

**Tomophan™ TSP004 Manual**

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**WARRANTY**

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2727 State Route 29  
Greenwich, NY 12834

By Mail

The Phantom Laboratory, Incorporated  
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Salem, NY 12865-0511

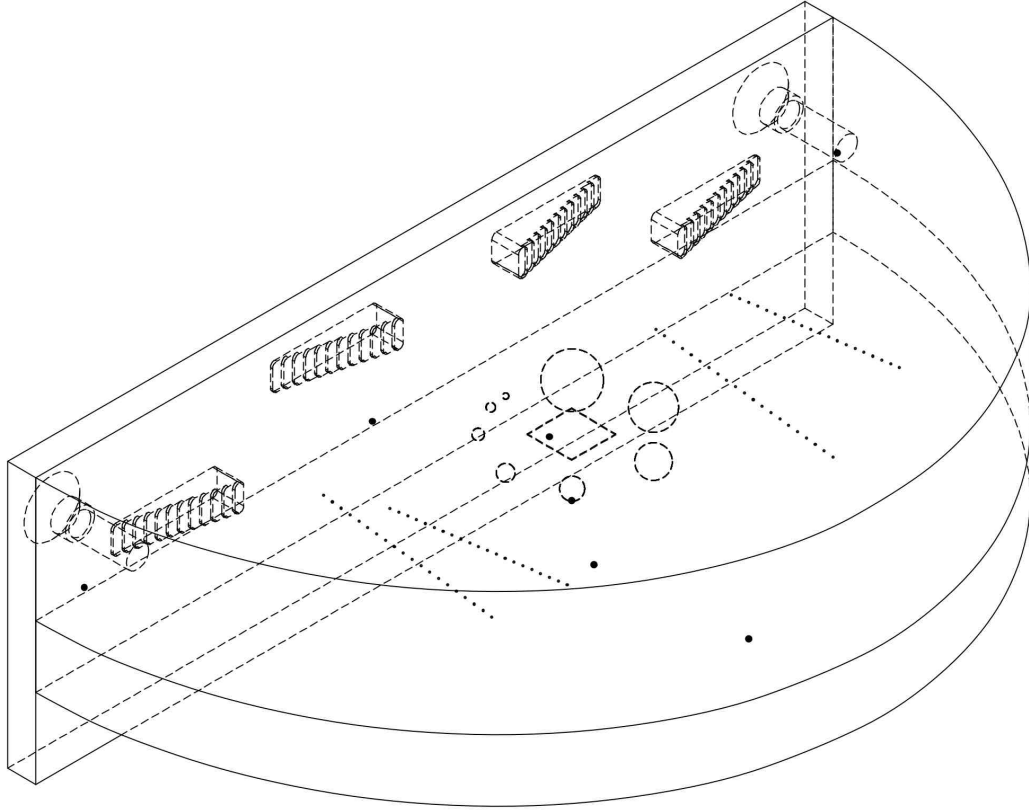
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**WARNING**

This product has an FH3-4 mm/min flame rating and is considered to be flammable. It is advised not to expose this product to open flame or high temperature (over 125° Celsius or 250° Fahrenheit) heating elements.

TSP004  
TSP014



# T h e   P h a n t o m   L a b o r a t o r y

## **Tomophan™ TSP004 Manual**

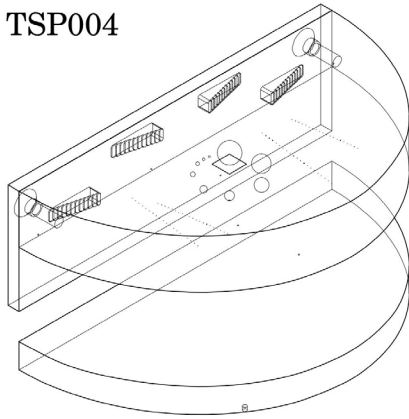
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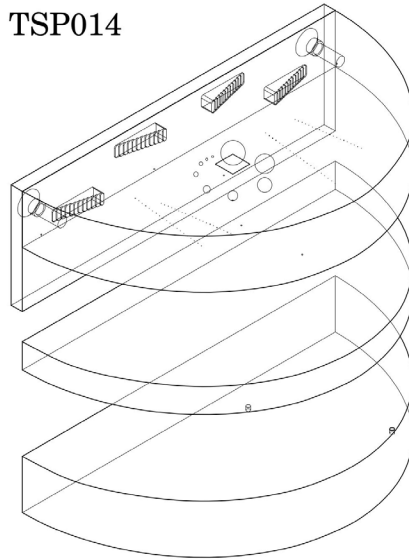
PDF copies of this manual are available at [phantomlab.com](http://phantomlab.com)



TSP004



TSP014



## Introduction

The Phantom Laboratory and physicist David J. Goodenough, Ph.D., are continually developing and researching new tests and modifications for imaging phantoms. The test objects that make up the current Tomosynthesis Phantom embody more than three decades of scientific evaluation and field experience in medical imaging phantom development.

In developing the Tomophan™ phantom we benefited from open discussions with Kish Chakrabarti, Ph.D., FAAPM and the information he presented in the AAPM TG245 task group meetings and follow up discussions. We also had fruitful discussions with Sara Vecchio, Ph.D. while she worked as a Fellow at FDA under Dr. Chakrabarti.

This manual outlines the design and applications of each test object contained in the Tomosynthesis Phantom.

We do not make specific recommendations regarding the content of your quality assurance program because each medical imaging facility has its own unique set of requirements. We suggest a review the manufacturer's QC program developed under the Mammography Quality Standards ACT (MQSA), regulated by the FDA, along with the Protocol for the Quality Control of the Physical and Technical Aspects of Digital Breast Tomosynthesis Systems, 2013, European Reference Organization for Quality Assured Breast Screening and Diagnostic Services, Committee Report.

Additionally refer to local governing regulations, manufacturer's specifications, and the needs of your radiologists and physicists before developing your Tomosynthesis quality assurance program.

If you have any additional questions please contact The Phantom Laboratory at:

Phone: 800-525-1190 or 518-692-1190

Fax: 518-692-3329

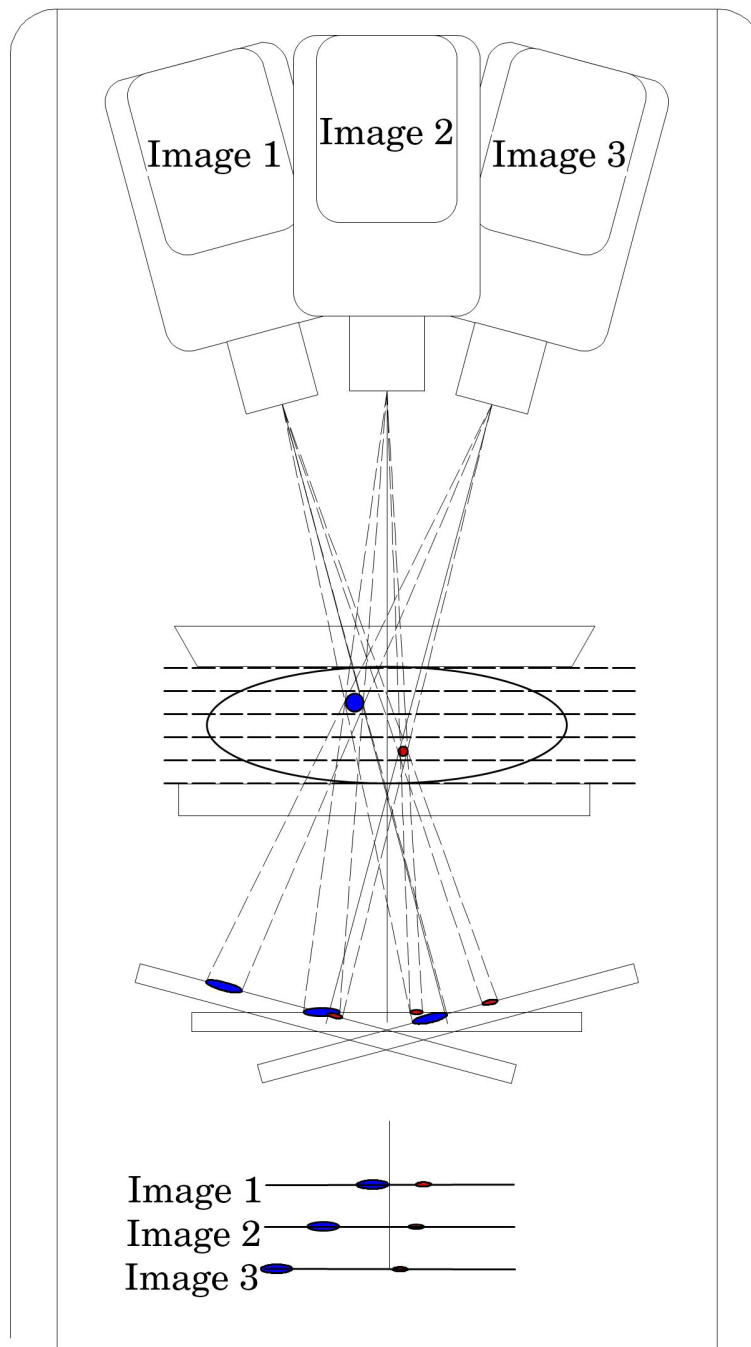
email: [sales@phantomlab.com](mailto:sales@phantomlab.com)

