

PHANTOMS FOR PERFORMANCE  
EVALUATION AND QUALITY  
ASSURANCE OF CT SCANNERS



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**Report No. 1**  
**PHANTOMS FOR PERFORMANCE EVALUATION  
AND QUALITY ASSURANCE  
OF CT SCANNERS**

**DIAGNOSTIC RADIOLOGY COMMITTEE  
TASK FORCE ON CT SCANNER PHANTOMS**

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## FOREWORD

The American Association of Physicists in Medicine is organized, as one of its declared purposes, to prepare and to disseminate technical information in medical physics and related fields. In fulfillment of this purpose, the AAPM through a structure of Task Forces, Committees, and Councils prepares recommendations, policy and state-of-the-art reviews in the form of reports. These reports cover topics which may be scientific, educational or professional in nature, and final approval of them is given by that Council of the Association charged with responsibility for the particular concerns of the report.

The present publication is the first of a series of AAPM Reports through which the Association will communicate to its members, and to other interested persons, the findings of selected groups of members in a variety of topical areas. The Publications Committee of the Association hopes that this series will provide an effective means of disseminating a major segment of its work.

Edward W. Webster, Ph.D.  
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## I. INTRODUCTION

The rapid proliferation of computed tomography (CT) scanners has created a need for a document on performance evaluation of a CT scanner. This particular report has as its major goals: (1) to define "performance" of a CT scanner and (2) to describe methods of performance testing through utilization of particular phantoms. The Task Force sees the major goal of this report as providing AAPM members with guidance as to practical methods of evaluating CT scanner performance not on specification of an industry standard phantom. The reader is assumed to have a modest background in CT scanner physics, for example, at the level of references I-4.

## II. PERFORMANCE TESTING:

The performance parameters discussed in this document are listed below:

- (1) Noise/contrast scale
- (2) Spatial resolution
  - (a) image plane
  - (b) slice thickness
  - (c) sensitivity (small lesion detection)
- (3) Patient dose
- (4) Artifacts
  - (e) motion and alignment artifacts
  - (b) spatial uniformity
  - (c) beam hardening
- (5) Linearity
- (6) Site independence
- (7) Reproducibility of performance/Quality assurance

The Task Force recognizes these parameters are not independent of each other. The particular values these parameters take for specification of performance of a CT scanner is a function of imaging task. Also, when the imaging task is defined, the order of importance may change.

It is recommended that the measurement of each performance parameter be measured with a separate phantom (except. in the case of uniformity and noise). One basis for recommendation is that scans of the phantom should produce accurate results for all existing and potential CT scanners.

For the sake of this report, performance tests have been distinguished from quality assurance tests in that performance tests will have an emphasis on measurement of a system's capability, whereas quality control testing is concerned with consistency. A phantom used for quality assurance testing may combine several tests that can be done simultaneously in one scan. Obviously performance evaluation phantoms can be used for quality assurance (although they may not be convenient to use), but the opposite may not be true.

The performance parameters should be estimated with reproducibility determined by the particular CT scanner. The reliability of components of CT scanners vary from design to design, therefore, the Task Force does recommend that each manufacturer provide a quality assurance phantom with their scanner as well as provide a protocol and software for its use.

(1) Noise:

In a CT scanner, if one images a uniform material (e.g., a water bath) and looks at the CT-numbers for a localized region, one would find that the CT-numbers are not all the same, but that they vary around some average or mean value. This variation is called the noise of the system. Noise is a very important measure of CT scanner performance since the naturally occurring difference in attenuation coefficient between normal and pathological tissues

is small<sup>5,6</sup>. Noise of a CT scanner can be measured by scanning a uniform water phantom. This should be done for all potential modes (subject size, kVp, and scan diameters/pixel widths) of clinical use. The noise should be indicated by the standard deviation (computed from  $\sigma = \left[ \sum_i (X_i - \bar{X})^2 / (N-1) \right]^{1/2}$ ) for a sufficient number of pixels (e.g. 25 or more). Noise should be examined for both central and peripheral regions of a scan.

