ROIs within each cylinder. The water cylinder is subtly seen as a large gray ring. Be sure to place the water ROI as shown in Figure 3. Film this image (WW = 400, WL = 0), with at least the ROIs over the polyethylene, water, and acrylic cylinders showing, on Film Page 1, Box 4.

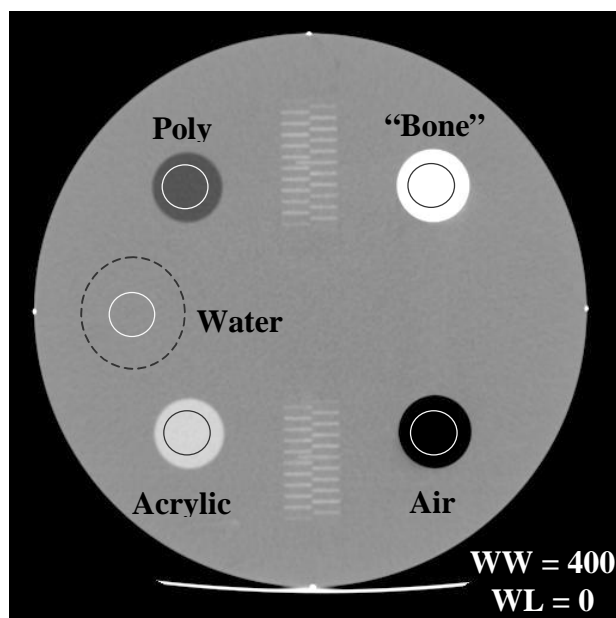


Figure 3. Regions of interest (ROIs) for each material and for the water-equivalent background material.

- 5.3 Repeat the Adult Abdomen axial scan, as above, for the following slice thickness settings (keeping all other parameters the same as those in the Adult Abdomen protocol): *the slice width used for the High Resolution Chest protocol, and the slice widths settings closest to 3, 5, and 7 mm*. Do not rescan the already acquired scan that used the typical slice thickness for your adult abdomen protocol; however, you must refilm the image in the appropriate box. Use a display field of view (reconstructed image diameter) as close to, but not smaller than, 21 cm.
- 5.4 For each image (each additional slice width), place a circular region of interest (ROI, approximately 200 mm<sup>2</sup>) within the water cylinder and record the mean value for water on the data sheet.
- 5.5 Film one image (WW = 400, WL = 0) at each slice thickness with the water ROI shown, beginning on Film Page 1, Box 5 (HRC), Box 6 (~3 mm), Box 7 (~5 mm), and Box 8 (~7mm).
- 5.6 Return to the original scan width and repeat the Adult Abdomen axial scan, as above, for each kVp setting available on the scanner (if possible, keep all other parameters the same as those in the adult abdomen protocol; if the mA, slice thickness, or time for the adult abdomen are unavailable at another kVp, use a parameter as close to

the adult abdomen parameter as possible). Do not repeat the already acquired scan that used the typical kVp for your adult abdomen protocol. Use a display field of view (reconstructed image diameter) as close to, but not smaller than 21 cm.

- 5.7 For each image (each kVp), place a circular region of interest (ROI, approximately 200 mm<sup>2</sup>) within the water cylinder and record the mean value for water on the data sheet. The visible wires are counted and divided by 2 to determine slice width. Slice width should be  $\leq 1.5$  mm of prescribed width. The water CT number should be  $0 \pm 5$ .
- 5.8 Film one image (WW = 400, WL = 0) at each kVp with the water ROI shown (see Figure 3), beginning on Film Page 1, Box 9. Again, the water CT number should be  $0 \pm 5$ .
- 5.9 For the center of Module 1 image, at each slice width scanned, count the number of wires visualized in each of the two slice thickness ramps (Figure 4). Count the number of wires in the top section separately from the number wires in the bottom section. The images should be viewed with a WW = 400 and a WL = 0. Count any wire that appears to be 50% or more as bright as the central wires. For both the top ramp and the bottom ramp, divide the total numbers of wires visualized by 2 and record the resultant *top scan width* and *bottom scan width* (both in mm) on the data sheet.

