MODEL L-610
CT PERFORMANCE PHANTOM

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Table of Contents

Overview

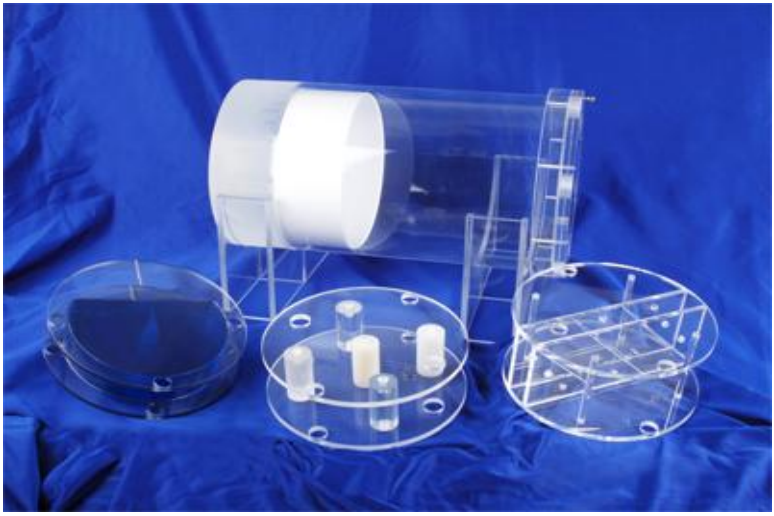
The Ludlum CT Performance Phantom is a modular phantom that provides the user with an efficient method to evaluate the performance of CT scanners. The "one" phantom allows for testing a full range of performance parameters like noise, spatial resolution, low and high contrast, slice thickness, alignment, and linearity. The phantom design is based on the guidelines provided in AAPM (American Association of Physicists in Medicine) Report #1.

The AAPM established a task force on CT scanner phantoms. Its goals were to define CT scanner performance and present practical methods of performance testing through the utilization of special phantoms. The phantom described here is based on the guidelines that were presented in Report #1 of the task force.

The modular CT performance phantom offers the CT user a single system with which to measure nine performance parameters. One phantom does it all. It permits the routine standardization of alignment, beam width, spatial uniformity, linearity/contrast, spatial resolution, line-spread, noise, size independence, and absorbed dose. All components of the phantom are housed in a compact, transparent tank (to be filled with water), which holds the system together in the correct orientation.

The phantom consists of an 21.6-cenitmeter (8.5-inch) diameter, acrylic tank containing a slice thickness insert, a spatial resolution and line-spread block, a CT number calibration insert, and a means for inserting alignment pins and/or TLD holders.

Additionally, a 0.64-centimeter (0.25-inch) thick Teflon band, positioned at the base of the tank and concentric to the 20.3-centimeter (eight-inch) internal diameter, simulates human bone. Attached to the base of tank is a low-contrast section with re-sealable cavities (from 2.5 centimeters [one inch] to 0.32 centimeters [0.13 inch] diameter), which can be filled with a diluted dextrose or other appropriate solution to provide a low-contrast media. An optional external resolution and noise ring slides snugly over the outside diameter of the tank, allowing whole-body scanner systems to be evaluated.



Specifications

Source Tank: 21.6 x 20.3 x 32.4 cm (8.5 x 8 x 12.6 in.) (Outside Dia x Inside Dia x L)

Linearity/Contrast Insert: 19.1 x 6.4 cm (7.5 x 2.5 in.) (Outside Dia x L)

Resolution Insert: 19.1 x 6.4 cm (7.5 x 2.5 in.) (Outside Dia x L)

Beam Width Insert: 19.1 x 8.9 cm (7.5 x 3.5 in.) (Outside Dia x L)

Low Contrast Insert: 21.6 x 9.5 cm (8.5 x 3.8 in.) (Outside Dia x L)

External Whole Body Ring: 30.5 x 21.6 cm (12 x 8.5 in.) Outside Dia x L)

Teflon Band (Bone Ring): 20.3 Inside Dia x 0.64 cm thick (8 x 0.25 in.)

Weight: 7.8 kg (17.3 lb)

General Setup and Filling Procedure

The phantom is shipped partially assembled. However, it may contain packing material that must be removed before filling the systems with water.