Scan to scan precision for a given tomographic section (detector system) can be obtained by the determination of the standard error (deviation of the mean) from 15 consecutive scans of a water phantom. Precision between tomographic slices (detector systems) of the same scan can be made by comparison of the means and standard deviation for the same matrix area for both slices from a single scan of water.

#### Contrast Scale:

Even though the most common display of the results of a CT scan is a gray level picture which is interpreted for clinical results and photographed for storage, the fundamental measurement of CT-scanners is narrow beam transmission resulting in a cross sectional reconstruction of numbers presumably related to the x-ray linear attenuation coefficient,  $\mu$ . The linear attenuation coefficient depends upon (1) physical density (grams/cm<sup>3</sup>), (2) atomic composition, and (3) photon energy. Most CT scanners utilize a polychromatic x-ray source and provide numbers related to an x-ray linear attenuation coefficient which has been averaged over the various energies in the photon spectrum being detected<sup>7</sup>. Because of this, CT numbers relative to water may depend on the size of the object being scanned and other physical properties of the object.

Since the number scale in any given CT scanner is arbitrary, one must determine the contrast scale (that is, the change in linear attenuation

coefficient per CT-number) in order to reduce the CT-number standard deviation to a machine independent basis. Since the average linear attenuation difference between Plexiglas and water is constant ( $\pm 0.001 \text{ cm}^{-1}$ ) for 100 kVp-150 kVp and moderate filtration (e.g. 1-5 mm Al), a measurement of CT-number for Plexiglas at the center of a water bath and water will permit computation of the contrast/scale through use of

$$CS = \frac{\mu_{\text{plex}} - \mu_{\text{water}}}{(\text{CT-No.})_{\text{Plex}} - (\text{CT-No.})_{\text{H}_2\text{O}}} \text{ cm}^{-1}/\text{CT-number.} \quad (1)$$

Since the variation in the physical density of any given plastic may be comparable to the accuracies desired for CT scanner evaluation it is important to ascertain physical density of the plastics. For Plexiglas with  $\rho = 1.19 \text{ grams/cm}^3$ ,  $\mu_{\text{plex}}/\mu_{\text{w}} = 0.024 \text{ cm}^{-1}$  may be used in equation (1).

If the contrast scale has been determined then the standard deviation (noise) may be estimated in absolute units ( $\text{cm}^{-1}$ ). The noise can be reported as a percentage of the attenuation coefficient of water,  $\% \sigma_{\mu_w}$ , and can be calculated using the relation

$$\% \sigma_{\mu_w} = \frac{\sigma \cdot CS \cdot 100}{\mu_w} \cdot \quad (2)$$

For scanners that operate with x-ray tube potentials of 100-140 kVp and water bath diameters between 8 and 12 inches, a nominal value for linear attenuation coefficient of water ( $\mu_w$ ) is  $0.190 \text{ cm}^{-1}$ .

(2) Spatial Resolution:

Spatial resolution is the ability to distinguish two objects from each other in a noiseless field. Although the concept of measuring the smallest visible object in a scan provides one approach to measuring "resolution", strictly speaking it is a function of contrast and noise as well as spatial resolution. This type of determination may be called sensitivity or, more appropriately, low contrast detectability. The Task Force emphasizes the need for determining both spatial resolution (high contrast response) and low



contrast detectability (sensitivity) in evaluating CT-scanner performance . Reasons for this include: (a) various scanners will have different approaches to the problem of the tradeoff of spatial resolution and noise for the same patient dosage and, more importantly, (b) manufacturers may employ some post-picture processing which may alter the “character” of the noise.

(2a) Image Plane

Spatial resolution should be distinguished from displayed picture element (pixel) width. The pixel size may be significantly smaller than the true resolution of the CT scanner, especially in a scanner which provides a very fine displayed matrix arrived at by interpolating from the true reconstruction matrix. Resolution should be checked over the entire field; this is especially true in fanbeam systems. It is highly desirable that spatial resolution of CT-scanner be expressed as the full width at half maximum of the line spread function (LSF).

