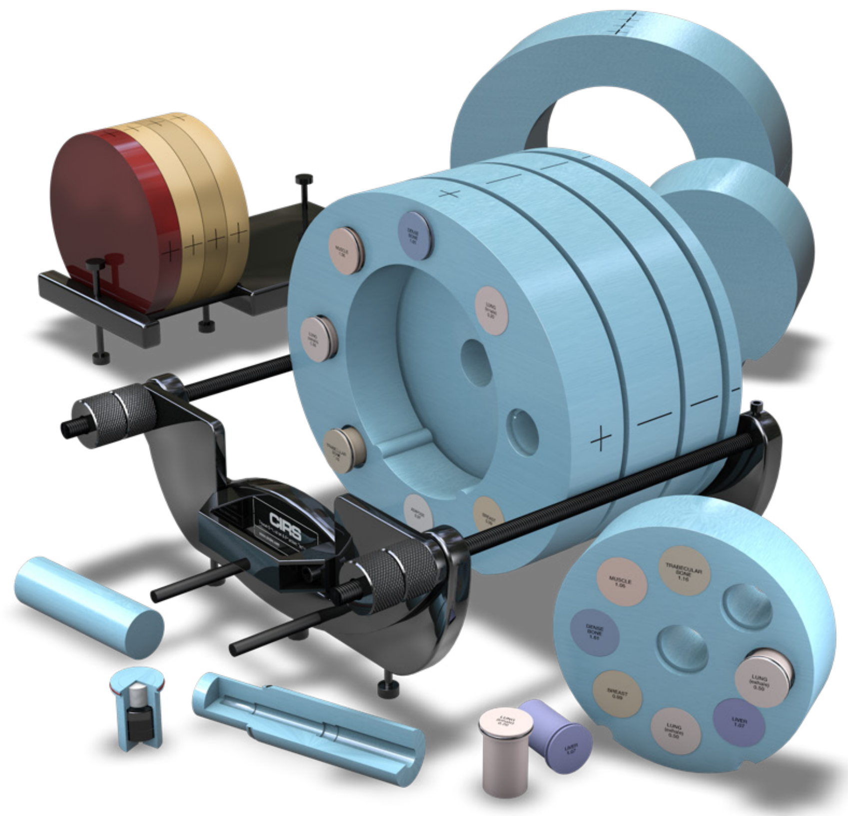
CBCT Electron Density & Image Quality Phantom System

Model 062M, 062MA & 062MQA



USER GUIDE

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CBCT ELECTRON DENSITY & IMAGE QUALITY PHANTOM SYSTEM

The CBCT Electron Density & Image Quality Phantom System integrates three phantoms in one highly functional and ergonomic package. The phantom system can be configured as:

Model 062M Electron Density Phantom

Model 062MA CBCT Electron Density Phantom

Model 062QA-35 Image Quality Phantom

Model 062MQA CBCT Electron Density and Image Quality Phantom

The "M" within the model numbers stands for "modular" and is used to suggest that any of these phantoms can be used separately or in combination with extra parts to form a different phantom.

Model 062M Electron Density Phantom configuration is composed of Head and Body Electron Density sections and tissue-equivalent electron density plugs.

Model 062MA CBCT Electron Density Phantom configuration is an extended version of the CIRS Model 062M Electron Density Phantom specially designed for Cone Beam kV and MV CT imaging systems. It was designed in collaboration with Dr. Peter H. Cossmann, PhD to provide a reliable tool for CT number to electron density calibration in volumetric imaging. Reliable CT electron density calibration curves help enable treatment plan adaptation directly from Cone Beam CT (CBCT) data. The phantom can also accommodate any ion chamber for dose measurements and validation of heterogeneity correction based on the corrected CT calibration curve.

Model 062MQA CBCT Electron Density & Image Quality Phantom configuration adds the Model 062QA-35 Image Quality Phantom to the 062MA CBCT Electron Density Phantom configuration. The Image Quality Phantom presents a series of features designed to perform the entire set of Image QA tests for Computed Tomography recommended in Report #1 of the Task Group as approved by the American Association of Physicists in medicine. This phantom is also compliant with TG-142 (Table VI) Report: QA of Medical Accelerators.

The size of the 062MA and 062MQA covers geometries for imager dimensions of up to 40 cm X 40 cm. They are made of Plastic Water®-LR (15 keV - 8 MeV) and contains a set of tissue equivalent electron density plugs for calibration. Additional interchangeable slabs along with the phantom's support system allow for off axis repositioning of the Electron Density section and CBCT Image Quality Phantom with an increment of 1.25 cm.

While the design intent of the both the Model 062MA and 062MQA is to account for the specific geometry of volumetric imaging equipment, these configurations are also suitable for axial/helical CT equipment and provides the user with an imaging volume that closely resembles an average male torso.

REFERENCES:

PH Cossmann, A Stuessi, C von Briel, Characterisation of a Linac Cone-Beam-CT Option: What Is the Future Potential for Treatment Planning? SU-GG-T-536, Medical Physics, Vol. 35, No. 6, June 2008.

PH Cossmann, U Gneveckow, C von Briel Characterisation of a Linac Cone-Beam-CT Option: What Is the Future Potential for Treatment Planning? SSK17-04, RSNA Scientific Assembly and Annual Meeting Program 2008, p. 546.

PH Cossmann, U. Gneveckow Characterisation of a Linac Cone-Beam-CT Option: What Is the Future Potential for Treatment Planning? Medical Physics (submitted).

PH Cossmann, V. Varchena A novel phantom design for the electron density calibration of a linac CBCT option, Zeitschrift fuer Medizinische Physik (submitted).

ICRU Report No.44, January 1989, p.22.

TABLE OF CONTENTS

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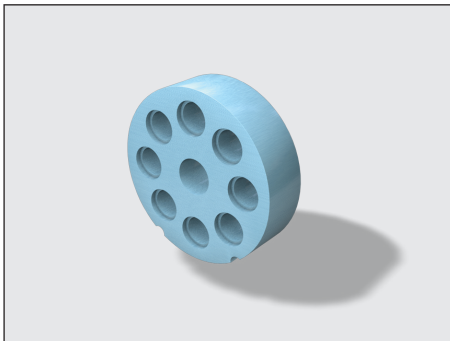
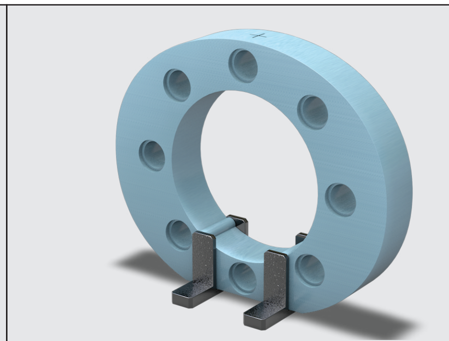
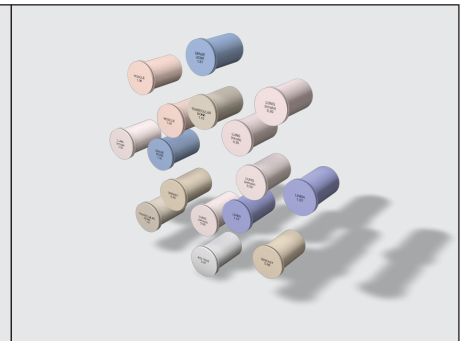
STANDARD SYSTEM COMPONENTS



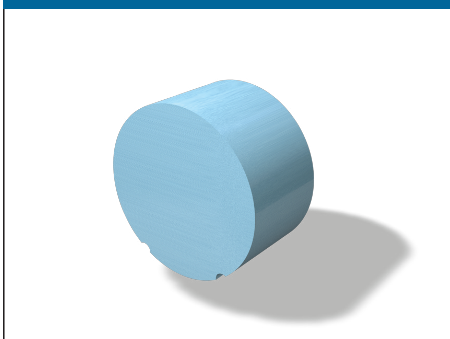
1 Electron Density Phantom Head Insert 062MA-01



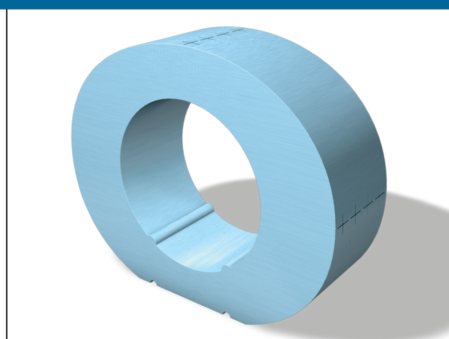
2 Electron Density Phantom Body w/feet 062MA-02



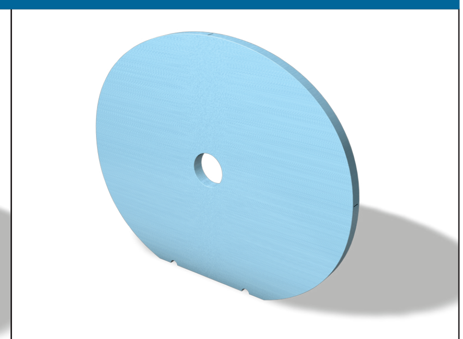
3 Electron Density Phantom Plugs



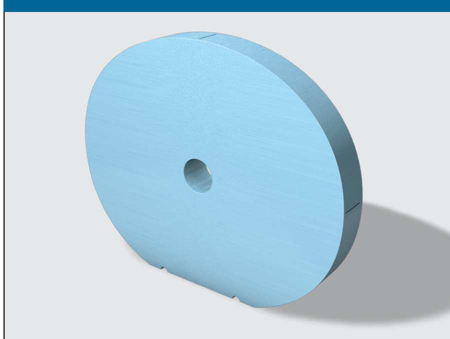
4 CBCT Electron Density Phantom Annulus Insert (100 mm thick) 062MA-37



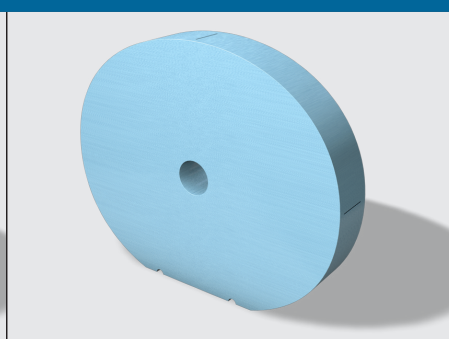
5 CBCT Electron Density Phantom Annulus (100 mm thick) 062MA-36



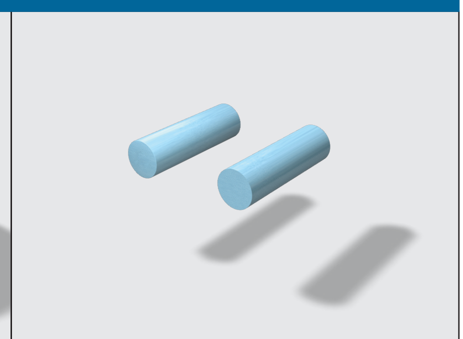
6 CBCT Electron Density Phantom Bolus Section (12.5 mm thick) 062MA-33