- Remove the top cover by unscrewing all the shipping screws.
- Remove the packing materials. Separate the two gate valves, aluminum alignment pin, TLD insert pin, and insert pin mounting plug. Replace the inserts.
- Re-install the cover and make sure the gasket is in place. Tighten all thumbscrews securely by hand.
- The shipment also contains two large plastic gate valves and two plastic pipe plugs, either of which can be used to fill and seal the phantom.

Using the Gate Valves

1. Stand the phantom on end on a level surface. Insert the gate valves located on the cover plate.
2. Hand-tighten until the gaskets are compressed.
3. Open both valves by turning the stem knobs counter-clockwise.
4. Install a water hose on one of the valve cocks. The other valve serves as a vent.
5. Fill the phantom slowly with warm water. The air will be displaced as the water level rises.
6. When all the air is displaced, water will flow out of the vent valve. Turn off water flow.

7. Let the phantom stand for three to four hours to allow dissolved air to disassociate from the water.
8. Add more warm water until all the air in the phantom has been displaced and water flows from the vent valve.

Using the Pipe Plugs

1. Using a funnel or other means, slowly add the warm water through either of the plug ports on the top cover.
2. When completely full, let the phantom stand three to four hours to allow dissolved air to disassociate from the water.
3. Add more water slowly until the phantom overflows and has no more air bubbles.
4. Seal with both pipe plugs. The phantom is now ready for use.

Filling Instructions for Low-Contrast Insert

Make up appropriate solutions of sodium chloride and water, or dextrose and water, to the desired density. Using a screwdriver, remove the plugs in the low-contrast insert. With a syringe, carefully fill each section to the top of the threaded portion of each cavity. With the screwdriver, carefully re-insert the filler plugs, being careful to advance the thread slowly so that no displaced air is trapped.

Performance Measurement Procedures

Beam Alignment and Noise Insert

Perform beam alignment measurements by scanning the aluminum pin, which is mounted axially on the inside of the phantom cover plate. The pin is true to the center of the phantom by 0.011 cm (0.025 inches) and has a run-out of less than 0.007 cm (0.015 inches) over its length.

1. Position the phantom in the scan circle so that it is parallel to the axis of the circle and perpendicular to the circle plane. Use a bubble level to set up these parameters for best results.
2. Position the scanner table so that the center of the pin is in the scan zone.
3. Scan the alignment pin and photograph for medium contrast (window width of 50 to 150).
4. Proper alignment yields a round and true image of the pin. If the CT scanner alignment is incorrect, the pin appears elliptical in shape or produces turning-fork type artifacts.
5. The image of the water surrounding the tank should be uniform and should show no major "streaking" artifacts.

Linearity and Contrast (CT Number) Insert

The CT number insert consists of five pins. Each is 0.45 centimeters (1 inch) in diameter, and of the following materials: Acrylic 1.19, Polystyrene 1.05, Polycarbonate 1.20, Polyethylene 0.95, and Nylon 1.10. [Density (g/cm^3)]

Although only polyethylene is less dense than water, radiographic densities (linear absorbent coefficients) differ greatly. Both polystyrene and polyethylene exhibit CT numbers less than water. Depending on your CT system's computational program and effective beam energy, the CT numbers may vary somewhat from published results.

Position and center the phantom in the scan circle so that it is parallel to the axis of the circle and perpendicular to the circle plane. Scan the insert using the window and level control or the "area of interest" system. Measure the CT scan number of each pin, using at least 25 pixels for the determination.

A typical CT number scale should yield the following results (±1000, ±500 number scale):

Polyethylene	-92 -46
Polystyrene	-24 -12
Water	0 0
Nylon	+92 +46
Polycarbonate	+102 +51
Acrylic	+120 +60

Slice Thickness Insert

The slice thickness insert allows the user to effectively measure both the slice thickness (cut) width and the adjacency of the successive cuts.

1. Position and center the phantom in the scan circle, parallel to the axis of the circle and perpendicular to the circle plane. Scan and image once.