Spatial resolution may be measured with established techniques. Several may be adapted to CT scanners; for example:

- (a) Wedge or spoke type modulation transfer function (MTF) phantoms<sup>8</sup>;
- (b) Edge response to obtain LSF and MTF<sup>9</sup>;
- (c) Impulse response for a small wire to obtain the LSF and

The Task Force wishes to point out that in CT scanners the limiting resolution of most units appears to be comparable to the reconstructed picture element (pixel) size. Hence, any determination of MTF using an impulse or discontinuity measurement is complicated by the fact that over the region of the size of one pixel the function being measured (e.g. LSF) changes drastically and one usually obtains only a few data points. Judy<sup>9</sup> has described a slant edge approach to generate a series of precisely known offset edge response functions. MacIntyre et al<sup>8</sup> accomplish a similar outcome by

averaging over several "oscillations" of their wedge phantom. Bischof and Ehrhardt average over several scans of a wire to average out noise in a determination of LSF<sup>10</sup>.

As a suitable alternative to the above methods, and to obtain relative information about "spatial resolution" of different CT scanners, a measurement of the disappearance spacing of moderate contrast holes can be used. For this method, holes drilled into Plexiglas can be filled with water and scanned. The Task Group wishes to point out the lack of rigor in this approach, but also wishes to emphasize its convenience. This approach also has the advantage of not requiring printout of digital CT values, a real problem since many radiologists are not ordering line printers. The disappearance distance will not be too dissimilar to the line spread function.

(2b) Slice Thickness

The slice thickness of a CT-scanner is determined by focal spot geometry as well as pre-patient and detector collimation, and alignment. The Task Force recommends that width at one half maximum response be used to express cut thickness and that a quantitative expression of relative sensitivity through the slice thickness be obtained.

(2c) Sensitivity

The sensitivity of a CT scanner may be defined as the smallest size circular object detectable. The difference of the attenuation coefficients between the object and its surrounding must be established. An equivalent measure of sensitivity is minimum detectable difference of attenuation coefficients for a given object size.

(3) Radiation Dose:

Radiation dose can be measured using thermoluminescence dosimeters (TLD) with noise phantoms or an anthropomorphic phantoms. Dosimetric techniques are described in ICRU 19 and will not be repeated in this document. Certain TLD

phosphors have increased sensitivity in the range of photon energies observed in CT scanners. The thermoluminescent phosphor, LiF, shows only modest increased energy response (relative to Cobalt-60) in the photon energy range relevant to CT-scanning. For LiF TLD dosimetry a  $\pm 10$  percent accuracy is to be expected in a measurement of exposure using a calibration factor 0.8 times an exposure calibration factor at Cobalt-60 energies. Since between scanners there is great variability in pre-patient collimation, dosages should be obtained for both single and multiple slice studies,

(4) Artifacts:

(a) Alignment and motion artifacts

The successful reconstruction process requires critical mechanical alignment and registration. Misalignment and patient movement produce the same type of artifact, i.e. streaking from high contrast details. Alignment can be checked with ½" aluminum pins placed at several non-symmetric locations in a water bath on sequential scans. The display is set for highest contrast and the lower level brought to just above water bath noise. Any significant streaking from image(s) of isolated pin(s) indicates poor registration,

(b) Spatial uniformity

Spatial independence can be measured by scanning a uniform object (e.g., water bath) and looking for deviations from uniformity. For example, if one examines a single line from the scan then it is possible to check for deviations of individual CT-numbers in excess of + 2 standard deviations of the central area values.

(c) Beam hardening

The use of a polychromatic x-ray beam in most CT scanners, makes these devices subject to artifacts due to unequal filtration in each of the "views" used to measure a point<sup>11-13</sup>. The severity of these effects can be checked by observing the **change in mean value** for a water bath in the presence of various amounts and varying geometries of non-water like substances. The Task Force

wishes to emphasize two points pertaining to evaluating artifacts in CT scanners. First, the difficulty of arriving at a consensus for a quantitative artifact test, Secondly, the simultaneous existence of more than one artifact in CT-scanning makes artifact performance evaluation and analysis intimately related to the imaging task.

(5) Linearity:

It is also of interest to establish whether CT-numbers vary in a linear fashion with the linear attenuation coefficients of the material studied, The verification of linearity is of interest because it establishes the constancy of contrast scale over the range of CT-numbers of clinical interest.