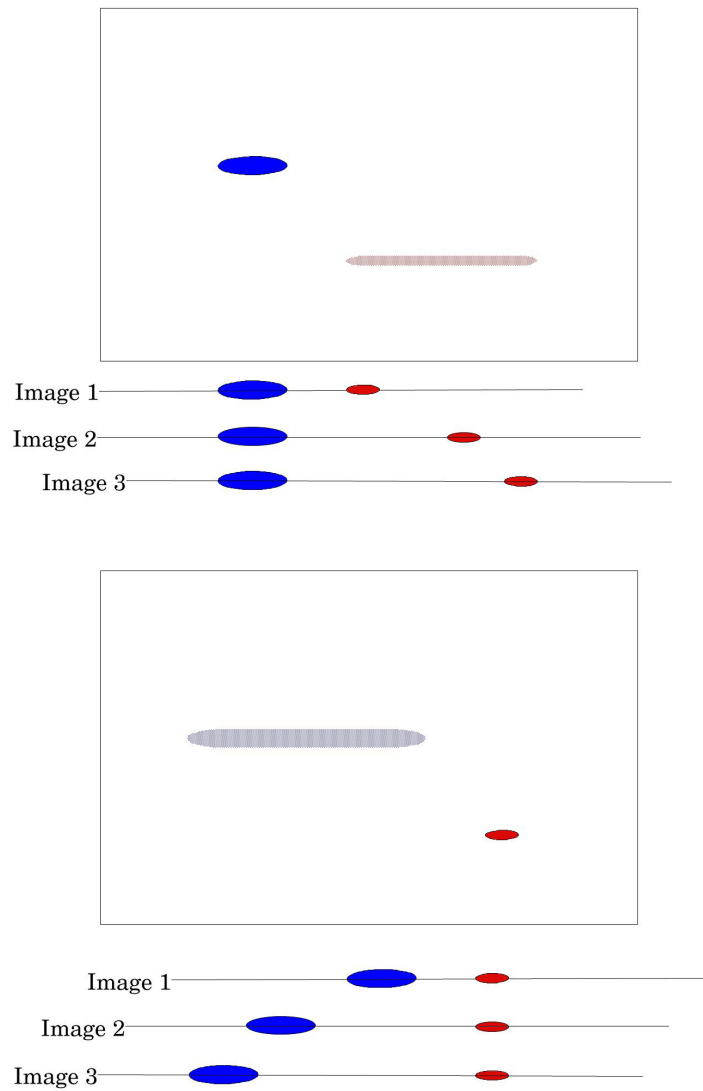
Additional product information is available at: [phantomlab.com](http://phantomlab.com)

### Tomosynthesis, by David Goodenough, Ph.D.

Tomosynthesis systems typically use a limited number of angled projections (views) of the breast. The image quality depends on the number of projections, e.g. 10-25, and the total angle over which they are taken, typically  $15^{\circ}$ - $50^{\circ}$ . With several caveats in mind, and all else being equal: the wider the angle of projections and the more projections within the angular width, the better the 3-D resolution (combination of z-axis, and in-plane (x,y)). The increased projections result in increased total scan time which can result in increased motion blurring and possibly other artifacts.

The following simplified image illustrates how images are taken at different angles through the breast. Due to the geometry, depending on the x, y and z location of internal structures they will project onto different locations of the detector.

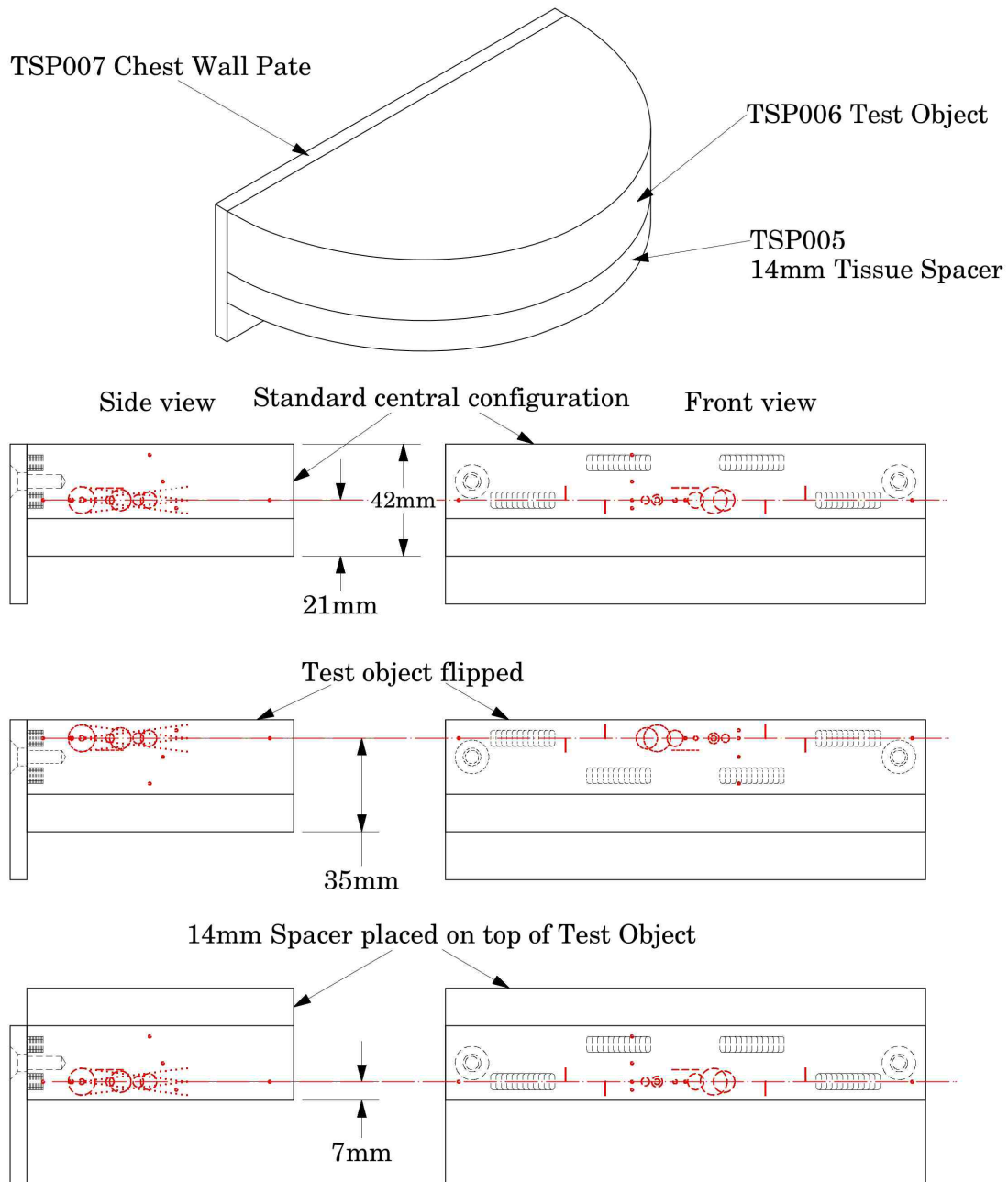




When these images are back-projected into slices the anatomy in the projected slice is put into sharp focus with maximum intensity and the anatomy out of the slice is blurred in increasing amounts depending on how far it is from the slice plane.