7 CBCT Electron Density Phantom Bolus Section (37.5 mm thick) 062MA-34

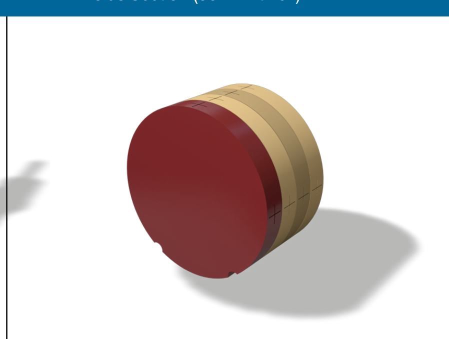


8 CBCT Electron Density Phantom Bolus Section (50 mm thick) 062MA-24

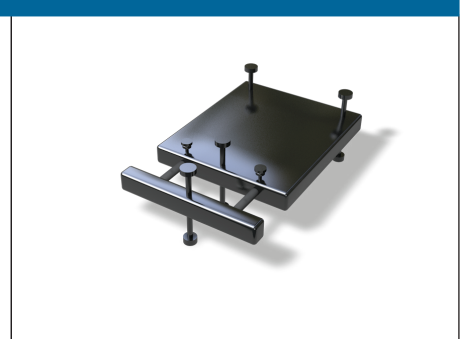


9 Background Insert (2 Units) 062MA-32

10 062MA & 062MQA Holder & Stand 062MA-30

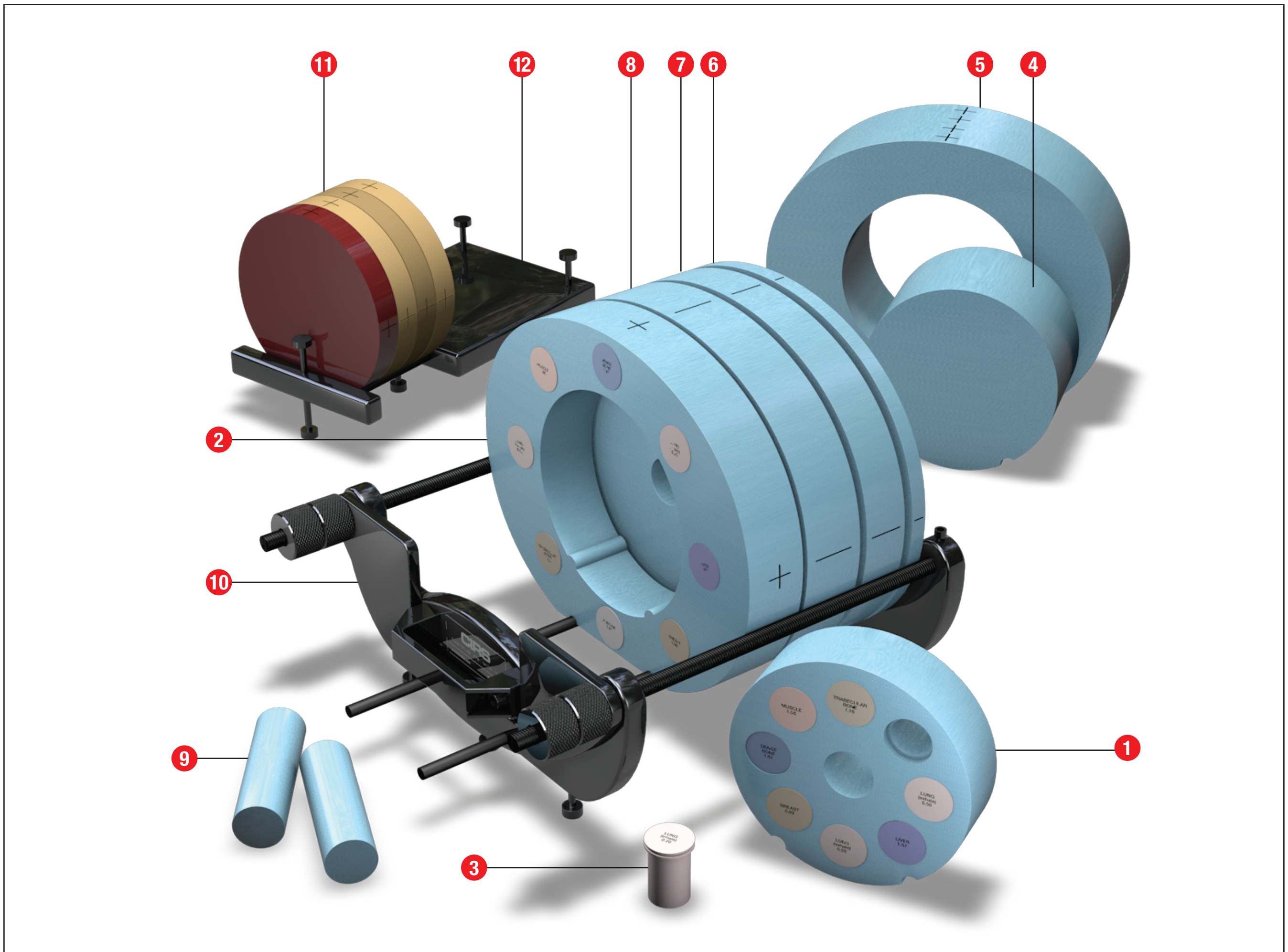


11 CT Image Quality Phantom 062MQA-50

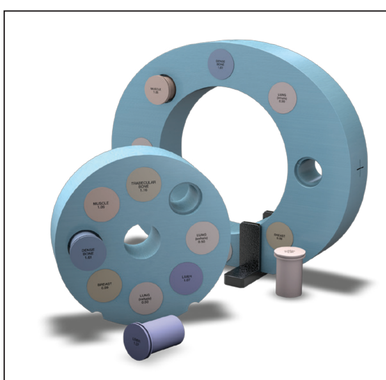


12 CT Image Quality Phantom Holder & Stand 062MQA-30

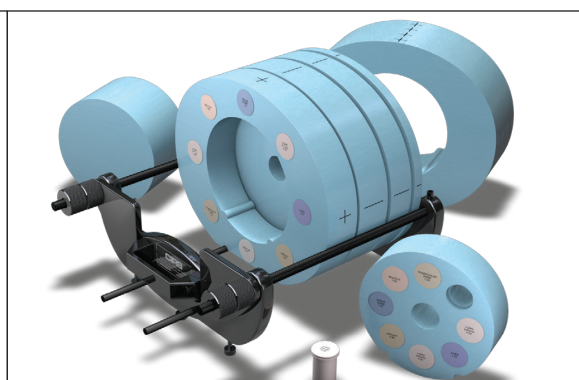
SYSTEM CONFIGURATIONS



CBCT ELECTRON DENSITY AND IMAGE QUALITY PHANTOM
Model 062MQA
Components 1-12



ELECTRON DENSITY PHANTOM
Model 062M
Components 1-3



CBCT ELECTRON DENSITY PHANTOM
Model 062MA
Components 1-10

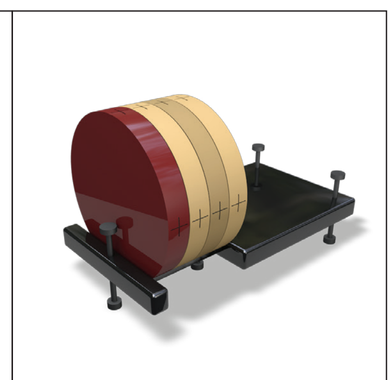
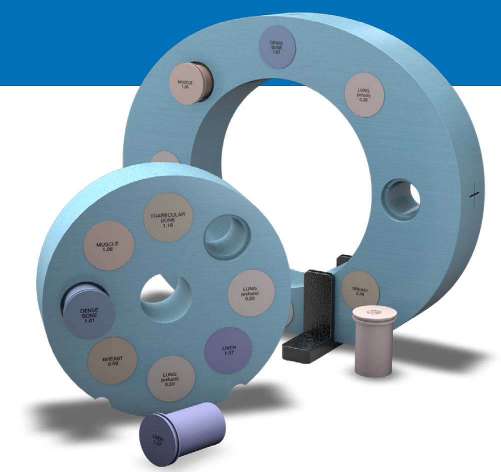


IMAGE QUALITY PHANTOM
Model 062QA-35
Components 11-12

ELECTRON DENSITY PHANTOM
MODEL 062M



The Electron Density Phantom, Model 062M, is used to account for tissue heterogeneity in radiotherapy treatment planning. The phantom is used with a CT scanner to provide precise correlation between electron density of tissues and their CT number in Hounsfield units (HU).

The Model 062M consists of 2 nested disks made from Plastic Water®-LR. They can represent both head and abdomen configurations. Nine different tissue equivalent electron density plugs can be positioned at 17 different locations within the scan field. Included is a water vial plug that can be filled with any fluid. Optional distance marker plugs enable quick assessment of the CT scanner's distance measurement accuracy.

FEATURES:

- **Evaluate CT scan data**
- **Correct for inhomogeneities**
- **Document relationship between CT number and tissue electron density**
- **Simulate indicated tissue within the diagnostic and therapeutic energy range**
- **Quick assessment of distance registration (optional)**

SPECIFICATIONS MODEL 062M - TABLE 1

OVERALL DIMENSIONS:	Electron Density Head Insert: Ø 180 mm x 50 mm (Ø x D) Electron Density Body without Head Insert: 330 mm x 270 mm x 50 mm (W x H x D) Electron Density Plugs: Ø 30 mm X 50mm (Ø X L)
WEIGHT:	Electron Density Head Insert: ≈ 0.950 kg (2 lb) Electron Density Body without Head Insert: ≈ 2.1 kg (4.7 lb)
MATERIALS:	Water and Tissue Equivalent Epoxy Resins

QTY	PART NO.	DESCRIPTION	*PHYSICAL DENSITY, g/cc	ELECTRON DENSITY, x 10^{23} electrons/cc	RED (RELATIVE TO H_2O)
1	062MA-01	Electron Density Head Insert	1.029	3.333	0.998
1	062MA-02	Electron Density Body without Head Insert	1.029	3.333	0.998
2	062A-04	Lung (Inhale) Equivalent Electron Density Plug	0.205	0.668	0.200
2	062A-05	Lung (Exhale) Equivalent Electron Density Plug	0.507	1.658	0.496
2	062A-06	Breast (50% Gland / 50% Adipose) Equivalent Electron Density Plug	0.99	3.261	0.976
2	062A-08	Solid Trabecular Bone (200 mg/cc HA) Equivalent Electron Density Plug	1.16	3.730	1.117
2	062A-09	Liver Equivalent Electron Density Plug	1.07	3.516	1.052
2	062A-10	Muscle Equivalent Electron Density Plug	1.06	3.483	1.043
2	062A-11	Adipose Equivalent Electron Density Plug	0.96	3.171	0.949
2	062A-15	Solid Dense Bone (800 mg/cc HA) Equivalent Electron Density Plug	1.53	4.862	1.456
1	062A-27	Solid Dense Bone (1250 mg/cc HA) Equivalent Electron Density Plug	1.82	5.663	1.695
1	062MA-39	Water-fillable Electron Density Plug, Ø 1" removable vial inside (Real water data provided)	1.00	3.340	1.000
1	062M-30	Set of 2 Feet for Model 062M			
1	062M-40	Soft Carry Case for Model 062M			

* Physical Density - The actual physical density of the insert can vary within ± 1% of the manufacturing target density.
Note: CIRS strongly recommends that the user inputs the electron density whenever prompted for material data by the TPS.

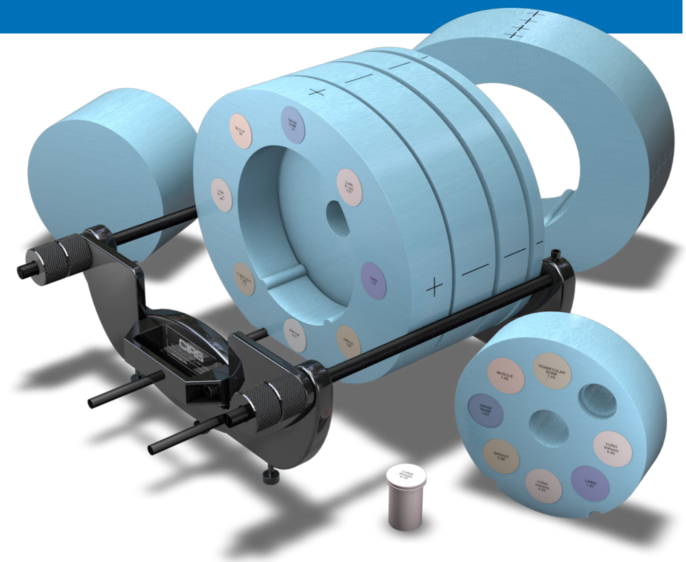
OVERVIEW & SPECIFICATIONS

CBCT ELECTRON DENSITY PHANTOM
MODEL 062MA

The Cone Beam (CBCT) Electron Density Phantom is an extended version of the CIRS Model 062M Electron Density Phantom specifically designed for Cone Beam CT Imaging systems. Preliminary data shows that there may be differences between the HU readings for Diagnostic CT and Cone Beam CT. The geometry of the Cone Beam CT requires additional material and suggests that off central axis measurements should be taken.

The phantom is a valuable tool for CT number to electron density calibration in volumetric imaging. Reliable CT calibration curves help enable treatment plan adaptation directly from Cone Beam CT data. Additionally, the phantom can accommodate any ion chamber for dose measurements and validation of tissue heterogeneity correction based on the corrected CT calibration curve.

The Model 062MA CBCT Electron Density Phantom's size covers geometries for imagers with dimensions up to 40 cm x 40 cm. It is made of Plastic Water®-LR and contains the same set of tissue equivalent electron density inserts as the standard Model 062M. Additional interchangeable slabs allow for repositioning of the electron density section off axis.



FEATURES:

- **Evaluate CT scan data**
- **Correct for inhomogeneities**
- **Document relationship between CT number and tissue electron density**
- **Simulate indicated tissue within the diagnostic and therapeutic energy range**
- **Quick assessment of distance registration (optional)**

SPECIFICATIONS **MODEL 062MA - TABLE 2**

OVERALL DIMENSIONS:	330 mm x 270 mm x 250 mm (W x H x D)
WEIGHT:	≈ 18 kg (40 lb)
MATERIALS:	Water and Tissue Equivalent Epoxy Resins

QTY	PART NO.	DESCRIPTION	*PHYSICAL DENSITY, g/cc	ELECTRON DENSITY, x 10^{23} electrons/cc	RED (RELATIVE TO H_2O)
1	062M	Electron Density Phantom - All standard parts (Table 1)			
1	062MA-24	50 mm Thick Bolus Slab	1.029	3.333	0.998
1	062MA-33	12.5 mm Thick Bolus Slab	1.029	3.333	0.998
1	062MA-34	37.5 mm Thick Bolus Slab	1.029	3.333	0.998
1	062MA-36	CBCT Electron Density Phantom - Annulus (100 mm Thick)	1.029	3.333	0.998
1	062MA-37	CBCT Electron Density Phantom - Annulus Solid insert (100 mm Thick)	1.029	3.333	0.998
2	062MA-32	100 mm L x Ø 30 mm Background Equivalent Plug	1.029	3.333	0.998
1	062MA-30	Holder/Support set for Model 062MA & 062MQA			
1	062MA-40	Soft Carry Case for Model 062MA			

* Physical Density - The actual physical density of the insert can vary within ± 1% of the manufacturing target density.
Note: CIRS strongly recommends that the user inputs the electron density whenever prompted for material data by the TPS.