Obviously, one must have the means of varying the linear x-ray attenuation by amounts adequate to give a reasonable difference in CT-numbers. For the photon energies used in most CT scanners, the range of fat to soft tissue attenuation is adequately covered by plastics with attenuation values between those for polyethylene and Plexiglas<sup>2</sup>. It should be noted that the physical density (grams/cm<sup>3</sup>) for any sample of a plastic should be determined so that the linear attenuation coefficients for the samples being studied can be accurately calculated from  $\mu = \mu_0 \cdot \rho$ . The Task Group notes the wide variations in density in certain plastics (e.g., Lexan, nylon).

(6) Size Independence:

The Task Force recognizes that tissue attenuation properties as measured by CT scanners are values relative to water. Unless the kVp or relative atomic numbers of the tissues vary significantly, CT numbers relative to water will be relatively independent of kVp or size of subject. However, the Task Force feels that the absolute CT number values for water should be relatively independent of subject size and kVp in order to facilitate the potential of providing differential diagnoses based on CT-numbers.

(7) Reproducibility/Quality Assurance:

The Task Force recommends that an evaluation of performance include the

consistency of certain performance descriptors. For example, scan-to-scan precision should be established to check on short term constancy, A program to check the following performance descriptors over the lifetime of the CT scanner should be established

- (a) noise (standard deviation)
- (b) mean CT-number for water and size/shape independence
- (c) contrast scale (e.g. polyethylene and Plexiglas)
- (d) spatial uniformity
- (e) alignment (if needed).

The Task Force encourages manufacturers of CT scanners to provide quality assurance phantoms and software for automatic interrogation and permanent storage.

PHANTOMS:

(1) Noise Phantom:

The noise phantom shall be filled with water. For water bath" CT scanners the dimension and construction of the noise phantom shall be that of the water box, For-non-water bath scanners the noise phantom shall have a circular cross section. Each wall shall be Plexiglas, less than 1 cm thick. Other material may be substituted for the wall, if the linear attenuation coefficient difference from water can be shown to be less than that of Plexiglas for all operating conditions of the scanner. The outer diameter of noise phantom shall be either 8 inches (203 mm) to simulate a head study or 13 inches (330 mm) to simulate a body study (Figures 1 + 5).

The Task Force recommends that the CT scanner noise level can be evaluated by determining the statistical fluctuations in the CT-numbers for a specified area within a single scan of a uniform object such as water. The noise is the standard deviation in CT-numbers from the scan of a water phantom converted to machine independent basis (e.g.  $\text{cm}^3$  or  $\% \sigma \mu_w$ ) using the contrast scale calibration. The CT-number sample is to be taken from the center for an area of  $2 \text{ cm}^2$  providing this area contains at least 25 picture elements (pixels).

Values of noise for peripherally located areas should also be examined. The Task Force wishes to emphasize the necessity of a separate measurement of noise for the various operational modes (kVp, scan time, pixel widths/scan diameter) of the CT scanner.

Scan to scan precision for a given tomographic section can be obtained by the determination of the standard deviation of the mean values.

(1b) Contrast Scale Phantom

A 2.5 cm diameter Plexiglas ( $\rho = 1.19 \pm 0.01$  grams/cm<sup>3</sup>) rod (Figure (2)) centered in the 8 in. diameter noise phantom or the center of the water box for "water-bath" CT-scanners. For "water-bath" scanners the user will have to provide the means for mounting the Plexiglas rod. For example, a Tupperware lettuce keeper provides an easy way to insert phantoms into "water-bath" head CT-scanners. The mean of the CT values at the center of the rod should be used for CT value for Plexiglas. The contrast scale shall be calculated using Equ.(1) with  $\mu_{\text{plex}} - \mu_w = 0.024$  cm<sup>-1</sup> and the mean CT number for water as determined using the 8 inch diameter noise phantom.

(2a1) Spatial Resolution Phantom (Edge Phantom):

The phantom shall have a straight edge at least 80 mm long (Figure 3). The change in attenuation coefficients across the edge shall be between 0.02-0.04 cm<sup>-1</sup>. The Task Force notes this may be achieved by placing a block of Plexiglas in the noise phantom and with the surface exactly parallel to the axis of rotation of the scanner. The true orientation angle is obtained from the viewer picture. The analysis may be carried out as described by Judy<sup>9</sup> and requires that the CT facility have the capability of printing out the CT-numbers.