## Phantom configurations

The Tomophan™ Phantom is comprised of three components: the TSP006 Test Object, TSP005 14mm Tissue Spacer and TSP007 Chest Wall Plate. In the standard configuration the test components are in the central plane of the phantom. These components can be configured in different positions to allow testing slices in the upper central and lower region of the assembly's 42mm thickness.



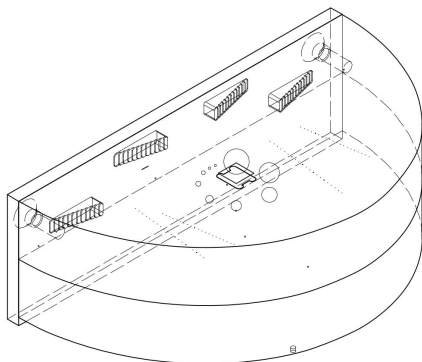
**Test components and their center line marked in red**

By flipping the TSP006 Test Object the test components are moved from the upper half to the lower half. To rotate the Chest Wall Plate when flipping the Test Object use a 4mm hex wrench, remove the two nylon screws, and rotate the Chest Wall Plate before re-attaching it with the nylon screws.

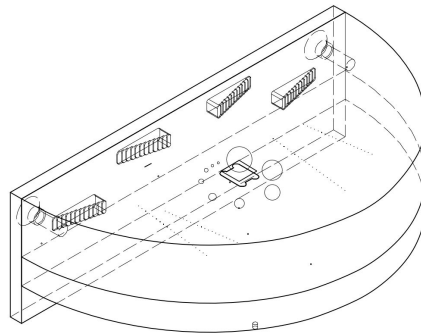


### Additional TSP014 configurations

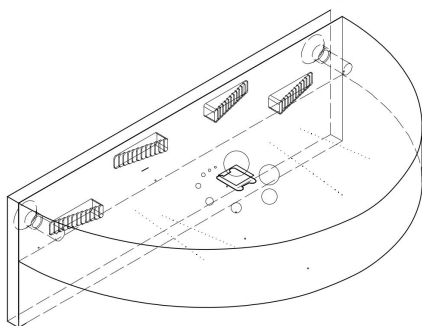
The use of the additional TSP009 28mm Tissue Spacer included with the Tomophan® TSP014 phantom enables the additional potential configurations.