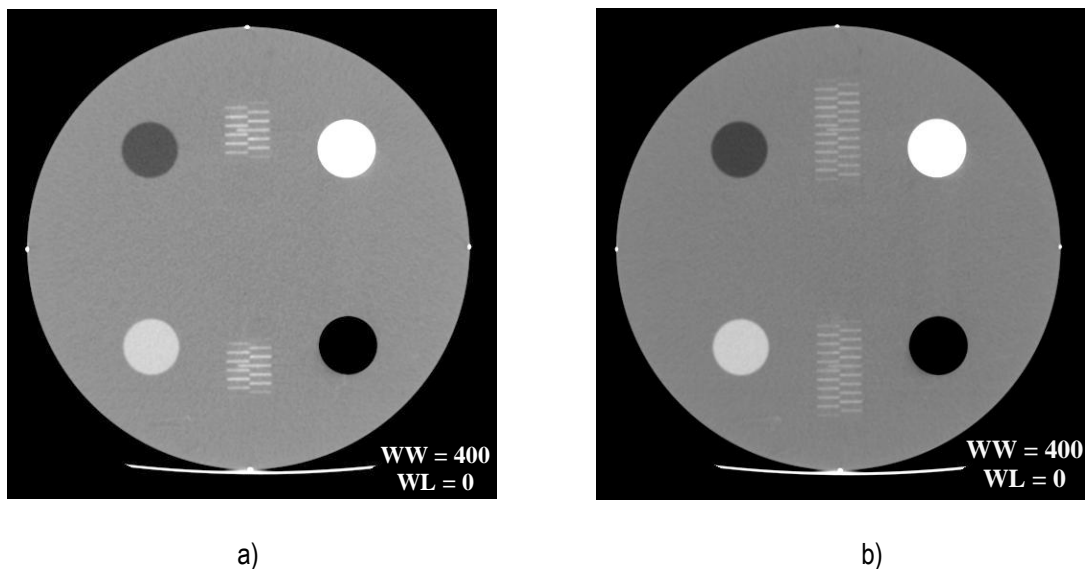


Figure 4 – Module 1 slice thickness wires. Each wire visualized represents 0.5 mm of slice thickness along the z-axis. To determine the total slice width (in mm), count all wires that appears to be 50% or more as bright as the central wires, and divide by 2. Images a) and b) were acquired with a) 5-mm and b) 10-mm scan widths. Be sure to count the number of bars in each ramp (top and bottom) separately. Enter the scan width (in mm) for the top and bottom ramps separately on the data sheet.

## 6. Module 2 - Low Contrast Resolution (Boxes 2:2 to 2:3)

- 6.1 Prescribe a scan using the Adult Abdomen technique. Use a display field of view (reconstructed image diameter) as close to, but not smaller than, 21 cm.
  - 6.1.1 If your Adult Abdomen scan is an axial acquisition, acquire three axial images at the following locations:

Center of Module 2 (S40 or 40 mm superior to the location of the center of Module 1).

Center of Module 3 (S80 or 80 mm superior to the location of the center of Module 1).

Center of Module 4 (S120 or 120 mm superior to the location of the center of Module 1).

The images from Module 3 and 4 will be analyzed in sections 7 and 8.

- 6.1.2 If your Adult Abdomen protocol is a spiral acquisition, perform one spiral scan beginning and ending at the following locations:

Start of scan: Center of Module 2 (S40 or 40 mm superior to the center of Module 1).

End of scan: Center of Module 4 (S120 or 120 mm superior to the center of Module 1).

Regardless of the scan reconstruction interval typically used in your Adult Abdomen spiral protocol, choose a scan reconstruction interval of 5 mm. This will insure that one image is reconstructed at the center of Modules 2, 3, and 4. The images from Module 3 and 4 will be analyzed in sections 7 and 8.

- 6.2 View the image located at the center of Module 2 using a WW = 100 and a WL = 100. Note that there are four cylinders for each of following diameters: 2, 3, 4, 5, and 6 mm (see diagram on Page 3 and Figure 5). Viewing the image on the monitor, with room lights lowered, and determine the cylinder set having the smallest diameter for which all four cylinders are visualized. Record the diameter of these cylinders on the data sheet.