2. Step the scanner table for the next adjacent cut and scan. Image in the frame of Step 3 and process the film.
3. The first image obtained is evaluated by taking the ratio of the film image diameter to that of the phantom's [21.6 cm (8.5 in.)] to obtain a reduction factor.
4. The second frame should display the image of the three aluminum strips with the second cut image adjacent to them. Any excessive separation or overlap indicates the need to adjust the table stepping mechanism.
5. To measure the widths of the aluminum ramps as shown on the image, obtain a CT number and printout of each aluminum ramp.

Spatial Resolution Insert

The high-resolution insert allows the measurement of system resolution on both small and large scan circles. A series of eight holes in Lucite block, ranging from 1.75 mm to 0.40 mm, with a 4.3 mm longitudinal spacing, are filled with air. A straight edge across this block 0.023 cm (0.009 in.), and a diameter stainless steel wire, allows a line-spread function to be calculated directly.

1. Position and center the phantom in the scan circle so that it is parallel to the axis of the circle and perpendicular to the circle plane. The Teflon ring should be positioned over the insert to simulate the beam hardening of bone as encountered in brain studies. The matrix of holes should be aligned to the vertical and horizontal axes.
2. Scan the insert and adjust the level and window width for the best picture, and then image. (Scan circle approximately 30 cm in diameter.)

3. Rotate the phantom so that the resolution hole matrix is at a 45° angle, and then re-scan.
4. Adjust the level and window for the best picture, and then image.
5. Evaluate both images for resolution. Compute the line-spread function if desired.

Contrast Sensitivity

The low-contrast extension block, mounted at the end of the phantom tank, allows the user to evaluate a scanner's ability to detect small differences in density. The cavities drilled in this section range from 2.5 centimeters (1.0 inch) outside diameter to 0.93 centimeter (0.37 inch) outside diameter. The acrylic block has a density of 1.19 gms/cm^3. Solutions of dextrose or NaCl and H_2O, prepared on a weight percent basis and differing by 1%, 2%, or 3% from the acrylic density, should be used to fill these cavities. Low-contrast detectability is easily determined by using solutions whose densities differ by a known percentage in adjacent cavities in the test block.

1. Position the low-contrast extension block in the scan circle so that it is parallel to the axis of the circle and perpendicular to the circle plane, and so the scan zone is over the center of the block.
2. Scan the block. Adjust the level and window setting for the best image, and then photograph.
3. Using the "region of interest" program, or the window and level, evaluate the cavities for CT number value as a function of cavity diameter. The smallest cavity set with visibly different CT numbers defines the limit of low-contrast detectability.

Noise Ring (Uniformity) Insert

The whole-body annulus allows resolution and noise measurements to be performed on whole-body scanners. The 30.5 x 21.6 cm (12 x 8.5 in.) (Outside Dia x Inside Dia) ring is designed to slip over the phantom tank so that the scan circle is filled. By positioning the ring over any of the internal or external sections, all performance parameters may be measured.

1. Position and center the CT phantom in the scan circle that is parallel to the axis of the circle and perpendicular to the circle plane.
2. Place the noise ring over the phantom and position it so that it rests over the inner high-resolution insert. Both inner and outer-hole patterns should be perpendicular to the table plane. Scan and adjust window and level settings for optimum image, and then image.
3. Evaluate both inner and outer-resolution patterns on the film. Evaluate MTF from the inner insert.
4. Rotate both the phantom and the noise ring so that the hole patterns are at a 45° angle. Scan and image. Note any difference in the resolution capability between the images (i.e., parallel to or angulated to the pixel matrix).
5. The image of the two-hole patterns should be uniform in size. The relative noise level in the noise ring and internal tank water should be the same.

General Notes

The 0.023 cm (0.009 in.) stainless steel wire used for line-spread functions can loosen due to vibrations during transit and use. To tighten, use an Allen wrench to loosen one of the set screws, securing the wire in the cover plates. Squeeze the two plates together, grasp the wire with a pair of needle-nosed pliers, and draw tight. Retighten the set screw and then release the pressure on the two plates.

The Teflon ring may be positioned over any of the internal inserts to harden the beam, simulating a clinical condition. The ring has been machined to slide easily over any of the internal inserts throughout the phantom.