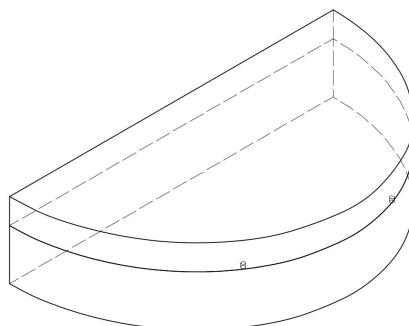
56mm Image Quality Configuration



42mm Image Quality Configuration

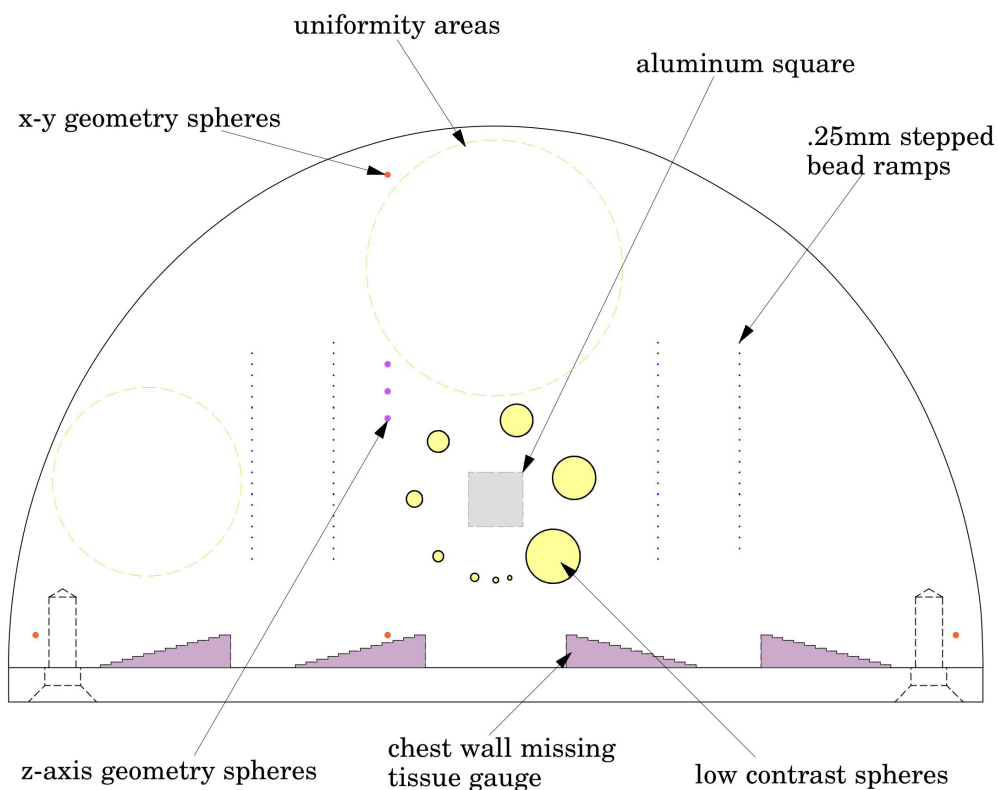


28mm Image Quality Configuration



42mm Image Uniformity Configuration

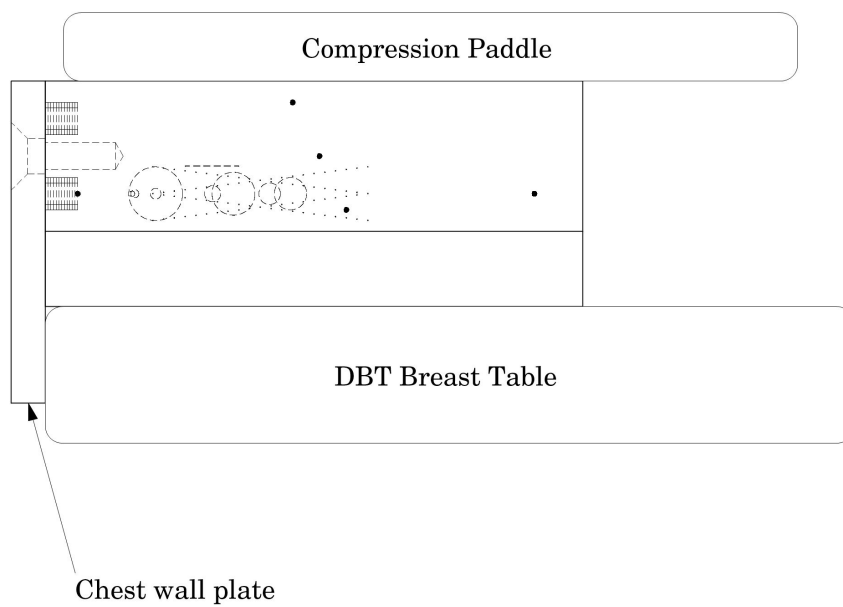
## Schematic drawings



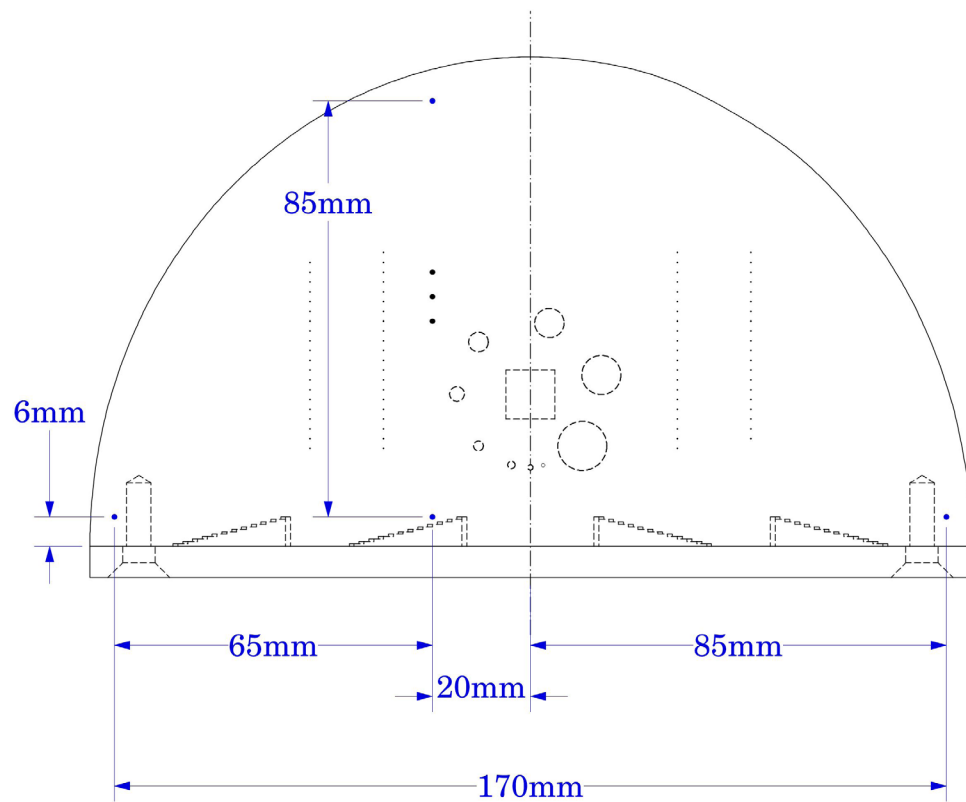
The above schematic shows the internal test components of the Tomophan™ phantom. In this view the z-axis geometry spheres are on the left side of the phantom (breast) indicating that the test components are on the upper half of the TSP006 Test Object. If the z-axis geometry spheres are on the right side of the phantom then the test components are in the lower half.

### Phantom positioning

Assemble the phantom in the desired configuration (see **Phantom configurations for scanning**) and place the phantom with the Chest Wall Plate firmly positioned against the breast table. Use the breast compression paddle to hold the phantom in position as illustrated below.

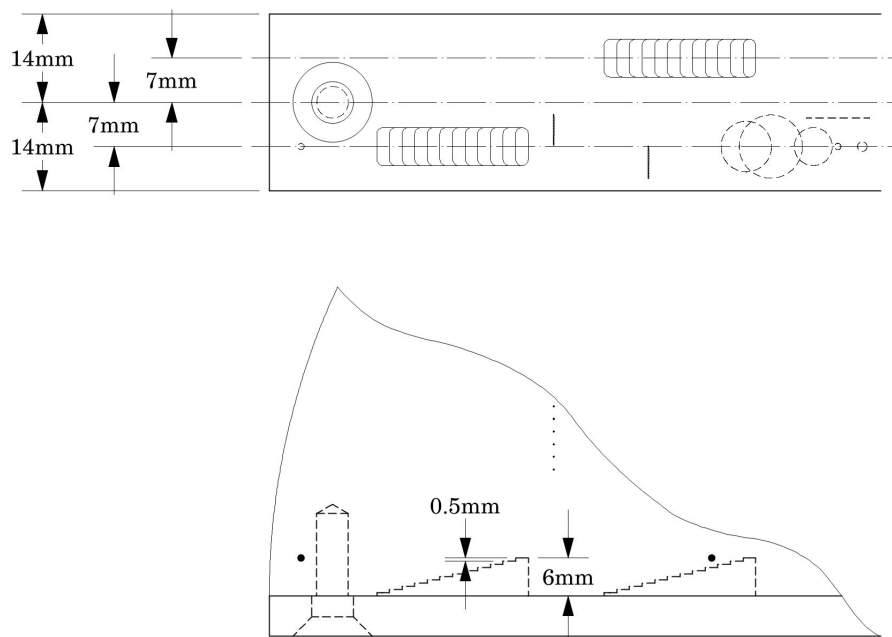


## Scan geometry and alignment



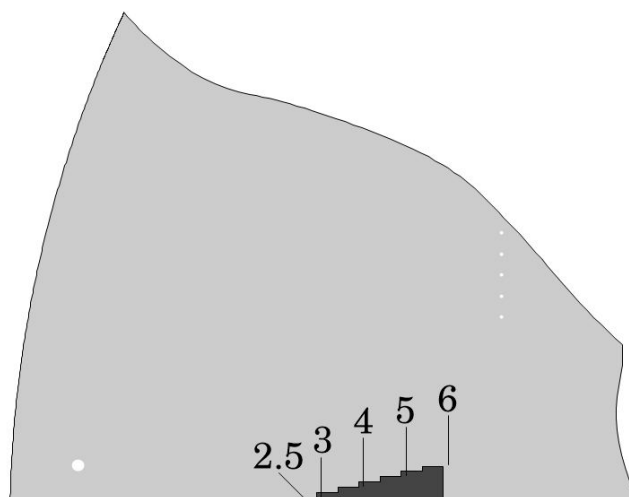
The x and y geometry can be verified by using the four 0.5mm aluminum beads located on the test plane of the phantom (shown in blue in the above illustration). These beads can be used to verify x and y geometry and to indicate the orientation of the Test Object. The spacings of the beads are shown above.

### Chest wall offset



Using the four stair-stepped chest wall missing tissue gauges a measurement of missing chest wall can be made in two locations along the wall at two different slice heights.

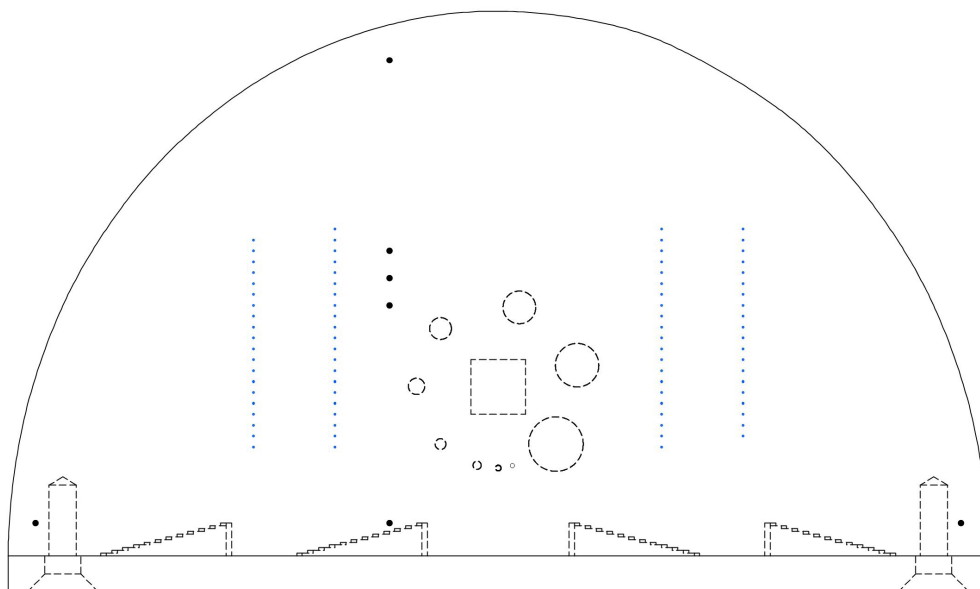
The four gauges have 12 steps in 0.5mm increments rising into the phantom from the chest wall.



Locate the slice which brings the gauge into the sharpest focus and then evaluate how many steps are seen. The above image represents 2.5mm of chest wall being lost.

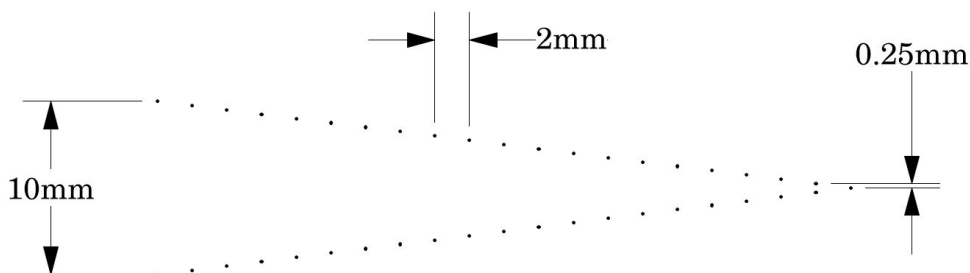
### Scan slice width and Slice Sensitivity Profile, SSP(z) slice geometry

The Tomophan™ phantom uses the well-established Phantom Laboratory technique of trigonometric projection of z-axis depth onto the x-y plane. The phantom includes two sets of two angled bead ramps (left and right of center). Each set has two ramps, with the top bead of the lower ramp centered .25mm below the bottom bead in the upper ramp (see illustrations below). The diameter of each bead is 0.18mm, and beads are spaced vertically at 0.25mm.