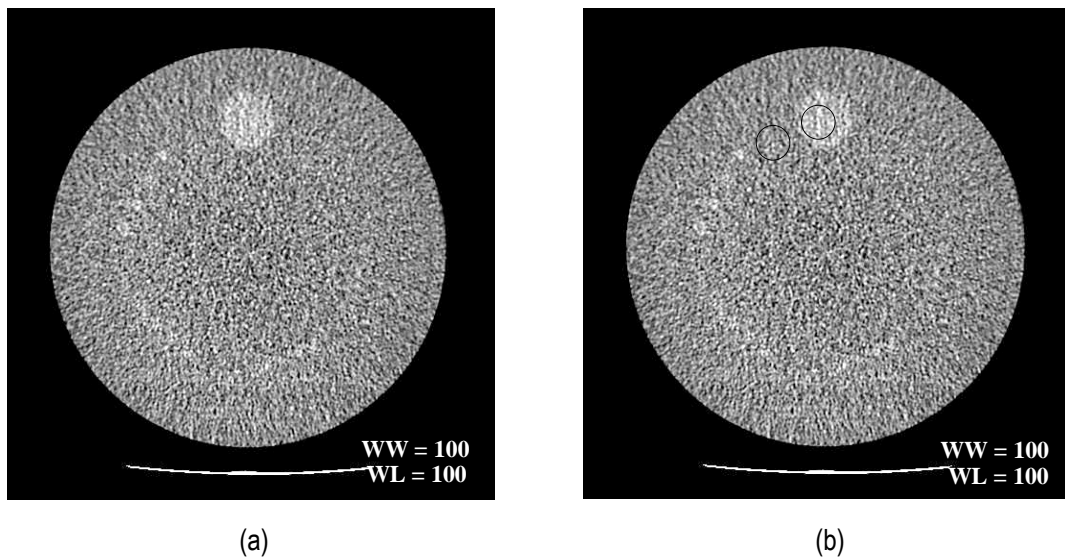


Figure 5 – a) Module 2 low contrast resolution image at WW = 100 and WL = 100. b) The correct ROI placement.

- 6.3 Place a ROI ( $\approx 100 \text{ mm}^2$ ) over the large (25-mm diameter) cylinder and next to the large cylinder (Figure 5b). Record the mean CT number for each ROI and calculate the difference. Film this image with the ROIs showing on Film Page 2, Box 2. All four rods (of a given diameter) must be seen. You should be able to see the 6-mm rod.
- 6.4 Repeat sections 6.1 through 6.3 using your Routine Head (cerebrum) technique. Film the low-contrast resolution image from the center of Module 2 for the Routine Head technique, with the ROIs showing, on Film Page 2, Box 3 (again use a WW = 100 and a WL = 100). All four rods (of a given diameter) must be seen. You should be able to see the 6-mm rod.



## 7. Module 3 - Uniformity and Noise and In-Plane Distance Accuracy (Box 2:4)

- 7.1 View the previously acquired Adult Abdomen image at the center of Module 3 (uniformity image) with a WW = 100 and a WL = 0. Place an ROI of approximately 400 mm<sup>2</sup> at the center of the image and the four edge positions shown in Figure 6. For the edge ROIs, place the center of the ROI approximately one ROI diameter away from the edge. Film this image, showing the center, 6 o'clock, and 12 o'clock ROIs, on Film Page 2, Box 4. Record the mean CT numbers for all five ROIs on the data sheet. Additionally, Record the standard deviation of the center ROI.

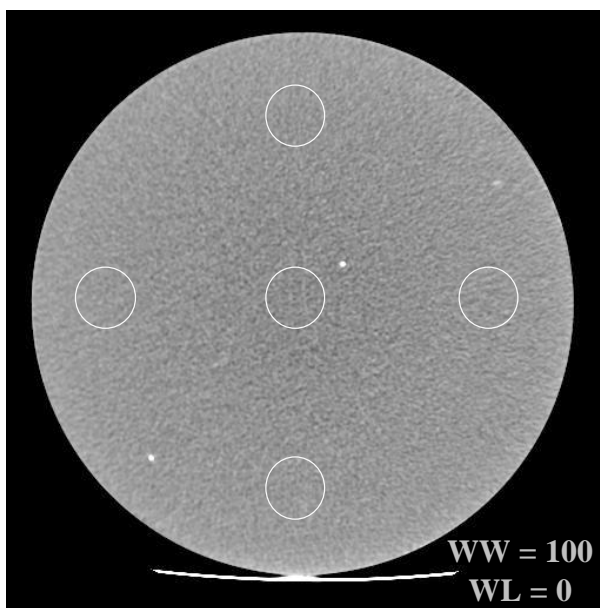


Figure 6 – Placement of uniformity center and edge ROIs.

- 7.2 On the data sheet, calculate and record the uniformity value (the absolute value of [center mean CT # - edge mean CT #]) for the four edge ROIs. Edge-to-center should measure  $\leq 5$  HU. The WW should equal 100 and the WL should equal 0. The center CT number must equal  $0 \pm 5$ .
- 7.3 With all graphics turned off, view the image carefully with the room lighting reduced. Examine the image for artifacts such as rings or streaks and record the presence and appearance of any artifacts on the data sheet. If artifacts are present, a service engineer may be needed to investigate the them.
- ## 8. Module 4 - High-Contrast (Spatial) Resolution (Boxes 2:5 to 2:6)
- 8.1 View the previously acquired Adult Abdomen image at the center of Module 4 (high contrast resolution) using a WW = 100, WL  $\approx$  1100 (the WL value can be adjusted slightly to optimize visualization of the bar patterns). Using Page 5 and Figure 7 as a reference, note the eight bar patterns, which represent spatial frequencies corresponding to: 4, 5, 6, 7, 8, 9, 10, and 12 lp/cm. Carefully view the image with the room light lowered and determine the highest spatial frequency for which the bars and spaces are distinctly visualized. Record the highest spatial frequency that can be visualized on the data sheet and film this image on Film Page 2, Box 5. You should be able to resolve 5 lp/cm. (The 4-lp/cm bar pattern is the easiest to resolve and appears to have the widest bars and widest spaces. The 12-lp/cm bar pattern is the hardest to resolve and, in this image, will likely appear as a uniformly filled square).