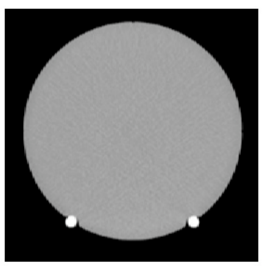
CBCT IMAGE QUALITY PHANTOM
MODEL 062QA-35

The purpose of image quality measurements is to quantify various image quality indicators for 3D images taken from a selection of image acquisition and reconstruction settings representative of clinical practices. Assessment of the image quality parameters over time can show trends in variation of said parameters helping the user to decide whether or not recalibrations of the imaging system are necessary.

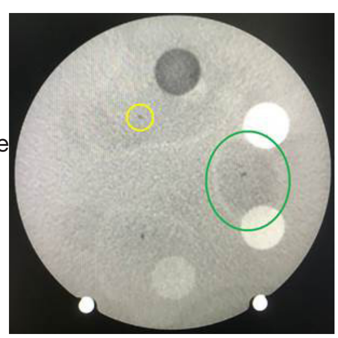
The Image Quality Phantom (062MQA-50) is composed of four layers: Uniformity, Low Contrast/Magnification, CT Number Linearity/Slice Thickness, and Spatial resolution.

UNIFORMITY LAYER

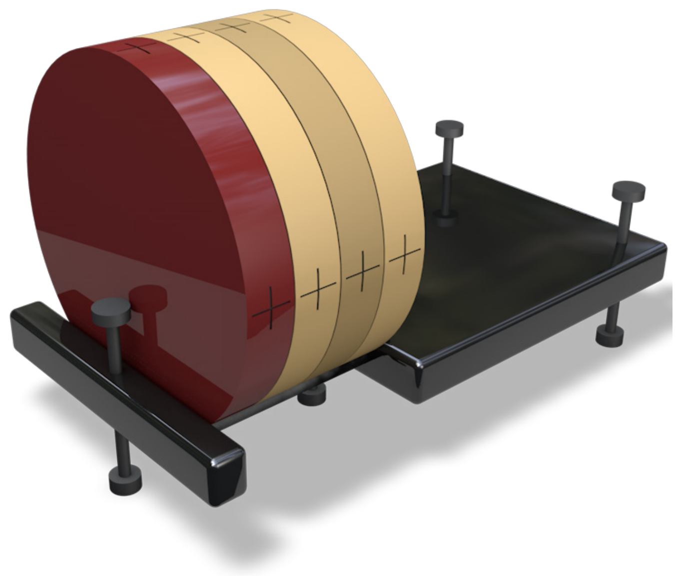
The Uniformity Layer is designed to measure the system's ability to produce uniform images across the field of view of an object with highly homogeneous physical properties in all directions.



BACKGROUND:	Plastic Water®-LR
DIMENSIONS:	Ø 180 mm x 25 mm thickness

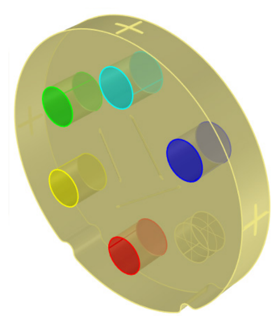


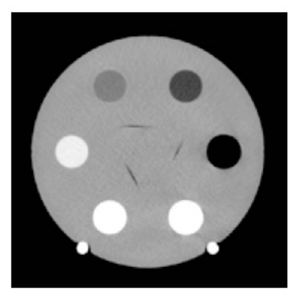
Note: Irregularities may be present when imaging the interface between phantom layers, as shown by the green and yellow circles in the image to the right. These irregularities are caused by coatings that protect air cavities and other imaging features from infiltration of the background material during fabrication. The coatings do not affect the performance of the phantom, as their radiation attenuation is closely matched to that of the bulk background. Furthermore, the imaging irregularities are isolated to the layer interface, where it is not recommended to take measurements.



CT NUMBER LINEARITY/SLICE THICKNESS LAYER

The CT Number Linearity and Slice Thickness Layer is designed to determine Contrast-to-Noise Ratio, CT Number consistency over time and Slice Thickness. Five rods made of Low-Density Polyethylene (LDPE), Polystyrene, Acrylic, Delrin and Teflon and a cylindrical air pocket (25.4 mm diameter x 15 mm length) are used to measure the CNR and HU. Three angled air channels placed within the middle of the layer, which are arranged in an equilateral triangle, are used to assess the Slice Thickness.





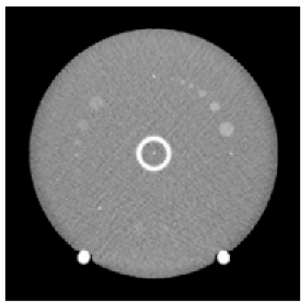
BACKGROUND:	Plastic Water®-LR
CT NUMBER LINEARITY:	Five ø 25.4 mm (1") x 25mm long rods made of: • Low-Density Polyethylene (LDPE) • Polystyrene • Acrylic • Delrin • Teflon Cylindrical air pocket ø 25.4 (1") mm diameter x 15 mm long
SLICE THICKNESS:	Three Ø 0.8 mm x 73.1 mm long air channel ramps placed at 20° with respect to the transversal plane arranged in an equilateral triangle
DIMENSIONS:	Ø 180 mm x 25 mm thickness

CBCT IMAGE QUALITY PHANTOM
MODEL 062QA-35

LOW CONTRAST/MAGNIFICATION LAYER

The Low Contrast Layer assesses the system's ability to detect small differences in contrast. It contains three sets of low contrast rods with linear attenuation differences of 0.5%, 1% and 2% relative to the background material. The diameters of the low contrast rods were chosen so as to provide a 0.5 ratio between two adjacent rods by cross section and volume.

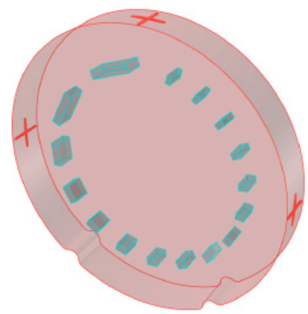
Additional layer features evaluate the magnification on the orthogonal axes of the transversal image and provide input for calculation of Point Spread Function and subsequent calculation of Modulation Transfer Function.

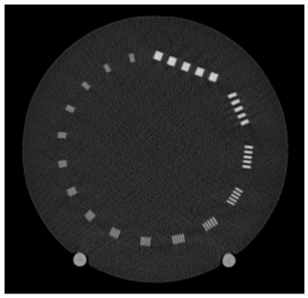


BACKGROUND:	Plastic Water®-LR
LOW CONTRAST:	3 sets of targets Ø 10, 7, 5, 3.5, 2.5, 1.8, 1.2 mm x 25 mm long with attenuation differences of 0.5%, 1% and 2% relative to the background
MAGNIFICATION:	Four Ø 0.050 mm x 25 mm long Tungsten wires which show on slices as four points, one at the center and three on a circle R55 mm at 0°, 90° and 225° or 0°, 135° and 270° (depending on scan orientation) going clockwise starting at 12 o'clock.
ALIGNMENT:	Ø Exterior 25.4 mm (1") x 25 mm long Delrin tube
DIMENSIONS:	Ø 180 mm x 25 mm thickness

SPATIAL RESOLUTION LAYER

The Spatial Resolution Layer is designed to evaluate the spatial resolution of IGRT systems. Line pair patterns from 1 lp/cm to 16 lp/cm are embedded in the background. In order to minimize artifacts, each line pair pattern is made from a material with ≈ 350 HU greater than the background attenuation. The line pair patterns are 3D patterns, 12 mm in height along the longitudinal axis of the CBCT Image Quality Phantom. The spatial resolution targets are arranged in a circular pattern.





BACKGROUND:	CIRS proprietary epoxy formulation (attenuation ≈ 70 HU)
LINE PAIRS PATTERNS:	From 1 lp/cm to 16 lp/cm (attenuation ≈ 420 HU; a difference that is often used in cardiac angiography imaging), embedded in the background
DIMENSIONS:	Ø 180 mm x 25 mm thickness

SPECIFICATIONS MODEL 062QA-35 - TABLE 3

OVERALL DIMENSIONS:	Ø 180 mm x 100 mm (Ø x D)
WEIGHT:	≈ 2.5 kg (5.6 lb)
MATERIALS:	Water and Tissue Equivalent Epoxy Resins, Engineered Plastics

	PART NO.	DESCRIPTION	*PHYSICAL DENSITY, g/cc	ELECTRON DENSITY, x 10^{23} electrons/cc	RED (RELATIVE TO H_2O)
1	062MQA-50	CBCT Image Quality Phantom			
		Background (Uniformity, Low Contrast/ Magnification, CT Number/Slice Thickness layer)	1.029	3.333	0.998
		Background (Spatial Resolution layer)	1.11	3.641	1.090
1	062MQA-30	Holder for 062MQA-50 CBCT Image Quality Phantom (assembled)			
1	062MQA-40	Soft Carry Case for 062MQA-50 CBCT Image Phantom and 062MQA-30 Holder			

* Physical Density - The actual physical density of the insert can vary within ± 1% of the manufacturing target density.
Note: CIRS strongly recommends that the user inputs the electron density whenever prompted for material data by the TPS.

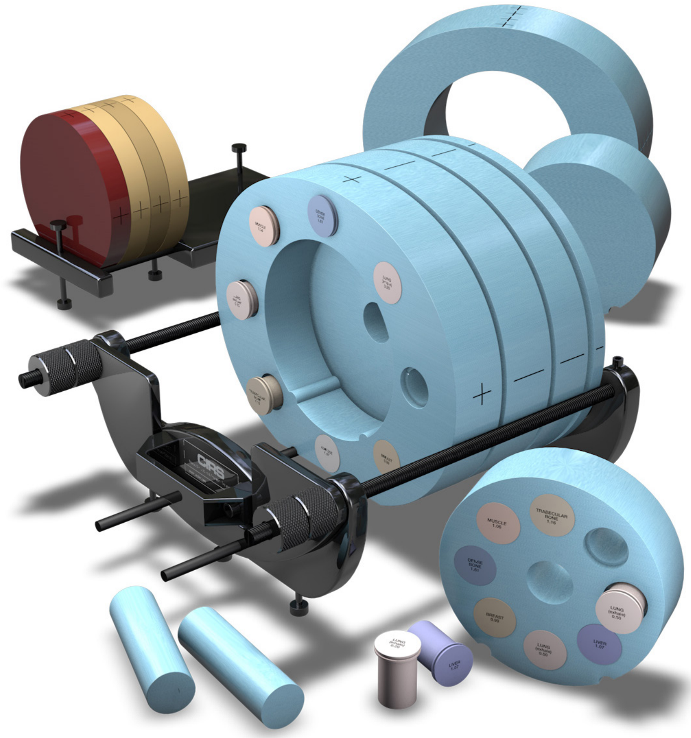
CBCT ELECTRON DENSITY & IMAGE QUALITY PHANTOM
MODEL 062MQA

The Model 062MQA phantom provides a comprehensive tool that can be used for both electron density calibration and image quality assessment of Cone Beam CT systems integrated in radiation therapy devices. The electron calibration function of the phantom enhances the outcome of the adaptive radiation therapy while the image quality features address the fine balance between optimizing image quality while minimizing radiation dose.

The 062MQA CBCT Electron Density & Image Quality Phantom incorporates 3 phantoms:

1. Electron Density Phantom (50 mm thick)
2. CBCT Phantom which is used with the Electron Density Phantom
3. CBCT Image quality phantom

The 100 mm thick body section has a central hole that receives the CBCT Image Quality Phantom. Each Bolus slab is drilled to accommodate an ion chamber insert and allow for ion chamber measurements regardless of the position of the Image Quality Insert. The thicknesses of the sections were selected to allow for positioning of any of the layers containing the Image Quality features in the central axis of the beam. Also sections of different thickness decrease the increment with which the electron density section can be offset from the central axis.