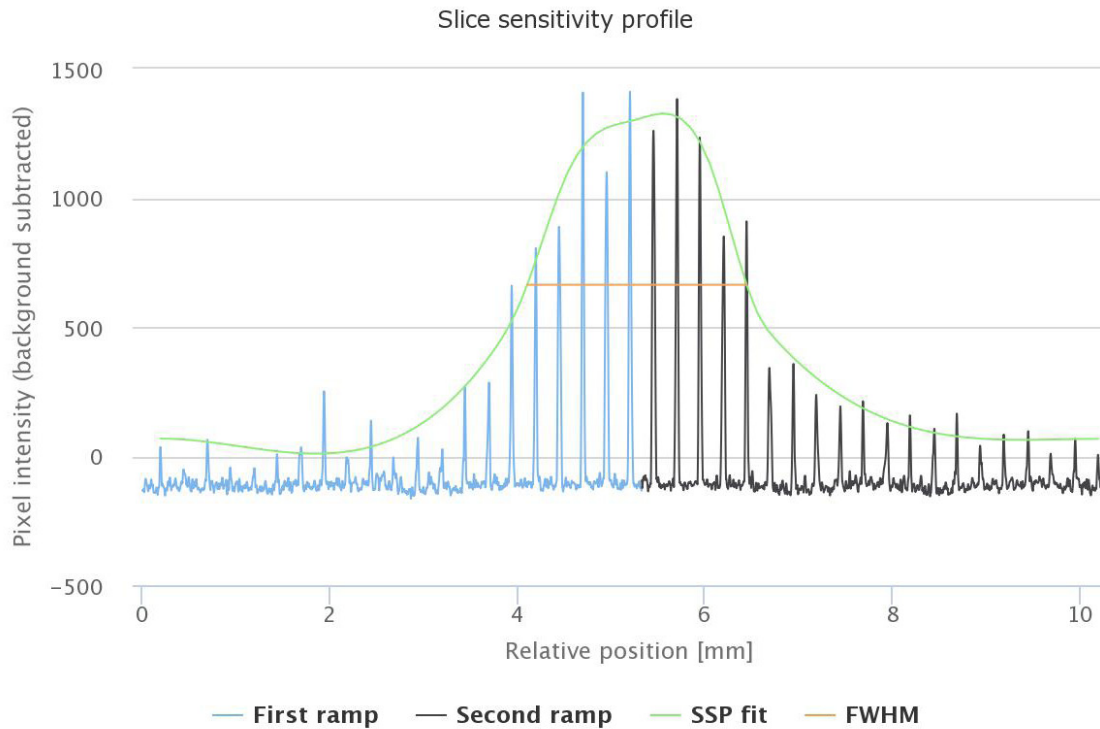


The angled bead ramps in the above illustration are shown in blue. The illustration below shows a side view of a reversing bead ramp set which rise 10mm in the z direction. The ramps on the right side of the phantom run opposite to the ramps on the left side of the phantom.

Reversing bead ramp set



To evaluate the slice width or slice sensitivity profile (SSP), measure the full width at half-maximum (FWHM) of the bead's intensity profile. Subtract the background value from the maximum value and add half that value to the background to calculate the half-maximum. Count the number of beads with a maximum intensity over the half-maximum and multiply by 0.25mm the z-axis spacing. Note a profile needs to be made through both ramps in the set to make sure all the beads over the half maximum are seen.

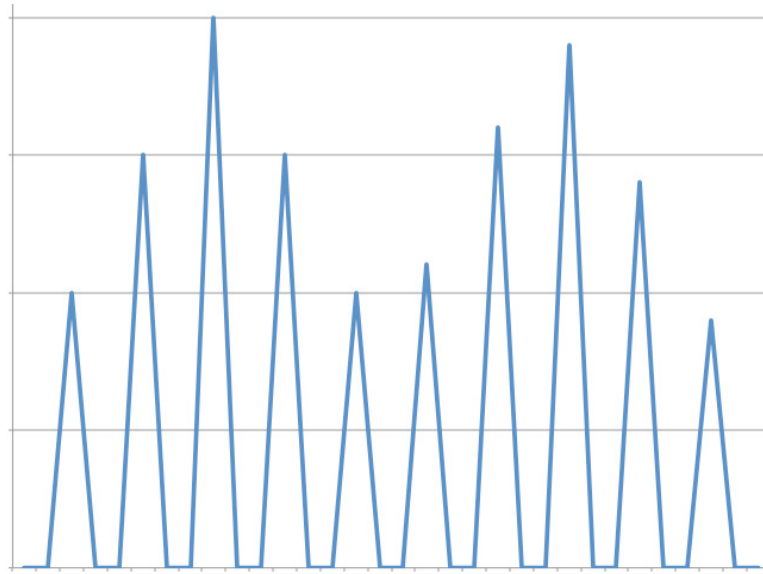


In the above example the maximum value is 1300 and the minimum value is 40 so the half maximum is 670. There are 10 beads with a maximum signal greater than 670 so the slice width would be measured as  $10 \times .25\text{mm} = 2.5\text{mm}$ .

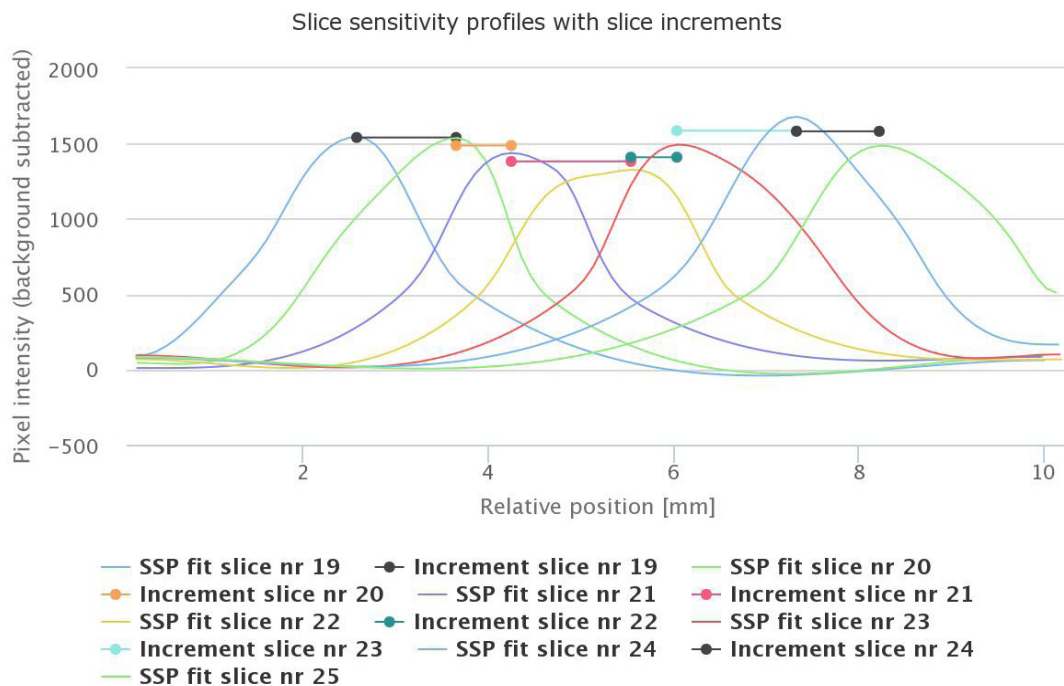
Note that as the slice thickness increases the maximum value for the beads decreases due to volume averaging. Presuming the slice thicknesses are accurate, the peak signal over background in a 1mm slice should be double that of the peak signal over the background in a 2mm slice. This rule, due to the effects of tomographic reconstruction only loosely applies.

## Scan incrementation

The bead ramps can be used to test for proper scan slice-to-slice incrementation or the z-axis distance between slice centers.



The illustration above shows the maximum values of two profiles through the bead ramp from two adjacent slices. There are 5 spaces between the two peaks indicating a slice increment of 1.25mm (5 x .25mm).