CT Relevant Data Selected Tissues and Tissue Substitutes

Material or Tissue	Gm/cc	Elec/gm X10E-23	Elec/cc. X10E-23	Elec/cc Relative
Air	0.0010	3.0060	0.0030	0.0009
Lung Equivalent	0.2400	3.2860	0.7886	0.2359
Fat	0.9160	3.3400	3.0594	0.9151
Polyethylene (C2H4)	0.9500	3.3400	3.1730	0.9491
Water (H_2O)	1.0000	3.3433	3.3433	1.0000
Polystyrene (C8H8)	1.1100	3.2430	3.5997	1.0767
Plastic Water	1.0300	3.3343	3.4343	1.0272
Soft Tissue	1.0400	3.4200	3.5568	1.0639
Nylon (C6H11N0)	1.1500	3.3200	3.8180	1.1420
Polycarbonate (C16H14O3)	1.1900	3.1770	3.7806	1.1308
Acrylic (C5H8O2)	1.1800	3.2480	3.8326	1.1464
Bakelite (C43H38O7)	1.2500	3.1790	3.9738	1.1886
Carbon	2.2500	3.0080	6.7680	2.0243
Teflon (C2F4))	2.2140	3.0110	6.6664	1.9939
Magnesium	1.7380	2.9905	5.1975	1.5546
Bone (Compact)	1.8500	3.1920	5.9052	1.7663
Bone Equivalent	1.9330	3.0800	5.9536	1.7808
Aluminum	2.6990	2.0920	7.8325	2.3427

Table continued on the next page.

F Ratios

Material/ Tissue	60 keV	65 keV	70 keV	75 keV	80 keV	100 keV
Air	0.9033	0.9028	0.9023	0.9017	0.9011	0.8927
Lung Equivalent	0.9033	0.9028	0.9023	0.9017	0.9011	0.8927
Fat	0.9603	0.9668	0.9743	0.9771	0.9806	0.9871
Polyethylene (C2H4)	0.9550	0.9668	0.9800	0.9829	0.9924	1.0010
Water (H_2O)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Polystyrene (C8H8)	0.9057	0.9200	0.9270	0.9347	0.9429	0.9502
Plastic Water	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Soft Tissue	0.9962	0.9955	0.9930	0.9926	0.9923	0.9915
Nylon (C6H11N0)	0.9365	0.9472	0.9537	0.9556	0.9619	0.9702
Polycarbonate (C16H14O3)	0.9061	0.9129	0.9197	0.9220	0.9239	0.9302
Acrylic (C5H8O2)	0.9291	0.9343	0.9395	0.9447	0.9500	0.9608
Bakelite (C43H38O7)	0.9049	0.9126	0.9202	0.9234	0.9261	0.9384
Carbon	0.8495	0.8593	0.8657	0.8700	0.8750	0.8850
Teflon	0.9117	0.9071	0.8983	0.8935	0.8927	0.8808
Magnesium	1.2475	1.1809	1.1295	1.0904	1.0598	0.9906
Bone (Compact)	1.5088	1.4016	1.3219	1.2565	1.2045	1.0869
Bone Equivalent	1.5088	1.4016	1.3219	1.2565	1.2045	1.0869
Aluminum	1.3520	1.2637	1.1975	1.1466	1.1031	1.0000

Table continued on the next page.

Expected CT Numbers

Material/ Tissue	60 keV	65 keV	70 keV	75 keV	80 keV	100 keV
Air	-999	-999	-999	-999	-999	-999
Lung Equivalent	-783	-783	-783	-784	-784	-786
Fat	-120	-114	-108	-105	-102	-96
Polyethylene (C2H4)	-93	-82	-69	-66	-57	-49
Water (H_2O)	0	0	0	0	0	0
Polystyrene (C8H8)	5	21	29	38	47	55
Plastic Water	30	30	30	30	30	30
Soft Tissue	36	35	33	32	32	31
Nylon (C6H11N0)	77	89	97	99	106	116
Polycarbonate (C16H14O3)	78	86	94	97	99	107
Acrylic (C5H8O2)	96	102	109	115	121	134
Bakelite (C43H38O7)	131	141	150	154	158	173
Carbon	911	933	948	958	969	991
Teflon (C2F4))	1019	1008	989	978	976	950
Magnesium	1168	1052	963	895	842	722
Bone (Compact)	1791	1593	1446	1324	1228	1011
Bone Equivalent	1916	1709	1555	1429	1328	1101
Aluminum	2649	2411	2232	2095	1977	1699