FEATURES:

- Perform all CT Image QA tests for AAPM TG Report #1
- Perform dose measurements using Ionization chambers
- Calibrate Electron Density in multi-slice CT and Cone Beam CT
- Perform central axis and off-set measurements
- Position simulated tissue materials in CT & CBCT energy range at 17 different locations
- Optimized for volumetric imaging
- Quick positioning and customized loading configurations

SPECIFICATIONS MODEL 062MQA - TABLE 4

	PART NO.	DESCRIPTION
1	062MA	Cone Beam (CBCT) Electron Density Phantom - All standard parts (Table 2)
1	062QA-35	CBCT Image Quality Phantom - All standard parts (Table 3)

OPTIONAL ACCESSORIES

MODEL 062M, 062MA & 062MQA

TABLE 5

PART NO.	DESCRIPTION	*PHYSICAL DENSITY, g/cc	ELECTRON DENSITY, x 10^{23} electrons/cc	RED (RELATIVE TO H_2O)
062MA-07**	800 mg/cc HA in Water Equivalent - Core Insert	1.53	4.862	1.456
062MA-12**	Titanium Rod Core Insert	4.51	12.475	3.735
062MA-13	Distance Marker Insert	1.029	3.333	0.998
062MA-14-CV†	Water Equivalent Chamber Rod with Cavity for Ion Chamber	1.029	3.333	0.998
062MA-16	Water Equivalent Insert	1.029	3.333	0.998
062MA-17**	1000 mg/cc HA in Water Equivalent - Core Insert	1.660	5.243	1.570
062MA-18**	1250 mg/cc HA in Water Equivalent - Core Insert	1.82	5.663	1.695
062MA-19**	ICRU Cortical Bone Equivalent Core Insert***	1.91	5.915	1.771
062MA-20**	1500 mg/cc HA in Water Equivalent - Core Insert	1.99	6.134	1.837
062MA-21**	1750 mg/cc HA in Water Equivalent - Core Insert	2.15	6.600	1.976
062A-26	Solid Dense Bone (1000 mg/cc HA) Equivalent Electron Density Plug	1.66	5.243	1.570
062A-28	Solid Dense Bone (1500 mg/cc HA) Equivalent Electron Density Plug	1.99	6.134	1.837
062A-29	Solid Dense Bone (1750 mg/cc HA) Equivalent Electron Density Plug	2.15	6.600	1.976
062MA-41	Water Equivalent Material Surrounding 6.4mm Diameter Stainless Steel (Alloy 20) Rod Core Electron	8.03	23.101	6.917
062MA-42	Water Equivalent Material Surrounding 6.4mm Diameter Aluminum Rod Core Electron Density Plug	2.70	8.008	2.398

* Physical Density - The actual physical density of the insert can vary within ± 1% of the manufacturing target density.
Note: CIRS strongly recommends that the user inputs the electron density whenever prompted for material data by the TPS.

** These inserts have a standard Ø D of 30 mm and contain a 10 mm diameter core of the indicated reference surrounded by H_2O-equivalent background.
The titanium reference has a unique diameter of 6.35 mm.

*** CIRS Cortical bone reference is based on ICRU Report No.44, and represents ≃12.2% H_20, 24.6% protein, 58% mineral (assumed to be Calcium Hydroxyapatite (HA)), and 5.2% monosaccharides. CIRS further offers a series of mineral density references that mimic various HA concentrations in a pure water-equivalent epoxy background matrix.

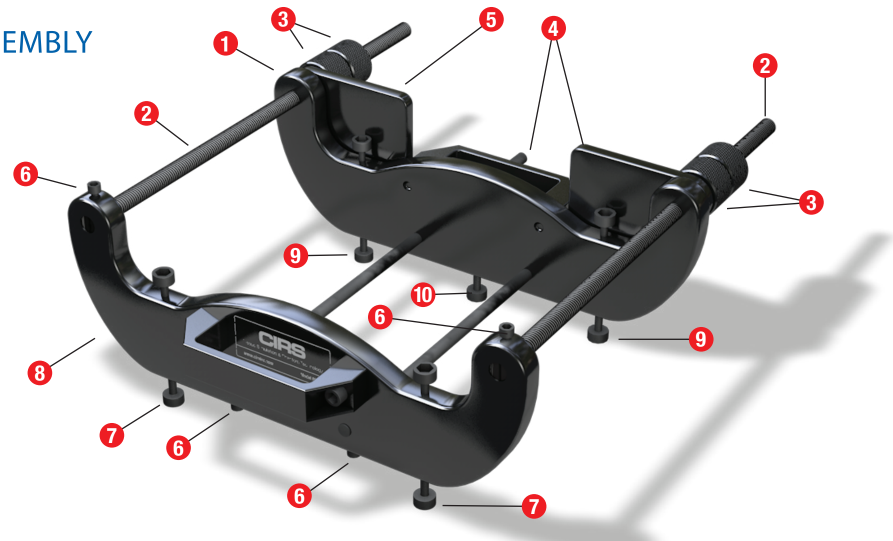
† Purchased separately. Refer to CIRS cavity and Plug code list for available Ion Chamber Cavities. If the ion chamber cavity is not specified by customer, phantom is supplied with Part No. 062MA-14-CV50-1 that accommodates a Farmer type ion chamber.

UPGRADE PACKAGES TABLE 6

	PART NO.	DESCRIPTION	INCLUDES
1	062MA-35	Converts Model 062M to Model 062MA	CBCT Electron Density Phantom Annulus Insert, CBCT Electron Density Phantom Annulus, CBCT Electron Density Phantom Bolus Section- (12.5 mm, 37.5 mm and 50 mm thick), ION Chamber Insert, Background Insert, Holder and Stand, Soft-Sided Carry Case
1	062QA-35	Converts Model 062MA to Model 062MQA	CBCT Image Quality Phantom, Holder and Stand, Soft-Sided Carry Case

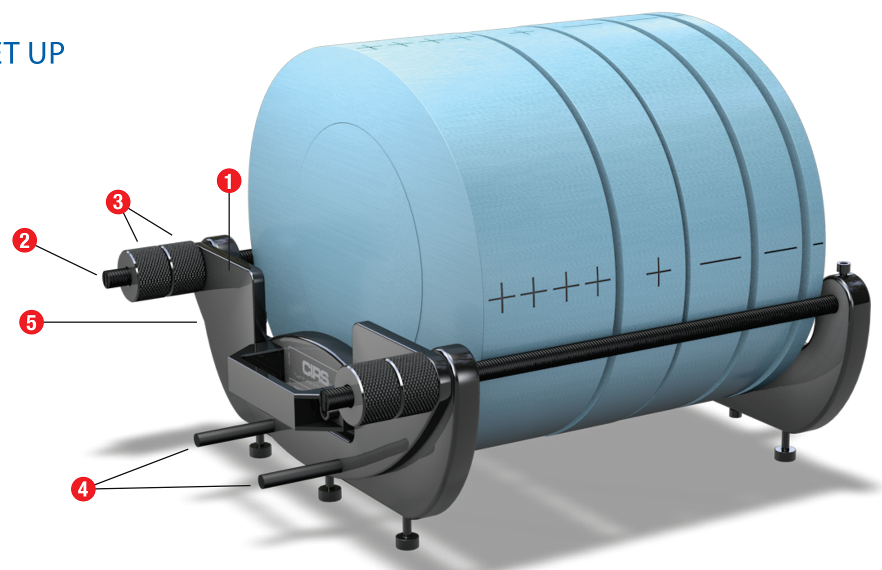
CBCT ELECTRON DENSITY & IMAGE QUALITY PHANTOM SYSTEM
MODEL 062MA & 062MQA

SUPPORT BASE ASSEMBLY



- Identify the front handle plate, 8 which has two adjustable legs. 7. The front handle plate is shipped with set screws 6 already inserted in proper places
- Attach the two threaded nylon rods 2 to the front handle plate by tightening them in the threaded holes until the ends of rods are flush with the face on which the CIRS label is affixed. Secure in place using provided set screws 6 (1/4-20 x ½" long set screws) and provided Allen wrench (do not over tighten the set screws).
- Insert the two carbon fiber rods 4 in the matching holes and secure in place using provided set screws 6 (1/4-20 x ½" long set screws) and provided Allen wrench (do not over tighten the set screws).
- Slide the back handle plate 1 (easily identifiable by the presence of three leveling feet) 9 10 through the nylon and carbon fiber rods 4 until it lies on top of the front handle plate. The plate face with the CIRS label affixed should be facing towards the outside.
- Slide the buffer plates 5 through the nylon and carbon fiber rods until it lies on top of the back handle plate.
- Tighten two plastic knurled knobs 3 on each threaded nylon rod.

CBCT SECTION SET UP

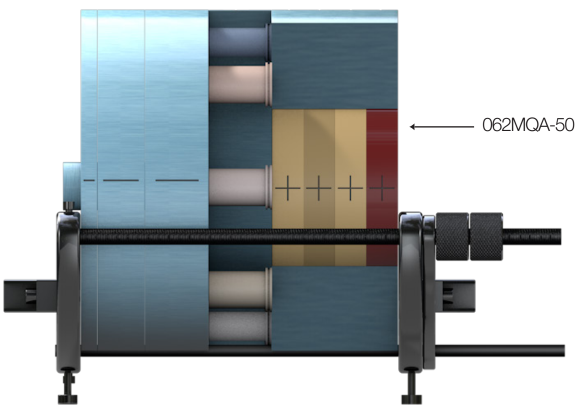


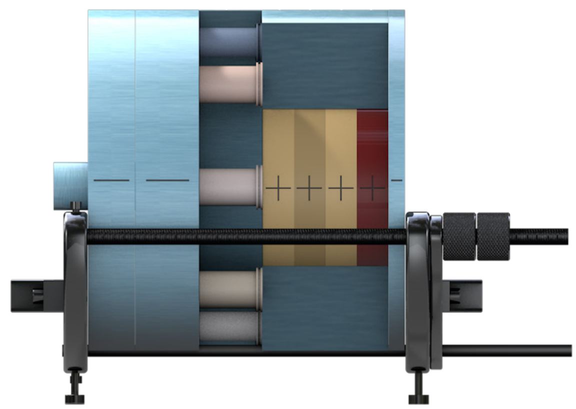
- Set up the phantom by pushing the back handle plate 1 and adjacent buffer plate 5 against the plastic knurled knobs. 3
- Fully extended the support before adding the phantom sections
- When placed on the support, the phantom sections rest on the two carbon fiber rods, 4 which align the sections with respect to each other and on the two threaded nylon rods. 2
- Secure sections on the support by tightening the knurled knobs. 3

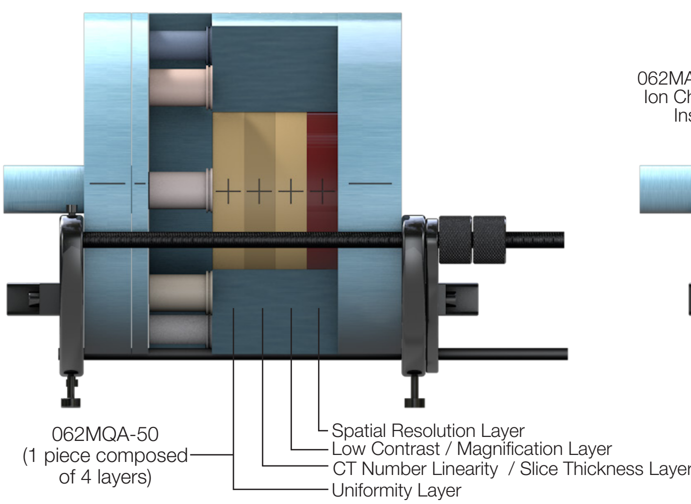
CBCT ELECTRON DENSITY & IMAGE QUALITY PHANTOM SYSTEM
MODEL 062MA & 062MQA

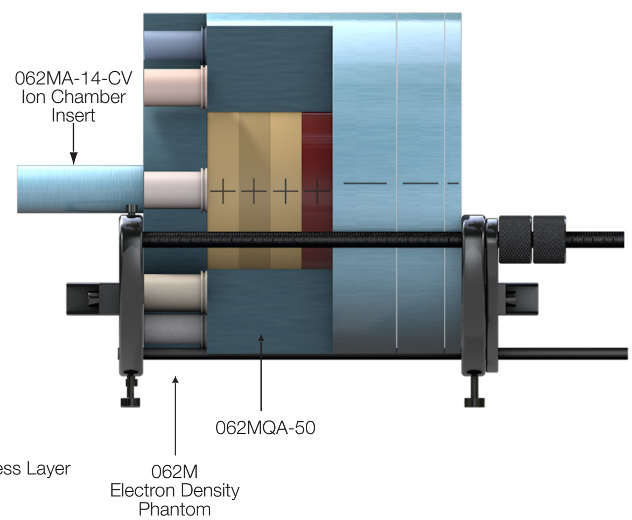
POSITIONING

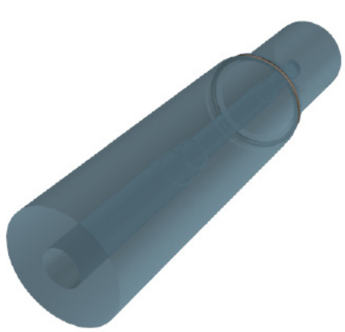
Images below show different positioning arrangements of sections, which allow for off axis Dosimetry measurements, Electron Density off axis measurements, and axial positioning of each layer of the CBCT Image Quality Phantom (062MQA-50).