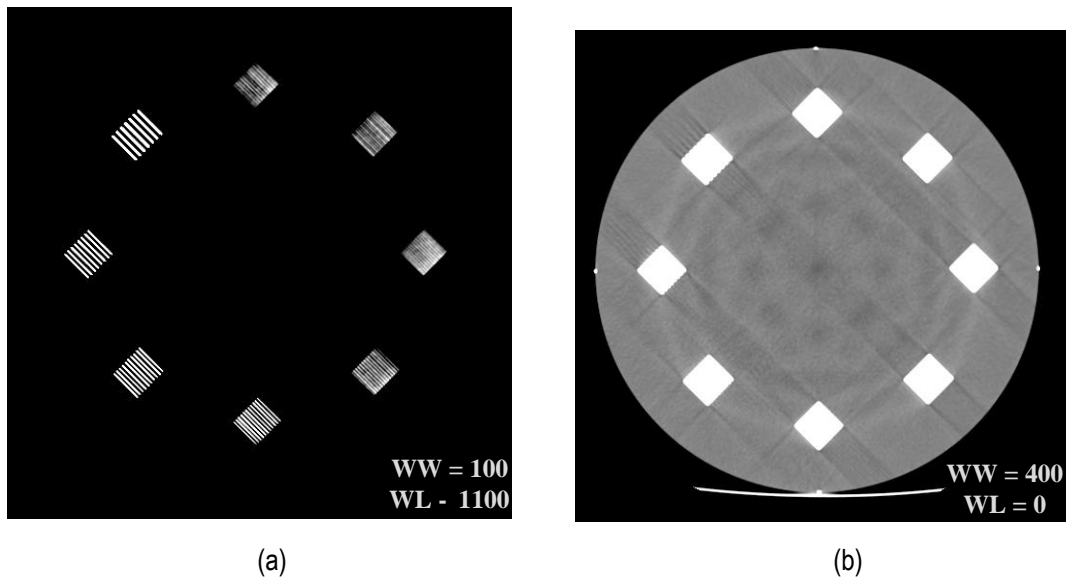


Figure 7 – Module 4- High contrast resolution bar patterns. (a) Correct window and level for determining limiting spatial resolution. (b) Streak artifacts seen at soft-tissue window and level values. These are due to the high attenuation of the aluminum bars and should be ignored for the purpose of this test.

8.2 Acquire one final scan, located at the center of Module 4 (S120 or 120 mm superior to the location of the center of Module 1), using your High Resolution Chest technique. Use a display field of view (reconstructed image diameter) as close to, but not smaller than, 21 cm.

8.2.1 If your standard High Resolution Chest protocol uses axial scans, acquire one axial scan at the center of Module 4.

8.2.2 If your standard High Resolution Chest protocol use spiral scans, acquire a spiral sequence starting and ending at the following locations:

Start location: S115 or 115 mm superior to the location of the center of Module 1.

End location: S125 or 125 mm superior to the location of the center of Module 1.

For the spiral acquisition, choose a reconstruction scan interval of 5.0 mm, such that three images will be reconstructed from the spiral sequence, the middle of which will be at the center of Module 4.

8.3 View the High Resolution Chest image at the center of Module 4 (High Contrast Resolution) using a WW = 100, WL ≈ 1100 (the WL value can be adjusted slightly to optimize visualization of the bar patterns). Carefully view the image with the room light lowered and determine the highest spatial frequency for which the bars and spaces are distinctly visualized. Record the highest spatial frequency that can be visualized on the data sheet and film this image on Film Page 2, Box 6. You should be able to resolve 6 lp/cm.

## 9. Radiation Dosimetry (Head) (Box 2:7)

9.1 This section provides explicit instructions for a medical physicist to measure Head CTDI values.

References for additional reading on dose measurements and calculations for CT include:

Rothenberg and Pentlow, "CT dosimetry and radiation safety," and McCollough and Zink "Performance evaluation of CT systems" In: *Categorical Course in Diagnostic Radiology Physics: CT and US Cross-Sectional Imaging*, Goldman and Fowlkes, eds.. Radiological Society of North America: Oak Brook, IL (2000).

AAPM Reports No. 31 (1990), "Standardized methods for measuring diagnostic x-ray exposure," and No. 39 (1993), "Specification and acceptance testing of CT scanners." American Association of Physicists in Medicine: New York, NY.

McCollough and Schueler, "Calculation of effective dose." *Medical Physics* 27:838-844 (2000).

Kalender et al. "A PC program for estimating organ dose and effective dose values in CT." *European Radiology* 9:555-562 (1999).