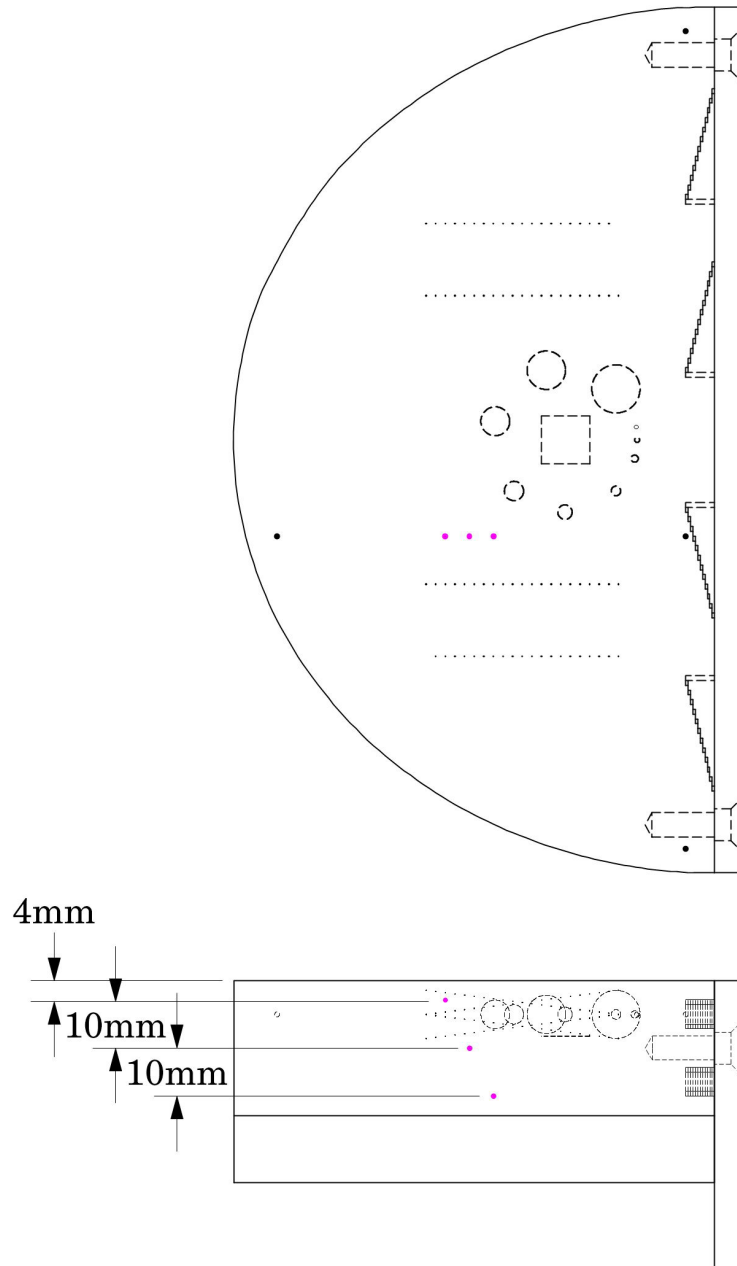


The illustration above shows best fit curves and the measurement between the peaks.

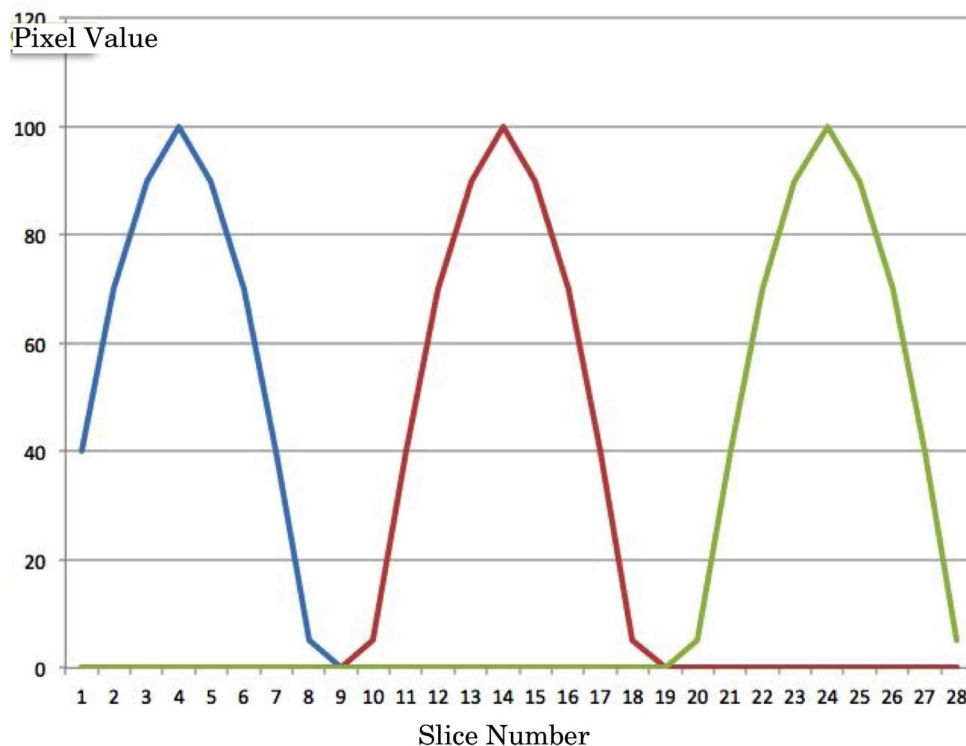


### z-axis geometry beads

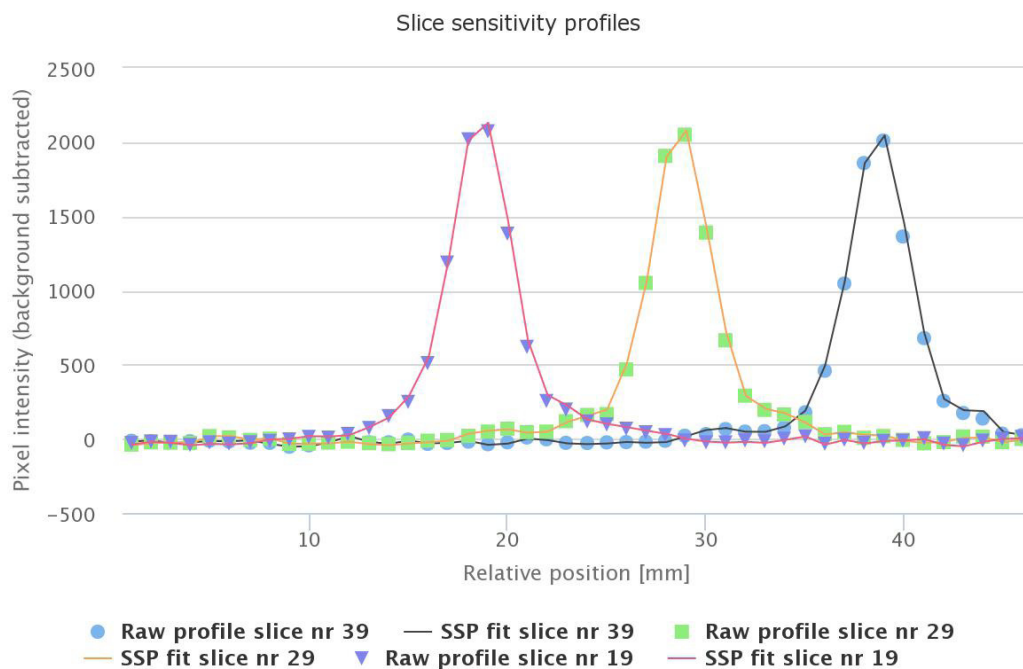
An additional test for z-axis spacing can be conducted with the 0.5mm aluminum z-axis geometry beads. The 3 beads illustrated in pink below are spaced 10mm apart covering a total of 20mm



To use the beads plot the maximum value of each bead on each slice going through the Test Object The maximum value of each of the 3 beads should be separated by 10mm of slices as illustrated in the figure on the next page.