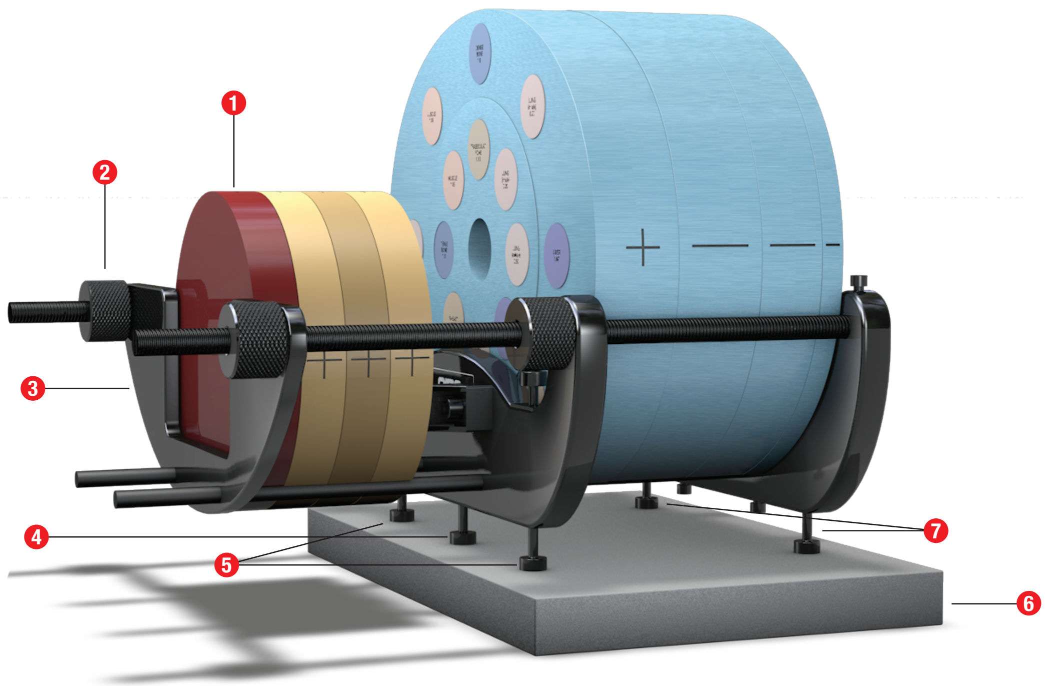




062MA-14-CV Ion Chamber Insert

CBCT ELECTRON DENSITY & IMAGE QUALITY PHANTOM
MODEL 062MQA

"IN AIR" SET UP



1. **CBCT Image Quality Phantom**
   Suspended "in air"
2. **Knurled Knobs**
   Secure back handle plate and buffer plate in place
3. **Buffer plate**
4. **Fixed length leveling leg**
5. **2x Consolidating legs**
6. **LINAC Couch**
7. **2x Adjustable leveling legs**

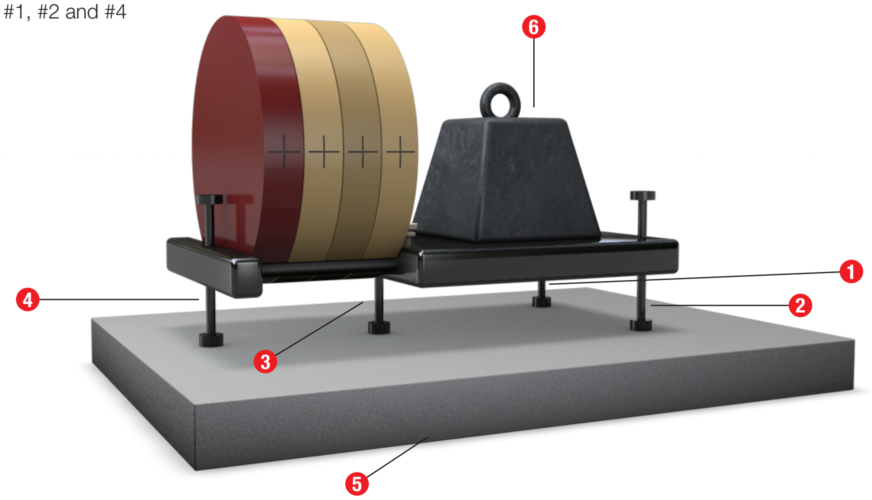
- The modular design of the phantom system allows for positioning the CBCT Image Quality Phantom over the LINAC couch so that "in air" measurements/tests can be performed with minimal interference from the support. Moreover, the CBCT Image Quality Phantom can be used "in air" or inserted in the 100 mm bolus section to simulate more realistic attenuation conditions.
- To perform tests/measurements "in air," extend the support and place it on the LINAC couch. Add the bolus and electron density sections on the couch side to serve as counterweight. Configure the support as shown above. Be sure that the counterweight actually weighs more than the part that is suspended "in air".
- Level the support using the provided Allen wrench (not shown in image) and bring the LINAC laser field lights in coincidence with the laser alignment marks engraved on the bolus sections. Secure this position by slowly twisting the consolidating legs 5 using the Allen wrench until they reach the LINAC couch.
- Place the CBCT Image Quality Phantom on the support rails (carbon fiber rods) against the buffer plate, which is secured by the knurling knobs. Carefully adjust the support and/or the LINAC couch so that the laser/field lights fall on the CBCT Image Quality Phantom laser alignment marks. Make any adjustments to the level and fix the leveled position again if needed.

  NOTE: The support is shipped with the fix length leveling leg fully inserted in its thread insert. If the user wants more clearance for the three point leveling scheme then the extra clearance can be obtained by unscrewing the threaded stud of the fix length leveling leg from the thread insert.
- Follow the same procedure to have the CBCT Image Quality Phantom set up "in air" while it is inserted in the 100 mm section. In this set up the user must use all the remaining bolus sections and the electron density section (body plus head) as counterweight.

CBCT IMAGE QUALITY PHANTOM
MODEL 062QA-35

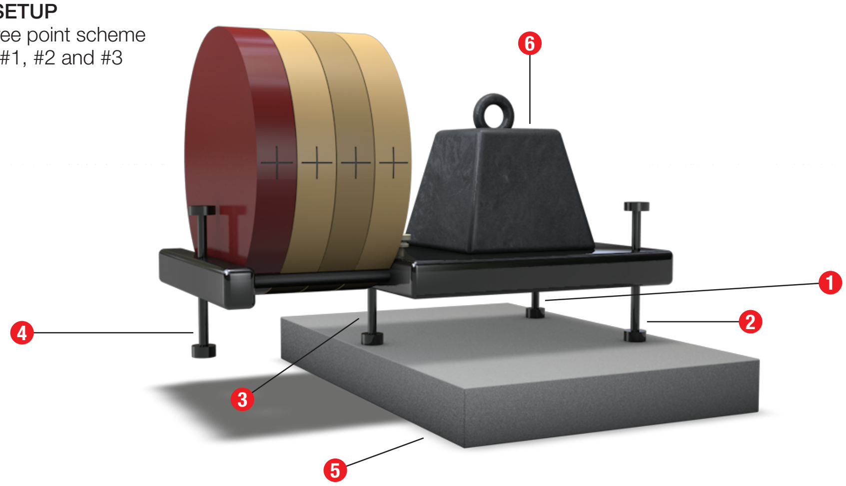
The CBCT Image Quality Phantom includes a Holder (062MQA-30) which comes assembled. This is provided as a convenience for when the user wants to use the Model 062QA-35 apart from the CBCT Electron Density Phantom.

"ON-THE-COUCH" SETUP
Level in three point scheme
using legs #1, #2 and #4



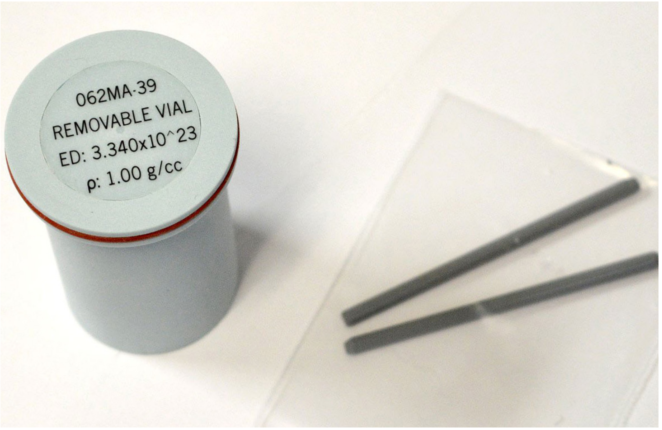
1 Leg #1
2 Leg #2
3 Leg #3
4 Leg# 4
5 LINAC Couch
6 Counterweight (NOT INCLUDED)
Place on the support before leveling

"IN-AIR" SETUP
Level in three point scheme
using legs #1, #2 and #3

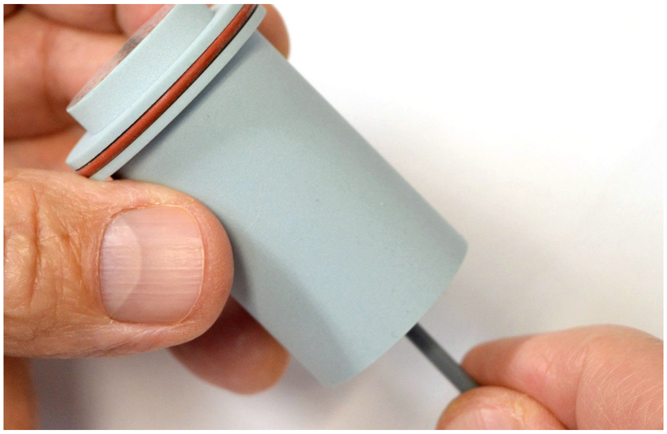


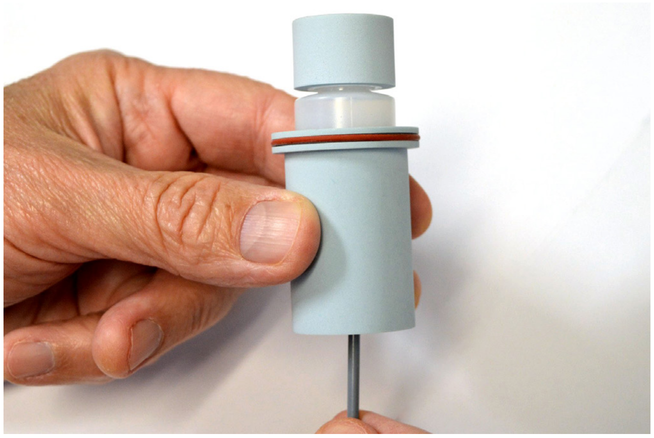
When the CBCT Image Quality Phantom is being used with the holder, a counterweight heavier than 3 kg is recommended for the "on the couch" set up, but is required for the "in air" set up. After extending and placing the support on the couch, the counter-weight should be placed prior to placing the CBCT Image Quality Phantom on the support rails.

WATER-FILLABLE ELECTRON DENSITY PLUG
MODEL 062MA-39



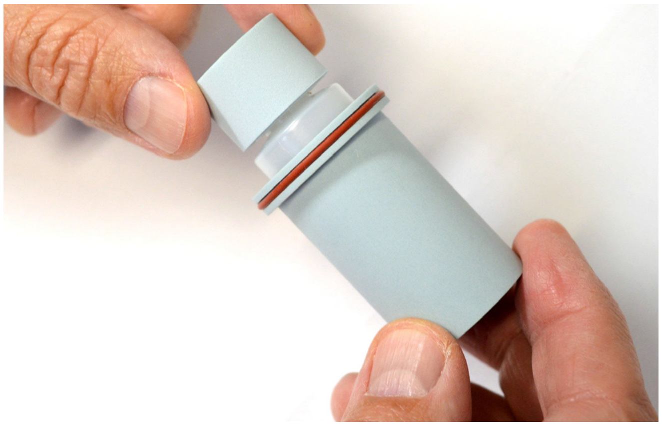
062MA-39 insert with removable vial and Push-Rods





Use Push-Rod provided to push the vial out of insert through the small hole in the bottom of the insert.

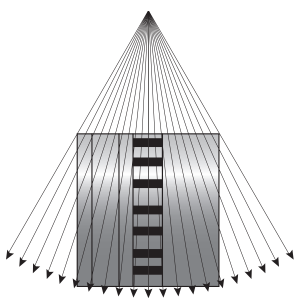
Fill vial (middle) with desired liquid and screw the lid onto the vial.



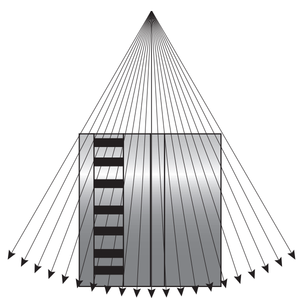
Insert vial back into the insert ensuring the lid is leveled with the insert. Please note that parts are machined with tight tolerances, there will be some friction.

TREATMENT PLANNING

- Set up with inserts in desired locations.
- Scan phantom using normal abdominal (or head for small section) scan protocol.
- Record CT "region of interest" (ROI) values for each insert in each location.
- Change location of inserts as desired and repeat scan/ record sequence.
- For CBCT Scanners: Loosen the rod and knobs and place the phantom body section (062MA-02) in a offset position as shown below. Repeat the above sequence of data collection. Use a curve fitting algorithm to determine the CT ROI data for each tissue. This can now be entered into treatment planning software with data conversion (using relative electron density factors (RED) listed on the specification page of this technical manual).