European Guidelines on Quality Criteria for Computed Tomography (EUR 16262 EN, May 1999). (available at [www.drs.dk/guidelines/ct/quality/index.htm](http://www.drs.dk/guidelines/ct/quality/index.htm))

Shrimpton and Wall, "Reference doses for paediatric computed tomography." *Radiation Protection and Dosimetry* 90:249-252 (2000).

Jessen et al., "Dosimetry for optimisation of patient protection in computed tomography." *Applied Radiation and Isotopes* 50:165-172 (1999).

Nagel, ed., et al. *Radiation Exposure in Computed Tomography*, 2<sup>nd</sup> ed., COCIR: Hamburg, Germany (2000). (available through [cocir@zvei.org](mailto:cocir@zvei.org))

9.2 Required Materials:

- Calibrated CTDI (pencil) ionization chamber (typically 10 cm in length)
- Calibrated electrometer
- Acrylic (PMMA) cylindrical phantoms (Figure 8), having cylindrical holes (four at 1 cm from the edge and one at the center):
  - Head CTDI phantom: 16-cm diameter, 15-cm length
  - Body CTDI phantom: 32-cm diameter, 15-cm length
- Dose calculation Excel spreadsheet, available at [www.acr.org](http://www.acr.org), under the CT accreditation section
  - If your electrometer measures exposure (R), use the Excel spreadsheet named Dose Calculator (exposure).
  - If your electrometer measures air kerma (mGy), use the Excel spreadsheet named Dose Calculator (air kerma).

All of the calculations in sections 9 – 11 should be made using the appropriate dose calculator Excel spreadsheet available at [www.acr.org](http://www.acr.org). The dose calculator spreadsheet pages MUST be printed and sent in lieu of pages 5 – 7 of the Phantom Scanning Data Form. Be sure that the ACR CT Accreditation Site ID number is noted on each page.

The physicist should record the make, model, and serial number of the electrometer and chamber used for dose measurements, as well as the latest calibration date for the chamber and electrometer. Calibration is required to have occurred within two years of the testing date.

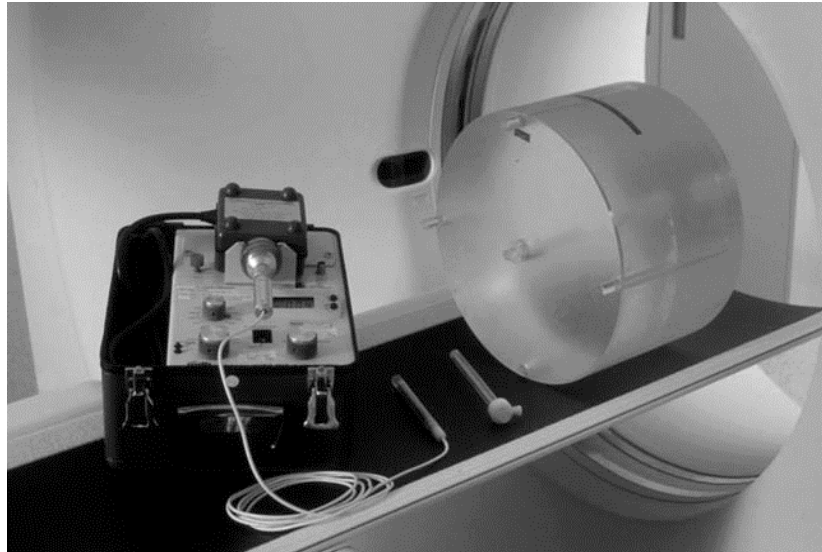


Figure 8: CTDI phantoms, pencil ionization chamber, and electrometer

- 9.3 Position the Head CTDI phantom at scanner isocenter in the head holder. Ensure that the phantom is correctly aligned sagittally, coronally, and axially.
- 9.4 Connect the pencil ionization chamber to your electrometer and insert the pencil chamber into the central hole in the phantom. Ensure that all other holes (those at 3, 6, 9, and 12 o'clock) are filled with acrylic rods.
- 9.5 Acquire one axial scan at the center of the phantom, with no table increment, using the Routine Head (Cerebrum) technique described in Table 1 of the Site Scanning Data Form. If your Routine Head (Cerebrum) technique is a spiral acquisition, perform an axial scan instead, while keeping the remaining technical parameters unchanged. CTDI dose information must be acquired using axial scan acquisitions.

In multi-slice CT, CTDI is a function of detector configuration. Thus, it is imperative that the detector configuration used in the site's clinical protocol ( $N \cdot T$ , where  $N$  may be less than or equal to  $N_{max}$ ) be used during dose measurements. As some systems do not explicitly note the value of detector configuration, the physicist may need to consult the operator's manual, literature, or manufacturer to determine the correct value of  $N \cdot T$  that corresponds to the site's helical scan protocol. (see McCollough and Zink, "Performance evaluation of a multi-slice CT system," *Medical Physics* 26:2223-2230 (1999)).