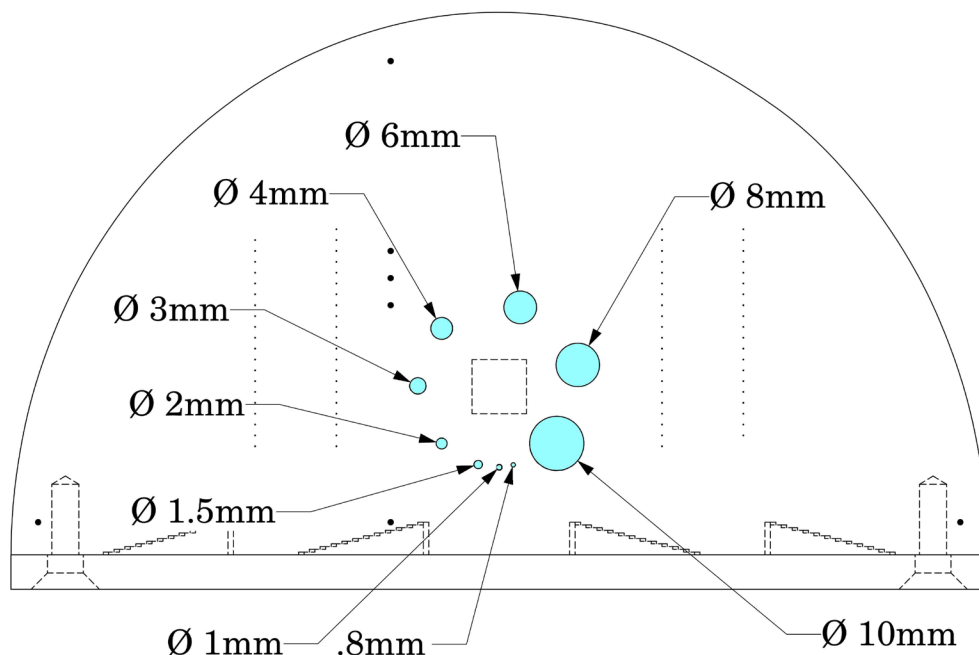
The illustration above shows the maximum value for each bead as we move through the scan. Blue indicates the upper bead, red the middle bead and green the lower bead. In this case the slices have 1mm indexes (y-axis on the scanner and x-axis in the figure). The max bead values are 10 slices or 10mm apart which correlates with the bead spacing.



Above is the Image Owl Tomophan® QA SSP plots for the z-axis geometry beads.

### Low contrast spheres

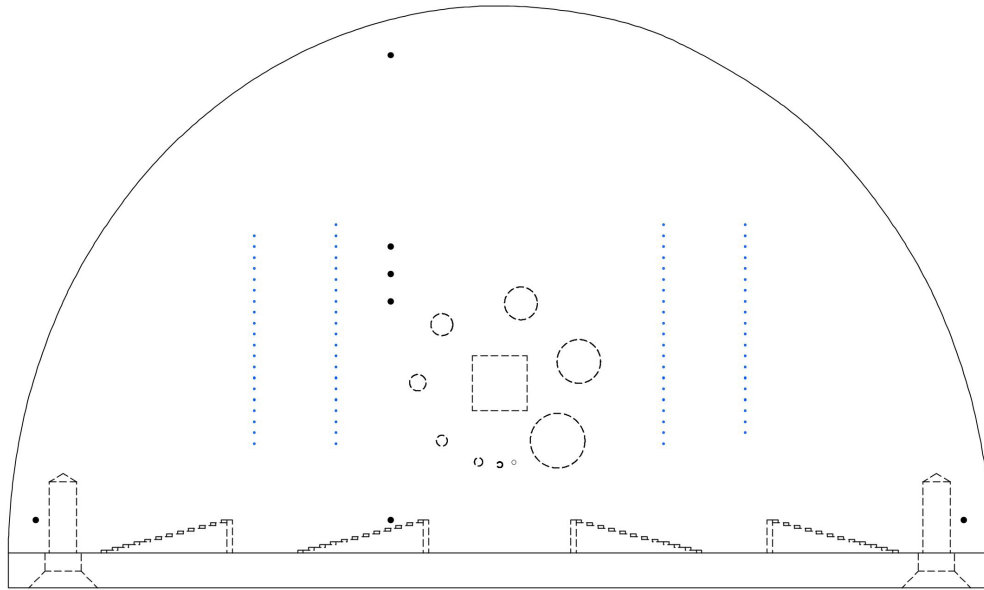
This section has 8 acrylic spheres located in a central circular pattern highlighted in blue in the illustration below. The spheres are used to evaluate the scanner's low contrast capability. The sphere diameters are 0.8, 1, 1.5, 2, 3, 4, 6, 8, and 10mm.



Since the target contrast is variable depending on exposing and reconstruction techniques used for the DBT image, the actual target contrasts need to be determined. The actual contrast levels are measured by making region of interest measurements over the target and in the local background area. To determine actual contrast levels, average the measurements made from several scans. It is important to measure the background area adjacent to the measured target because non-uniformity effects may cause variation of pixel numbers from one image region to another.

Position the region of interest ROI in the central portion of each target to avoid the target edges. The size of the region of interest should be small compared to the contrast sphere diameter, typically 4 x 4 pixels in diameter. Because low contrast measurements are “noisy” it is advisable to calculate an average of multiple measurements made from several scans. Carefully monitor the mAs and kVp settings because the photon flux will improve with increased x-ray exposure (dose) and the contrast of the sphere may vary. Use the size of the targets visualized at various noise levels to estimate information on contrast detail curves.

### Bead point source for point spread function (PSF) and MTF



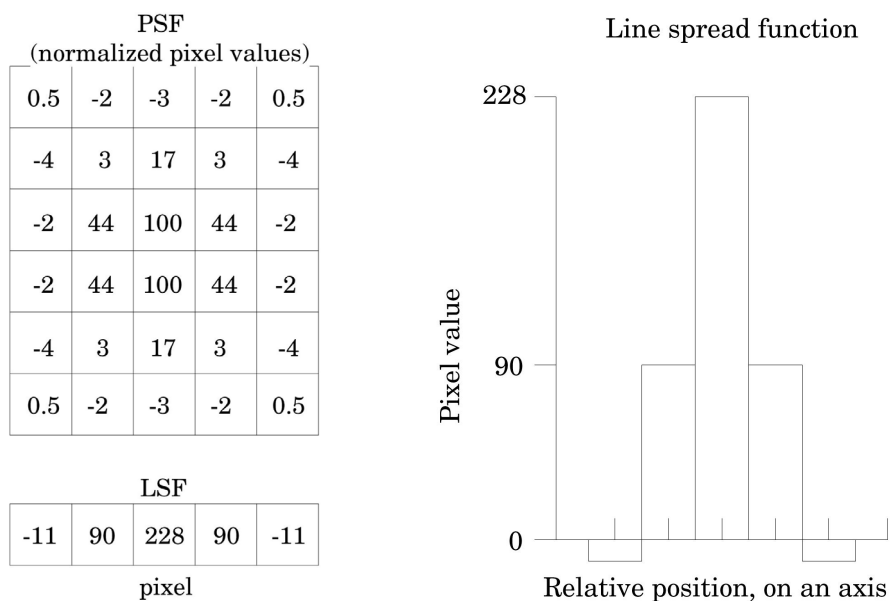
The small beads in the ramps may also be used as impulse sources to estimate the point source response function of the Tomosynthesis system. Use the pixel values of the area surrounding the impulse source to determine the two-dimensional array of the image values arising from the impulse source.

The FWHM of the point spread function is determined from the best-fit curve of the point-spread function numerical data following subtractions of any background intensity.

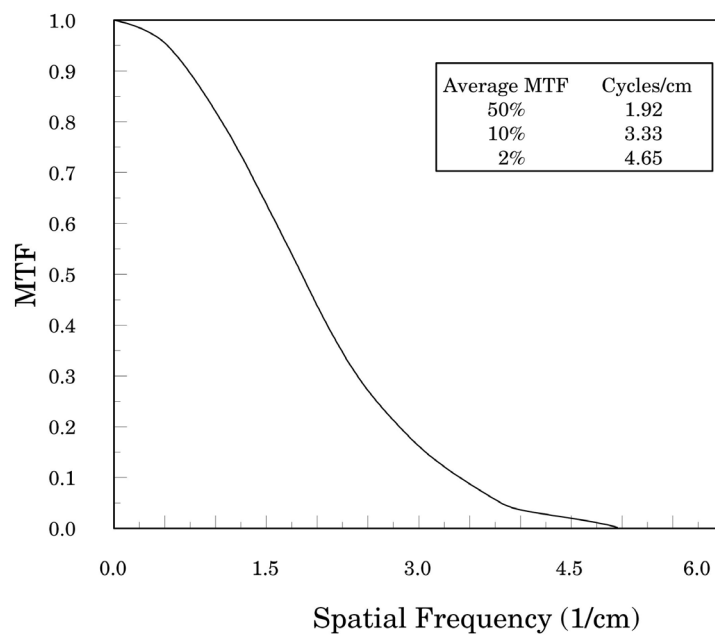
The average of several different arrays of impulse response (beads) functions is calculated to obtain the average point spread function of the system. These numerical values are used in conjunction with a Fourier Transform Program to provide an estimate of the two-dimensional spatial frequency response characteristics (MTF) of the DBT system. This is illustrated on the next page.