CBCT Electron Density Phantom
Central Axis Configuration



CBCT Electron Density Phantom
Offset Configuration

QUALITY ASSURANCE TESTING

QA testing can be as thorough as the user may require. Scanner manufacturer's recommendation should be followed in developing a QA plan. Phantom scanning provides a method for learning about the stability of the scanner in question and its ability to image and display various tissues.

- **CTU OF H_2O**
  The Real Water Electron Density Plug (062MA-39), which incorporates a Ø 25.4 mm (1") vial, allows for scanning of regular water at various positions in the scan field with beam hardening effects in existence. A good QA practice involves keeping records over time of the CT value of the H_2O insert in various locations. Alternatively, the insert can be used for scanning contrast agents.

  Filling Instructions: Remove the vial by pushing it out of the plug shell using the provided push rod (there is a hole on the bottom face of the plug shell that matches the size of the push rod.) Do no remove the shell cap that is glued to the vial's top cap. Fill with water or desired contrast agent, and tighten the shell cap so that it is flush with the face of the plug that encapsulates the water vial.

- **CTU OF HOMOGENEOUS SIMULATED TISSUES**
  The phantom accommodates 8 (eight) pairs of tissue-equivalent plugs and a water vial (encapsulated in a containing plug). All plugs are optimally positioned to obtain maximum CTU information from a single exposure while minimizing artifacts (See page 24). Water is placed in the middle of the phantom as a reference, and one of each tissue-equivalent plug is spread to a peripheral ("body") and a centralized ("head") location. Since some CT scanners display significant CTU variations depending on an object's location in the gantry, this method of positioning is beneficial for single exposure evaluation in each location.

  CTU variations can be tested by comparing an exposure of the Electron Density Phantom (062M) facing front, with an exposure of the phantom turned in the opposite direction. Users are free to determine the location of each insert, although configuration options may be limited due to situations where single (optional) inserts are chosen for evaluation.

  If the user is using the "head" section alone or with the electron density image quality insert (062QA-35), it is advisable to use one of each tissue-equivalent insert for a quick measurement of a full range of densities.

- **DISTANCE MEASUREMENTS**
  An optional distance marker insert with small longitudinal holes is available. Measure the distance between holes using scanner "caliper" function and compare to actual distance measured on the phantom with a ruler or caliper.

EVALUATION OF EFFECTIVE ENERGY IN CT

The reference data provided below, used for this evaluation, are the recalculated attenuations and the expected CT values for the 800 mg HA in H_20 insert.

TABLE 7

	Mass Attenuation, cm^2/g	Expected CTU Value, HU	Linear Attenuation, cm^{-1}
KEV = 40	MRO = 0.6346	2652.75	MU = 0.9742
KEV = 50	MRO = 0.4132	1805.64	MU = 0.6344
KEV = 60	MRO = 0.3112	1326.01	MU = 0.4778
KEV = 80	MRO = 0.2240	875.23	MU = 0.3439
KEV = 100	MRO = 0.1879	690.57	MU = 0.2884

- Physical Density = 1.53 g/cc
- Electron Density = 4.862×10^{23} electrons/cc
- RED (Relative Electron density to H_20) = 1.456
- Based on a 4-degree polynomial fitting, the effective energy in keV is given by the following formulation:

$$\textbf{(keV) eff} = a/(CTU) + b + c\,(CTU) + d(CTU)^2$$

With (CTU) = measured CTU value for the bone insert and:

a = 78387.86
b = -35.71341
c = 0.03691735
d = -7.364412×10^{-6}

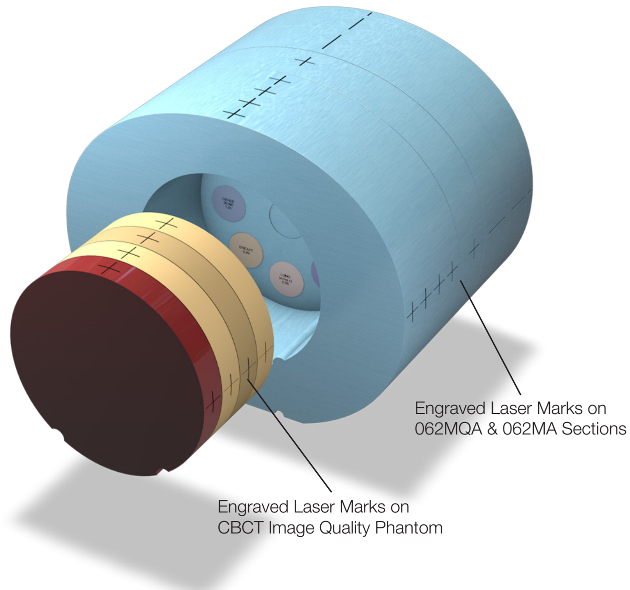
This formulation is valid between 50keV to 100keV.

CBCT ELECTRON DENSITY PHANTOM & IMAGE QUALITY PHANTOM
MODEL 062MQA

IMAGE QUALITY OVERVIEW

The purpose of image quality measurements is to quantify various image quality indicators for 3D images taken from a selection of image acquisition and reconstruction settings representative of clinical practices. Assessment of the image quality parameters over time can show trends in variation of said parameters helping the user to decide whether or not recalibrations of the imaging system are necessary. It was observed that there is a great variation of image quality parameters based on the position of a testing feature within the imaging volume. To account for such facts and for consistency in time and space both the CBCT Electron Density Phantom (062MA) and CBCT Image Quality Phantom (062QA-35) were designed to allow the positioning of any of the image quality features (layers of 062QA-35) in the central transversal plane of the CBCT beam.

Laser marks are engraved on three sides on all CBCT Electron Density Phantom sections as well as on each layer of CBCT Image Quality Phantom.



INITIAL PHANTOM SET UP

The design of the phantom system allows for the same alignment to the laser lights/field lights system regardless of the configuration chosen for testing. Remember that the phantom system is modular allowing the user to order/select just the parts that form the configuration most appropriate for the measurements to be performed.

- Set up the holder/support on the table.
- Place the desired sections of the phantom system on the holder/support. If the "in air" configuration is chosen remember to place first on the support the sections chosen to play the counterweight role and then the sections to be tested on the overhang portion of the support.
- Tighten/secure the phantom sections in place (see Sections Set Up).
- Align the whole phantom system to the laser/field lights by superimposing the lights on the top engraved laser marks.
- Raise or lower the LINAC/CT couch until the laser/field lights are superimposed on the lateral engraved laser marks. If the lights are not collinear with the engraved laser marks, adjust the two leveling feet of the phantom system support until the superimposition/co-linearity of lights - laser marks is obtained, then consolidate the new position using the two consolidating legs.
- Verify again the superimposition/co-linearity of lights to the top laser marks and adjust if necessary by lateral translation of the LINAC couch and/or phantom system.
- The positioning of the phantom system with respect to the LINAC/CT laser and field lights should be verified again during the image analysis stage of testing. There are three testing features designed to verify the positioning/alignment of the phantom system. All theses positioning/alignment check features, some of which play a role in image QA testing, are embedded in the Image Quality Insert (062QA-35). These positioning/alignment check features are:

  - Ø 25.4 mm (1") x 25.4 mm L machined Delrin ring (embedded in Low Contrast Layer/Magnification layer). CBCT/CT software specific distance measurement tools should yield equally orthogonal diameters, when the phantom is properly aligned.

  - Low Contrast Layer/Magnification layer contains four wires (seen as bright spots in transversal images), one in the center, one on the vertical axis, one on the horizontal axis, and one at 45° from the horizontal axis. Use of any CBCT/CT orthogonal measuring/visualization tool should show the parallelism of the wires to the image axes.

  - A well positioned/aligned phantom should yield equal lengths of the slice thickness ramps, which are embedded in the CT Number Linearity/Slice Thickness layer.

UNIFORMITY

Uniformity is defined as the system's ability to produce a uniform image across the entire field of view (FOV) when an object with homogenous density is scanned.

- In CBCT systems there can be variation between the uniformity measurements taken in the central plane of the beam and offset from this plane due to the specifics of the CBCT imaging geometry. It is recommended that measurements with the Uniformity layer placed axial and off central axis be taken.
- To account for the influence of beam hardening and the scattering observed in volume imaging, measurements taken with the Image Quality Insert (062QA-35) inserted in the CBCT Image Quality Phantom should be compared with measurements taken using the Annulus Solid (062MA-37).

There are different methods to analyze uniformity:

A value for uniformity can be calculated using one of the following formulas:

$$U = \frac{(CT\#_{max} - CT\#_{min})}{(CT\#_{max} + CT\#_{min})/2} \qquad (1)$$

$$U = \frac{(CT\#_{Average\ (peripheral)} - CT\#_{Average\ (center)})}{CT\#_{Average\ (center)}} \qquad (2)$$

To evaluate the uniformity using the above formulas it is recommended that at least five ROI measurements are taken (Figure 1). The ROI should be approximately equal in size and should encompass an adequate number of pixels.

Formula (1) can be used for each individual ROI, or "max" and "min" can refer to the maximum and minimum pixel values averaged over each ROI.

In formula (2) the $CT\#_{Average\ (peripheral)}$ is calculated from all the peripheral ROIs.

- Use a CBCT/CT software profiling or histogram measuring function to assess uniformity.
- The displayed image of the uniformity layer should show no "streaking" artifacts.
- For spiral multi-slice acquisitions ensure that any part of the spiral that contribute to the image is constrained to be within the volume of the uniformity layer.

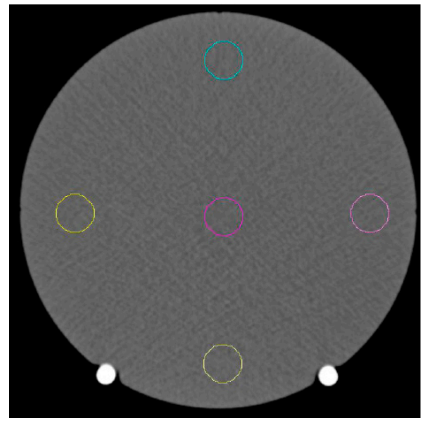


FIGURE 1. ROI MEASUREMENTS

CT NUMBER LINEARITY

Assessment should be performed in different locations within the scanned 3D volume. The effective value of the CT Number for each reference insert is dependent on the computation used and the spectrum of the beam energy. Thus, these values may vary from published data.

- The numbers provided (Table 8) are for reference only. If the phantom system was ordered in a configuration that includes the electron density sections (062MA-01 and 062MA-02) then it is recommended that a thorough electron density calibration be performed. Calibration ensures that the system is optimized for CT Number linearity assessments.

TABLE 8

Material	Physical Density, g/cc	Expected CT# (on a 12 bit scale)
Air	0.00	≈ - 1000
LDPE	0.92	≈ -97
Polystyrene	1.05	≈ -40
Acrylic	1.18	≈ +120
Delrin	1.41	≈ +360
Teflon	2.20	≈ + 1080

- After the scan is performed, use the window and level functions along with ROI tool to measure the CT number of each rod. Use ROI that cover the center of each CT Number rod with an area of approximately 50% from that of the rod diameter ($R_{ROI} = 12.7 / \sqrt{2}$).

CONTRAST-TO-NOISE RATIO (CNR)

CNR gives an indication of an imaging system ability to distinguish the difference between two structures in the presence of image noise. CNR is expressed as the ratio of the difference in mean gray level between two objects (a.k.a. contrast) by the standard deviation of the noise.

- One formula that can be used to calculate CNR is: $CNR = |G_A - G_B| / (\sigma_N)$, where GA is the mean gray level of object A, G_B is the mean gray level of object B, and σ_N is the image noise.
- If G_A is calculated for an ROI placed over one of the CT Number rods then G_B and σ_N should be calculated for an ROI adjacent to that respective rod.

SLICE THICKNESS

Slice thickness evaluation can provide the user with valuable information about the systems ability to accurately reconstruct imaged geometry. Therefore, it is recommended that the slice thickness be calculated from images of the slice thickness layer taken in different places within the FOV.

The results of this test are highly dependent on phantom alignment thus the user is advised to carefully align the phantom during the set up phase.

- Since there is a variation in the length of visible slice thickness ramp projections, it is recommended that a similar approach to the one described for magnification test be taken. Select a good slice to be analyzed.
- Slice thickness is expressed as (thickness in mm in this case) the value at “full with at half maximum value” (FWHM) (Figure 2). For slice thickness evaluations f_{max} = largest CT number in absolute value (in this case the minimum HU value), which represents the peak of the slice thickness ramp projection, while ½*f_{max} is the value of the pixel corresponding to the voxel that encloses 50% from the slice thickness ramp structure and 50% background material (Figure 3).