- 9.6 Record the kVp, mA, exposure time (sec), z-axis collimation ( $T$ , in mm), and number of data channels *used* ( $N$ ).
- 9.7 Record the exposure in mR (or air kerma in mGy) from the scan. Be sure to know the chamber correction factor for your particular combination of electrometer and ionization chamber.
- 9.8 Repeat the above scan two more times and record the measurement from each scan. Film the image from the third exposure on Film Page 2, Box 7 using a WW = 400 and a WL = 100.
- 9.9 Calculate and record the average measurement (exposure or air kerma) for the scan. If the data differ by more than 5%, check your equipment and reacquire the data until the three measurements agree to within 5%.

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9.10 Using that average measured value (exposure or air kerma), calculate CTDI<sub>100</sub>:

$$\text{CTDI}_{100} = f \cdot C \cdot E \cdot L / (N \cdot T)$$

Where  $f$  = conversion factor from exposure to dose in air, use 0.87 rad/R  
(or conversion factor from air kerma to dose in air, use 1.0 mGy/mGy)  
 $C$  = calibration factor for electrometer (typically 1.0, but may be 2.0 for some equipment)  
 $E$  = average measured value (exposure or air kerma)  
 $L$  = active length of pencil ion chamber (typically 100 mm, but 160 mm for some chambers)  
 $N$  = *actual* number of data channels used during one axial acquisition  
( $N_{\text{max}}$  is the *maximum possible* number of data channels used simultaneously in one rotation.  
For multi-slice CT,  $N$  may be less than or equal to  $N_{\text{max}}$  for a given protocol. For single-slice  
scanners,  $N = N_{\text{max}} = 1$ ).  
 $T$  = nominal slice width of one axial image (scan collimation)

### Sample Calculations

Single-slice scanner, 120 kVp, 340 mA, 1-second scan and 10-mm slice thickness

Electrometer measures exposure: 513 mR

$$\text{CTDI}_{100} = (0.87 \text{ rad/R})(1.0)(0.513 \text{ R})(100 \text{ mm}) / [(1) (10 \text{ mm})] = 4.5 \text{ rad} \quad (45 \text{ mGy})$$

Single-slice scanner, 120 kVp, 340 mA, 1-second scan and 10-mm slice thickness

Electrometer measures exposure: 250 mR

Electrometer-chamber correction factor = 2.0 when used in conjunction with a pencil ionization chamber

$$\text{CTDI}_{100} = (0.87 \text{ rad/R})(2.0)(0.250 \text{ R})(100 \text{ mm}) / [(1) (10 \text{ mm})] = 4.4 \text{ rad} \quad (44 \text{ mGy})$$

Single-slice scanner, 120 kVp, 340 mA, 1-second scan and 10-mm slice thickness

Electrometer measures air kerma: 5.0 mGy

$$\text{CTDI}_{100} = (1.0 \text{ mGy/mGy})(1.0)(5.0 \text{ mGy})(100 \text{ mm}) / [(1) (10 \text{ mm})] = 50 \text{ mGy} \quad (5.0 \text{ rad})$$

Multi-slice scanner, 120 kVp, 400 mA, 0.8-second scan and 4 x 2.5 mm

(four 2.5-mm axial scans acquired per 0.8-second exposure)

Electrometer measures exposure: 540 mR

$$\text{CTDI}_{100} = (0.87 \text{ rad/R})(1.0)(0.54 \text{ R})(100 \text{ mm}) / [(4) (2.5 \text{ mm})] = 4.7 \text{ rad} \quad (47 \text{ mGy})$$

*For multi-slice scanners, it is helpful to understand that the value of  $N \cdot T$  represents the total z-axis width (in mm) of the active detector (relative to gantry isocenter). Theoretically, this value should equal the nominal width of the radiation beam (in mm) at isocenter. For example, use of a 4 x 2.5-mm detector configuration yields  $N = 4$  and  $T = 2.5$ , so  $N \cdot T = 10$ . Use the value of  $N \cdot T$  for the CTDI acquisition (which MUST be in the AXIAL mode!), even if the routine protocol is a helical acquisition.*

9.11 Record the resultant value (in mGy) as the CTDI at isocenter in Head phantom.

9.12 Move the pencil chamber from the isocenter position to the 12 o'clock peripheral position. Ensure that an acrylic rod is then inserted into the vacated isocenter position.