The tungsten carbide bead has a diameter of 0.18mm. Compensation may be made for the near pixel size of the bead and some MTF programs are designed to do this.

Note from examination of profiles from several beads as shown on the next page, the general Gaussian-like nature of the profiles can be used for either the point source response function or the corresponding Fourier Transform (FT) to obtain the frequency response estimation for the system.

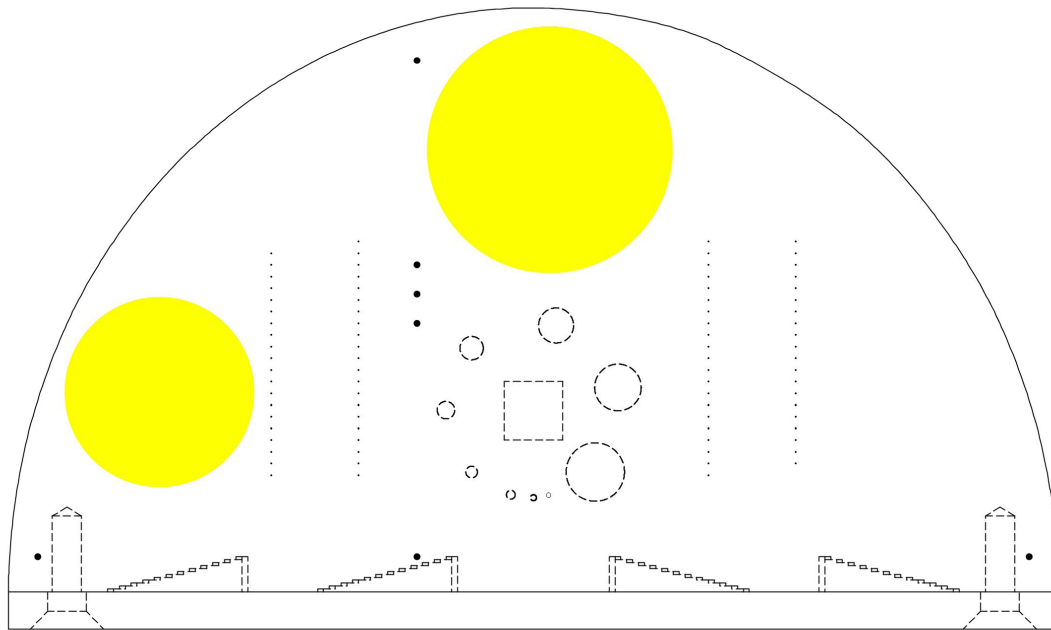


The above illustration shows how by summing the columns (y axis) of numbers in the point spread function (PSF) the line spread function (LSF) for the x axis is obtained.



The MTF curve results from the Fourier transform of the LSF data. Generally it is easiest to use automated software for this operation. Image Owl Inc. ([imageowl.com](http://imageowl.com)) is currently developing an automated service for this phantom.

## Image uniformity tests



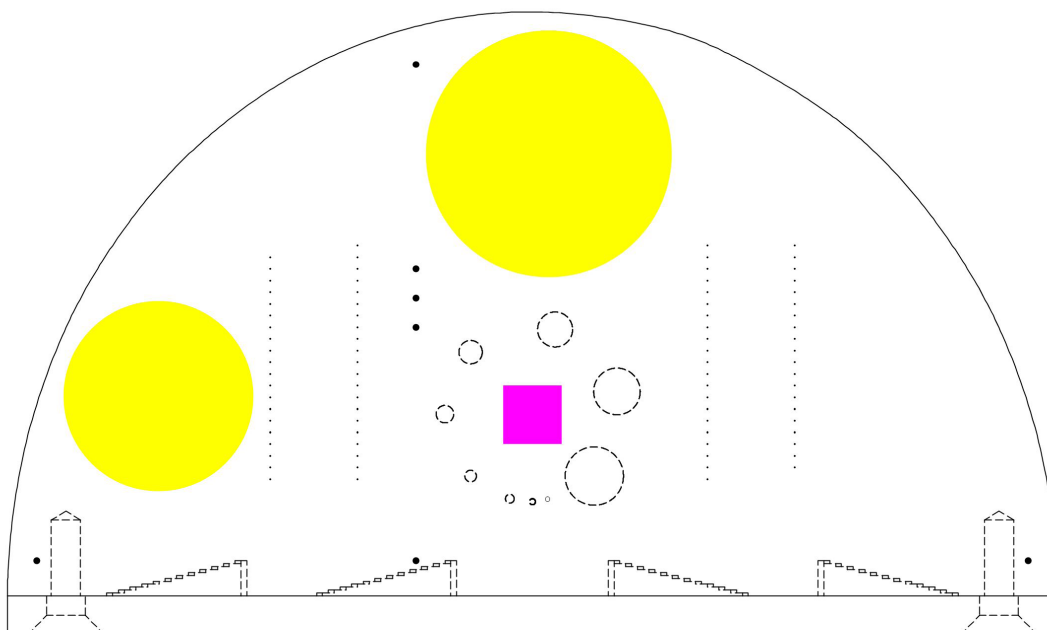
The phantom is cast from a uniform material. The design sets aside areas to be used in uniformity measurements which are seen in the above image as two yellow circles. The material's pixel value is designed to be uniform over the local region.

These areas are used for measurements of spatial uniformity, mean pixel number and noise standard deviation values.

The mean pixel value and standard deviation of a large number of points, (say 1000 for example), in a given ROI of the scan, is determined for central and peripheral locations of the region for each type of exposing protocol. Inspect the data for changes from previous scans and for correlation between neighboring slices.

From the uniformity areas, several parameters can be calculated including signal-to-noise ratio (SNR), and noise power spectrum (NPS).

### Contrast to noise ratio (CNR)



Along with the uniformity areas marked in yellow above, the Tomophan™ phantom has a .2mm thick, 1cm square Aluminum foil insert marked in pink above. This Aluminum square can be used in the calculation of the Contrast to Noise Ratio (CNR)

Measure the pixel values in regions below the Aluminum square, and in similar small regions of noise adjacent to the Aluminum square.

The contrast is defined as the difference between the pixel value of the pixels in the Aluminum square and the pixel value just outside the square. This contrast can be scaled to the typical noise (standard deviation) found in the pixels adjacent to the Aluminum square to arrive at the CNR, Contrast to Noise Ratio. This can be plotted as a function of mAs (or scaled to automatic exposure control (AEC) levels) to look at Dose dependency of the system.

The edge profile of the aluminum square can be used to calculate the line spread function and the corresponding MTF in both x and y directions.

## Bibliography

1. Goodenough  
Assessment of Image Quality of Diagnostic Imaging Systems  
In: Gray GA, ed. Medical images: formation, perception and measurements. Proceedings of the 7th L.H.Gray Conference, New York: John Wiley & Sons, 1976:263-77
2. Goodenough  
Psychophysical Perception of Computed Tomography Images  
In: Newton and Potts (eds). Radiology of the skull and brain: technical aspects of computed tomography. Vol 5, St. Louis: CV Mosby, 1981:3993-4021
3. Vecchio, Brunner, Kaczmarek, Williams and Chakrabarti  
Phantom Design for Image Quality Assessment in Digital Breast Tomosynthesis.  
Presented as a Poster at AAPM 55th Annual Meeting, Indianapolis Indiana, August 2013
4. Rossmann  
Point Spread Function, Line Spread Function and Modulation Transfer Function: Tools for the Study of Imaging Systems  
Radiology 1969:93:257-72
5. Yester and Barnes  
Geometrical Limitations of Computed Tomography (CT) Scanner Resolution Optical instrumentation in Medicine VI. SPIE, 1977:127:296-303
6. R. van Engen et al.  
Protocol for the Quality Control of the Physical and Technical Aspects of Digital Breast Tomosynthesis Systems, 2013, European Reference Organization for Quality Assured Breast Screening and Diagnostic Services, Committee Report