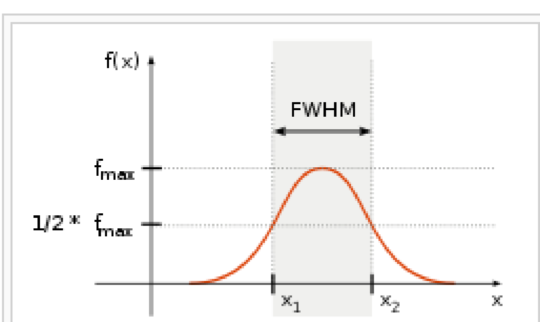


FIGURE 2. SLICE PROFILE

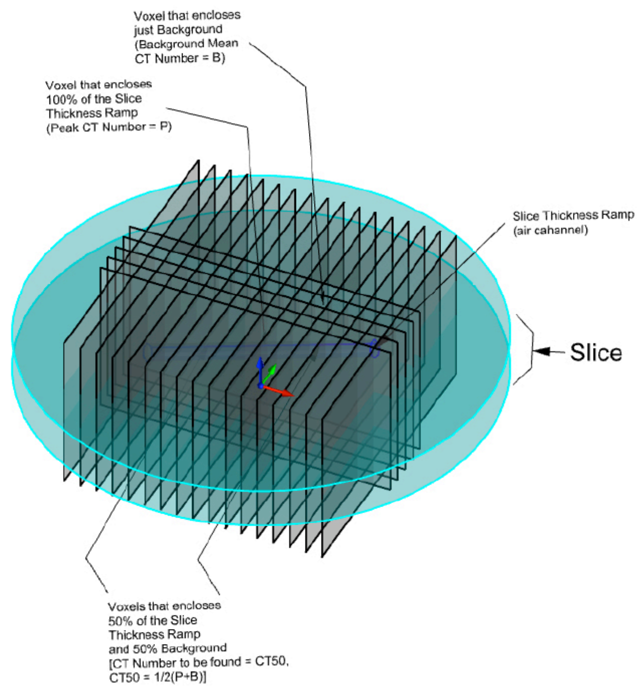


FIGURE 3. SLICE RECONSTRUCTION

- Place ROI over all the ramp projections and one over the background (Figure 4). Record the minimum HU value (since the slice thickness measuring ramps are air channels, the minimum value is the CT Peak Number “P”) for each ramp projection ROI. Record the mean HU value of the background ROI (value “B”) (Figure 4).

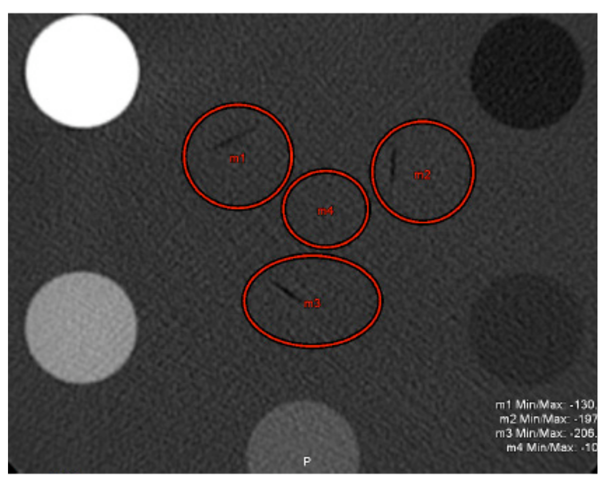


FIGURE 4.

- For each individual ramp projection calculate the CT50 and adjust the window to a low value (W = 4 for example) and the level to the calculated CT50 (Figure 5). The length of the slice thickness ramp projections that needs to be measured stands out in the image.

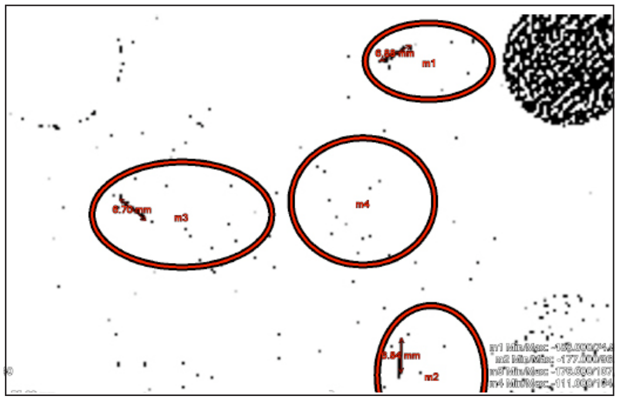


FIGURE 5.

- Since the ends of the slice thickness ramp projections are hard to identify, it is recommended that the user adjust back the window and level to see if the right ends were selected (Figure 6).

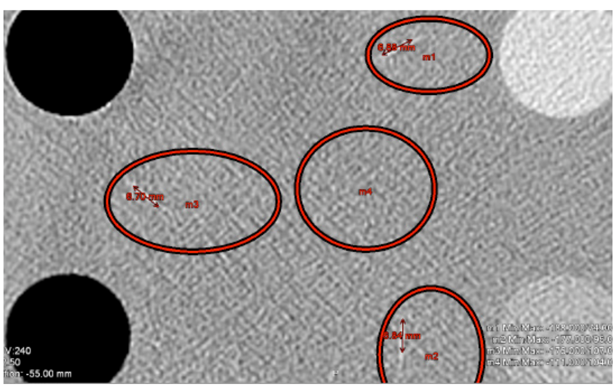


FIGURE 6.

- Average the three measured distances and multiply the result with "tan (20°)" (2.36397). The calculated value is the slice thickness at FWHM.

LOW CONTRAST VISIBILITY

The low contrast visibility (resolution of closed attenuations) is highly subjective depending on the individual performing the test. It is recommended that the user be more concerned with the consistency of the test rather than the absolute contrast and size threshold established by a particular test.

- As explained, for the uniformity test it is recommended to assess the low contrast visibility with the low contrast/ magnification layer positioned in different locations within the imaged 3D space.
- Scan the phantom system in a configuration that is deemed the most appropriate for the scanning protocol. Adjust the window and level settings for the best image display.
- The smallest discernible target defines the limit of the low-contrast detectability.
- If the low contrast visibility is determined through a quantitative method, average the measurements made from several scans.
- For a more objective evaluation of low contrast visibility the user may construct a contrast detail curve. The shape of the curve is however dependent of on scan parameters (mA, kV, etc) and reconstruction algorithms.

MAGNIFICATION/SPATIAL LINEARITY

Tests should be performed in different locations within the scanned 3D volume.

- Use the visualization software's distance measuring tool to measure the distance between the central tungsten wire and the wires arranged on the circle with a radius R = 55 mm. Measured distances that are equal to actual distances show that the geometric accuracy of the CBCT/CT is such that the actual divergence of the x-ray beam matches the divergence assumed in the reconstruction algorithm.
- One way to ensure that the right points are selected for distance measurements is to place an ROI over one of the wires and then to determine the maximum CT number value for that ROI.
- Then, using a very narrow window adjust the level close to that maximum value (Figure 1), which will show just the pixels that have the maximum CT Number value. The distance measurements should be done between these pixels (Figure 7. Note that the distance at 45° may not equal the mathematically calculated distance because the measure distance tool jumps from center of pixel to center of pixel).

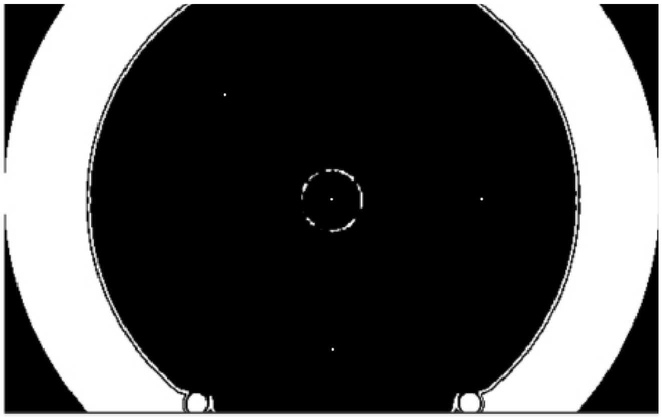


FIGURE 7.

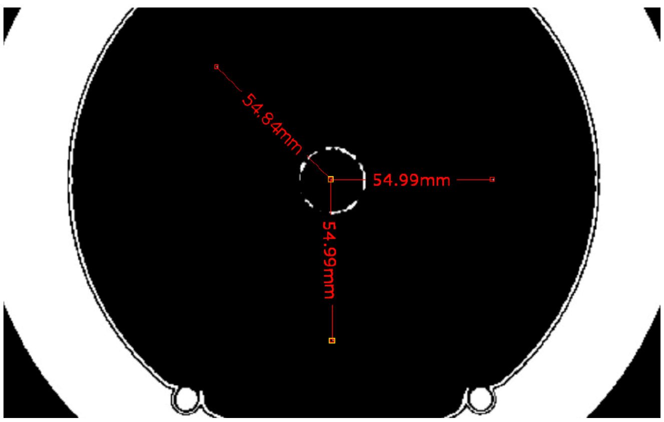


FIGURE 8.

SPATIAL RESOLUTION

The 1 to 16 line pairs/cm patterns are used to visually assess the imaging system's ability to resolve fine detail, respectively lines of high contrast placed close
together.

The image should be adjusted for the best image visibility using the tools provided by the visualization software.

MODULATION TRANSFER FUNCTION (MTF)

The visual evaluation of spatial resolution based on line pairs/cm is subjective depending on a series of factors chief among them being the visual acuity of the observer.

- To eliminate the subjectivity of the visual spatial resolution evaluation the user can calculate the “Modulation Transfer Function” of the imaging system using a Droege-Morin algorithm applied to the line pairs/cm patterns.
- Also, the MTF, which is 2D FFT (Fast Fourier Transformation), can be calculated using the tungsten wires from the low contrast/magnification layer, which in this case play the role of “delta input signals”.
- Both the Droege-Morin and 2D FFT algorithm can be difficult to perform manually so the user is advised to employ specialized software (Figure 9).

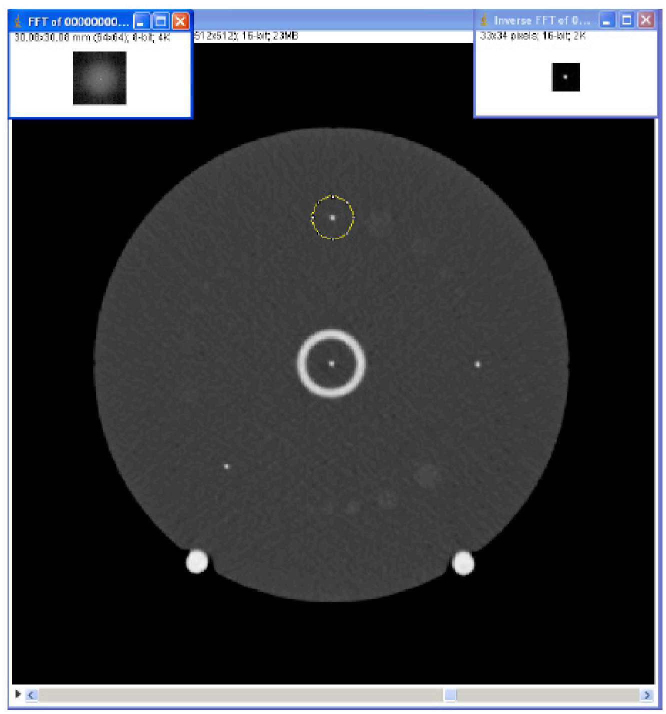


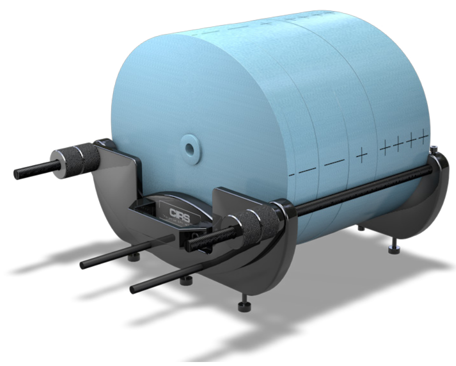
FIGURE 9. FFT/ INVERSE FFT

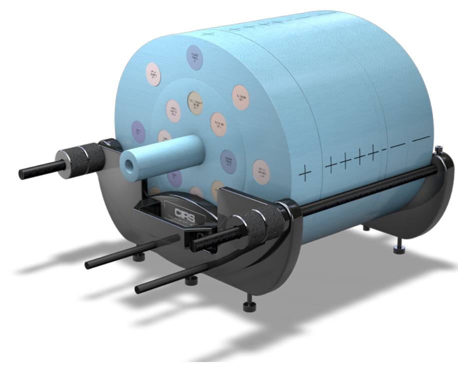
CBCT ELECTRON DENSITY & IMAGE QUALITY PHANTOM SYSTEM
MODEL 062MA & 062MQA

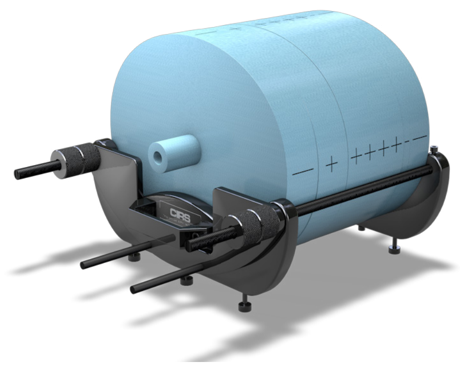
DOSIMETRY ARRANGEMENTS & MEASUREMENTS

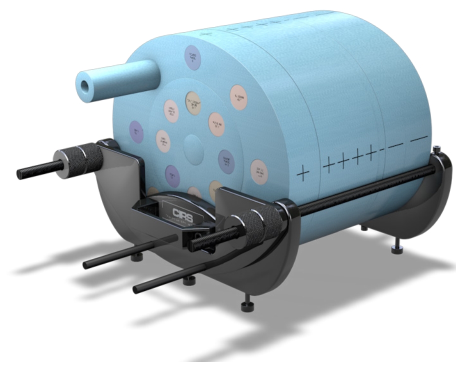
Both 062MA CBCT Electron Density Phantom and 062MQA CBCT Electron Density & Image Quality Phantom are designed to allow for dosimetry measurements in the central location of the Electron Density Head section or in special cases in any other location of the 062M.