9.13 Repeat sections 9.5 through 9.10 and record the resultant value (in mGy) as the CTDI at 12 o'clock in Head phantom.

9.14 Calculate and record (in mGy) CTDI<sub>w</sub>:

$$\text{CTDI}_w = 1/3 \cdot \text{CTDI}_{100,\text{center}} + 2/3 \cdot \text{CTDI}_{100,\text{edge}}$$

Where,  $CTDI_{100,center} = CTDI$  at isocenter in Head phantom

and  $CTDI_{100,edge} = CTDI$  at 12:00 in Head phantom

- 9.15 Using the technical parameters of your routine Head (Cerebrum) protocol (the values of N, T, and I defined in Table 1), calculate and record (in mGy) the Volume CTDI<sub>w</sub> (CTDI<sub>vol</sub>):

$$\text{For axial imaging: } CTDI_{vol} \text{ (mGy)} = CTDI_w \cdot N \cdot T / I$$

$$\text{For spiral imaging: } CTDI_{vol} \text{ (mGy)} = CTDI_w \cdot N \cdot T / I = CTDI_w / P$$

Where P = Pitch.

*It is essential that Pitch be calculated according to the IEC definition, even if the value disagrees with that displayed on the scanner console:*

$$\text{Pitch (P)} = \text{Tablespeed (I, mm/rotation)} / (N \cdot T)$$

- 9.16 Using an assumed total scan length of 17.5 cm, calculate and record (in mGy-cm) the dose-length product (DLP)

$$DLP \text{ (mGy-cm)} = CTDI_{vol} \text{ (mGy)} \cdot \text{total scan length (cm)}$$

- 9.17 Calculate and record (in mSv) the *estimated* Effective Dose (E)

$$E \text{ (mSv)} = k \text{ (mSv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}) \cdot DLP \text{ (mGy-cm)}$$

Where,  $k = 0.0023$  for a head exam

(European Guidelines on Quality Criteria for Computed Tomography, EUR 16262 EN, May 1999)

It is important to note that alternative methods and conversion coefficients exist to calculate Effective Dose. *This is an estimate only, and can differ from other estimates by as much as a factor of 2. This estimate is NOT the dose for any given individual, but rather, for a standardized anthropomorphic phantom, representative of the "whole-body-equivalent" radiation detriment (risk) associated with the "partial-body" CT exam. These values can be used to optimize protocols, and as a broad indication of the relative risk of the CT exam compared to background radiation or exams from other modalities.*

## 10. Radiation Dosimetry (Pediatric Body, 5 years old) (Box 2:8)

- 10.1 This section provides explicit instructions for a medical physicist to measure Pediatric Body CTDI values, assuming a 5-year-old child. If the scanner only performs exams on adult patients, skip this section for that scanner. See section 9.1 for references.
- 10.2 Use the same Required Materials noted in section 9.2.
- 10.3 Remove the table pad and position the Head acrylic phantom at scanner isocenter on the table. Ensure that the phantom is correctly aligned sagittally, coronally, and axially.
- 10.4 Insert the pencil chamber into the central hole in phantom. Ensure that all other holes (those at 3, 6, 9, and 12 o'clock) are filled with acrylic rods.
- 10.5 Acquire one axial scan at the center of the phantom, with no table increment, using the Pediatric Abdomen technique described in Table 1. If your Pediatric Abdomen technique is a spiral acquisition, perform an axial scan instead, while keeping the remaining technical parameters unchanged. CTDI dose information must be acquired using axial scan acquisitions.

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In multi-slice CT, CTDI is a function of detector configuration. Thus, it is imperative that the detector configuration used in the site's clinical protocol ( $N \cdot T$ , where  $N$  may be less than or equal to  $N_{max}$ ) be used during dose measurements. As some systems do not explicitly note the value of detector configuration, the physicist may need to consult the operator's manual, literature, or manufacturer to determine the correct value of  $N \cdot T$  that corresponds to the site's helical scan protocol. (see McCollough and Zink, "Performance evaluation of a multi-slice CT system" *Medical Physics* 26:2223-2230 (1999)).

- 10.6 Record the kVp, mA, exposure time (sec), z-axis collimation ( $T$ , in mm), and number of data channels *used* ( $N$ ).
- 10.7 Record the exposure in mR (or air kerma in mGy) from the scan. Be sure to know the chamber correction factor for your particular combination of electrometer and ionization chamber.
- 10.8 Repeat the above scan two more times and record the measurement from each scan. Film the image from the 3rd exposure on Film Page 2, Box 8 using a WW = 400 and a WL = 100.
- 10.9 Calculate and record the average measurement (exposure or air kerma) for the scan. If the data differ by more than 5%, check your equipment and reacquire the data until the three measurements agree to within 5%.
- 10.10 Using the average measurement (exposure or air kerma) and the same definitions and examples given in section 9.10, calculate  $CTDI_{100}$ .
- 10.11 Record the resultant value (in mGy) as the *CTDI at isocenter in Ped Body phantom*.
- 10.12 Move the pencil chamber from the isocenter position to the 12 o'clock peripheral position. Ensure that an acrylic rod is then inserted into the vacated isocenter position.
- 10.13 Repeat sections 10.5 through 10.10 and record the resultant value (in mGy) as the *CTDI at 12 o'clock in Ped Body phantom*.
- 10.14 Calculate and record (in mGy)  $CTDI_w$  (as in 9.14).
- 10.15 Using the technical parameters of your routine Pediatric Abdomen protocol (the values of  $N$ ,  $T$ , and  $I$  defined in Table 1), calculate and record (in mGy) the Volume  $CTDI_w$  ( $CTDI_{vol}$ ) (as in 9.15).
- 10.16 Using an assumed total scan length of 15 cm, calculate and record (in mGy-cm) the dose-length product (DLP) (as in 9.16).
- 10.17 Calculate and record (in mSv) the estimated Effective Dose ( $E$ ) (as in 9.17), where  $k = 0.0081 \cdot 2.6$  for a 5-year-old abdomen exam.  
(Shrimpton and Wall, *Radiation Protection and Dosimetry* 2000: 90:249-252.)

## 11. Radiation Dosimetry (Adult Body) (Box 2:9)

- 11.1 This section provides explicit instructions for a medical physicist to measure Adult Body CTDI values. See section 9.1 for references.
- 11.2 Use the same Required Materials noted in section 9.2.
- 11.3 Remove the table pad and position the Body acrylic phantom at scanner isocenter on the table. Ensure that the phantom is correctly aligned sagittally, coronally, and axially.
- 11.4 Connect the pencil ionization chamber to your electrometer and insert the pencil chamber into the central hole in phantom. Ensure that all other holes (those at 3, 6, 9, and 12 o'clock) are filled with acrylic rods.

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- 11.5 Acquire one axial scan at the center of the phantom, with no table increment, using the Routine Adult Abdomen technique described in Table 1. If your Routine Adult Abdomen technique is a spiral acquisition, perform an axial scan instead, while keeping the remaining technical parameters unchanged. CTDI dose information must be acquired using axial scan acquisitions.

In multi-slice CT, CTDI is a function of detector configuration. Thus, it is imperative that the detector configuration used in the site's clinical protocol ( $N \cdot T$ , where  $N$  may be less than or equal to  $N_{max}$ ) be used during dose measurements. As some systems do not explicitly note the value of detector configuration, the physicist may need to consult the operator's manual, literature, or manufacturer to determine the correct value of  $N \cdot T$  that corresponds to the site's helical scan protocol. (see McCollough and Zink, "Performance evaluation of a multi-slice CT system" *Medical Physics* 26:2223-2230 (1999)).

- 11.6 Record the kVp, mA, exposure time (sec), z-axis collimation ( $T$ , in mm) and number of data channels *used* ( $N$ ).
- 11.7 Record the exposure in mR (or air kerma in mGy) from the scan. Be sure to know the chamber correction factor for your particular combination of electrometer and ionization chamber.
- 11.8 Repeat the above scan two more times and record the measurement from each scan. Film the image from the third exposure on Film Page 2, Box 9 using a WW = 400 and a WL = 100.
- 11.9 Calculate and record the average measurement (exposure or air kerma) for the scan. If the data differ by more than 5%, check your equipment and reacquire the data until the three measurements agree to within 5%.
- 11.10 Using the average measurement (exposure or air kerma) and the same definitions and examples given in section 9.10, calculate  $CTDI_{100}$ .
- 11.11 Record the resultant value (in mGy) as the *CTDI at isocenter in Body phantom*.
- 11.12 Move the pencil chamber from the isocenter position to the 12 o'clock peripheral position. Ensure that an acrylic rod is then inserted into the vacated isocenter position.
- 11.13 Repeat sections 11.5 through 11.10 and record the resultant value (in mGy) as the *CTDI at 12 o'clock in Body phantom*.
- 11.14 Calculate and record (in mGy)  $CTDI_w$  (as in 9.14).
- 11.15 Using the technical parameters of your routine Adult Abdomen protocol (the values of  $N$ ,  $T$ , and  $I$  defined in Table 1), calculate and record (in mGy) the Volume  $CTDI_w$  ( $CTDI_{vol}$ ) (as in 9.15).
- 11.16 Using an assumed total scan length of 25 cm, calculate and record (in mGy-cm) the dose-length product (DLP) (as in 9.16).
- 11.17 Calculate and record (in mSv) the estimated Effective Dose ( $E$ ) (as in 9.17), where  $k = 0.015$  for an abdomen exam.  
(European Guidelines on Quality Criteria for Computed Tomography, EUR 16262 EN, May 1999)

#### PHANTOM TESTING CHECKLIST:

- ρ Phantom images: one phantom set and Site Scanning Data Form from each scanner being accredited.
- ρ Dose measurements: adult head, adult abdomen, and pediatric abdomen dose calculations from every scanner being accredited.