When the section arrangement is such that the CBCT Electron Density Body with Head Insert is at one end of the phantom, dosimetry measurements (see image on lower right) can be taken in locations other than the central hole of the CBCT Electron Density Head Insert by exchanging the Ion Chamber insert with any of the Electron Density inserts (plugs).

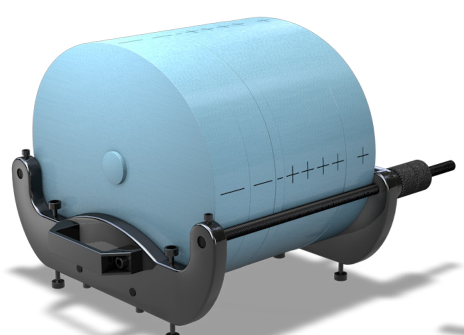


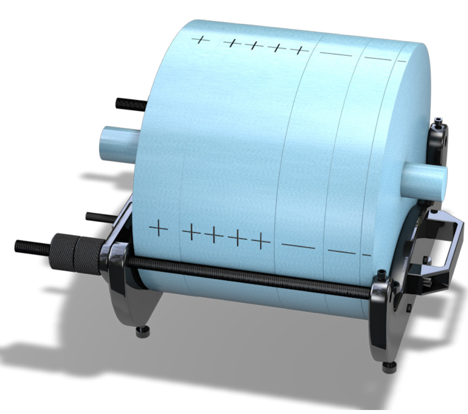






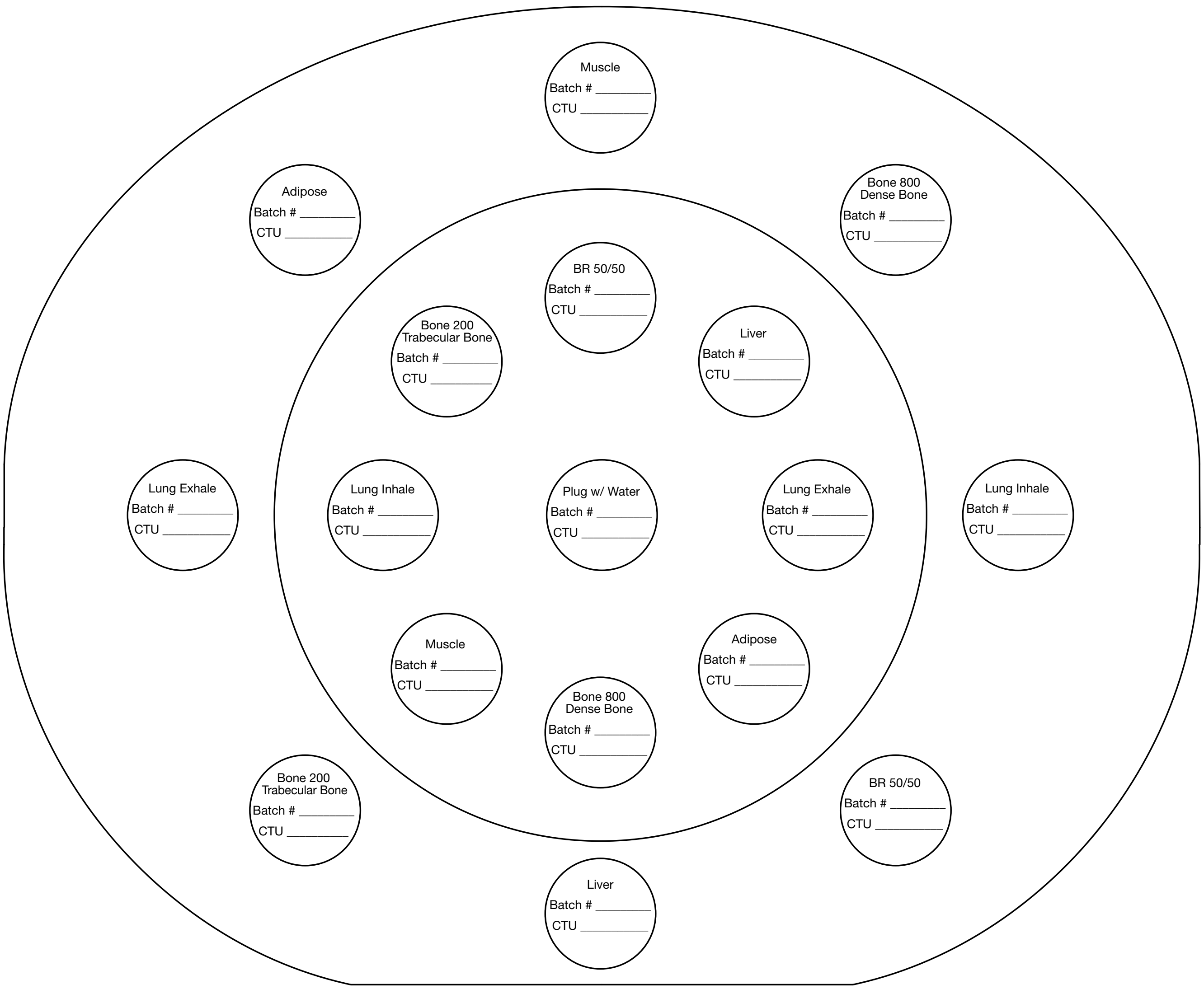
When the Ion Chamber insert is not in use, one or both Ø 30 mm x 100 mm Long Background Equivalent Inserts can be placed in the central hole of bolus sections depending on the arrangement.





ELECTRON DENSITY SAMPLE TEST DATA SHEET

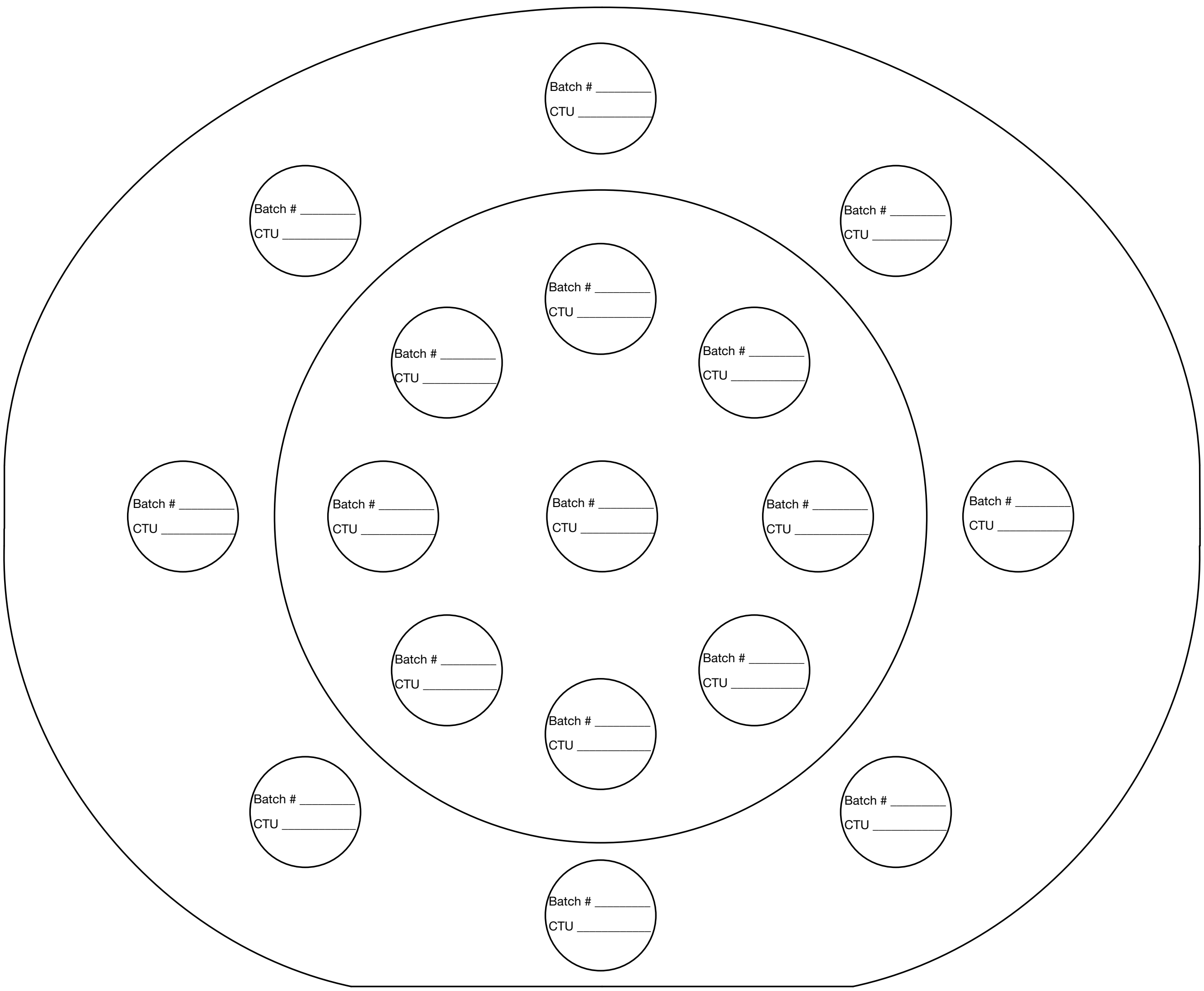
The arrangement below shows each plug optimally positioned to obtain maximum CTU information from a single exposure while minimizing artifacts.



ELECTRON DENSITY TEST DATA SHEET

TEST DATE:_______________ PHANTOM S/N:_____________

PHANTOM S/N:_____________ DATE:_______________



TESTER: ________________________

HANDLING & WARRANTY

HANDLING INSTRUCTIONS

It is recommended to store phantom and its inserts in the provided carrying case. In order to minimize the shrinking/collapsing of the phantom's holes (shrinking/collapsing magnitude can be up to a few tenths of microns) due to the material nature and long term storage it is recommended that the caring case that stores the phantom is laid on one side so as the phantom's sections have the holes in a vertical orientation. Also, it is recommended that for long term storage all the phantom's holes are fitted with the appropriate matching parts.

WARRANTY

All standard CIRS products and accessories are warranted by CIRS against defects in material and workmanship for a period as specified below. During the warranty period, the manufacturer will repair or, at its option, replace, at no charge, a product containing such defect provided it is returned, transportation prepaid, to the manufacturer. Products repaired in warranty will be returned transportation prepaid.

There are no warranties, expressed or implied, including without limitation any implied warranty of merchantability or fitness, which extend beyond the description on the face hereof. This expressed warranty excludes coverage of, and does not provide relief for, incidental or consequential damages of any kind or nature, including but not limited to loss of use, loss of sales or inconvenience. The exclusive remedy of the purchaser is limited to repair, recalibration, or replacement of the product at manufacturer's option.

This warranty does not apply if the product, as determined by the manufacturer, is defective because of normal wear, accident, misuse, or modification.

NON-WARRANTY SERVICE

If repairs or replacement not covered by this warranty are required, a repair estimate will be submitted for approval before proceeding with said repair or replacement.

RETURNS

If you are not satisfied with your purchase for any reason, please contact Customer Service or your local distributor prior to returning the product. Visit https://www.cirsinc.com/distributors/ to find your local distributor. Call 800-617-1177, email rma@cirsinc.com, or fax an RMA request form to 757-857-0523. CIRS staff will attempt to remedy the issue via phone or email as soon as possible. If unable to correct the problem, a return material authorization (RMA) number will be issued. Non-standard or "customized" products may not be returned for refund or exchange unless such product is deemed by CIRS not to comply with documented order specifications. You must return the product to CIRS within 30 calendar days of the issuance of the RMA. All returns should be packed in the original cases and or packaging and must include any accessories, manuals and documentation that shipped with the product. The RMA number must be clearly indicated on the outside of each returned package. CIRS recommends that you use a carrier that offers shipment tracking for all returns and insure the full value of your package so that you are completely protected if the shipment is lost or damaged in transit. If you choose not to use a carrier that offers tracking or insure the product, you will be responsible for any loss or damage to the product during shipping. CIRS will not be responsible for lost or damaged return shipments. Return freight and insurance is to be pre-paid.

WITH RMA NUMBER, ITEMS MAY BE RETURNED TO:

CIRS Receiving
900 Asbury Ave
Norfolk, Virginia, 23513 USA

PRODUCT	WARRANTY PERIOD
Model 062M, 062MA & 062MQA - CBCT Electron Density & Image Quality Phantom System	60 Months

Publication: 062M 062MA 062MQA UG 072721

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