(2a2) Spatial Resolution Phantom (Hole Pattern):

holes drilled into Plexiglas can be filled with water and scanned. Each row of holes should consist of a series of holes with center-to-center distance equal to twice the hole diameter (Figure 3). This provides equal alternating

widths of Plexiglas and water. The Task Force suggest holes of diameter 0.75, 1.00, 1.25, 1.50, 1.75, 2.00 and 2.50 mm  $\pm$  5 percent be used. Scanners measured to date suggest that this resolving power range is adequate. Since resolving powers are usually 1.5 times the pixel widths, this hole pattern should be adequate for some of the scanners advertising 0.5 mm pixel widths. Use of a small amount of wetting agent assists in minimizing trapped air bubbles.

The Task Force recommends a peripheral assessment of spatial resolution in addition to a central one. The annulus (Figure 5) that fits over the basic 8" diameter test object tank has two Plexiglas/water resolution targets at 90 degrees apart.

(2b) Slice Thickness

Slice thickness is to be specified as the full width at half maximum of the response across the slice. Goodenough et al related a means of getting an approximate measure of beam width using a series of small beads angled across the beam width and spaced so that center to center separation across width of beam is of the order of 1 mm<sup>14</sup>. However, this phantom is difficult to use for a quantitative measure of response across the width of the beam. Full width at half maximum can be determined by scanning across a 0.5 mm. thick by 1" wide Aluminum piece oriented 45 degrees across the beam width (Figure 4). Beam width (FWHM) can be measured directly from a beam profile plot if care is taken to insure the Aluminum is oriented at 45 degrees across the width of the beam. Slice thickness should be measured both at the center and periphery of the scanned field.

(2c) Sensitivity (Detectability):

The average linear attenuation coefficients of nylon and Lexan differ by about 1 percent. There is a variation in the densities of nylon and

Lexan, so the attenuation difference should be verified by scanning large samples from the same stock used for any phantoms. For the lower contrast phantoms, pin or hole sizes ranging from about 20 mm (3/4 inch) to 3.0 mm (~1/8 inch) are appropriate. In addition to the fact that press fitting small rods without the entrapment of air is not easily accomplished (and is expensive), this phantom only provides one value of relative contrast. Because of this it may be preferable to use various liquid mixtures in contrast to Plexiglas. For example, a 0.55% solution of potassium iodide (550 mg KI in 100 ml distilled water) has been suggested. The Task Force feels that use of a liquid with an effective atomic number,  $\bar{Z}$ , substantially different from that of Plexiglas (6.25) may cause the sensitivity phantom to be much more sensitive to details of the scanner beam and phantom than desirable. The following table (supplied by D. Boyd, Ph.D.) lists relevant factors for some solutions suitable for a low contrast phantom (Figure 6).

<u>Material</u>	<u>Formula</u>	<u>Nominal Density</u>	<u>Electrons per cm<sup>3</sup>/N<sub>A</sub></u>	<u><math>\bar{Z}^a</math></u>	<u><math>A-A_w^b</math></u>
Ethylene glycol <sup>f</sup>		1.12	0.612	6.96	0.016
Glycerol <sup>d</sup>		1.26	0.685	6.99	0.040
Isopropyl alcohol		0.79	0.580	6.34	-0.043
60% glycerol/40% alcohol		1.07	0.643	6.81	0.024
Plexiglas		1.19	0.643	6.60	0.024
Water		1.00	0.556	7.54	0.000
50% dextrose solution <sup>e</sup> .		1.18	0.634	7.10	0.027

- a. effective atomic number calculated assuming <sup>3.80</sup> variation in photo-electric effect (see reference 7)
- b. for a photon energy of 70 keV
- c. antifreeze
- d. glycerine available at drugstores
- e. from reference 18.

### (3) Dose Phantom:

The noise phantom shall be used to measure radiation dose. The dose to the noise phantom should be estimated at the surface of the phantom and at



the center of rotation of phantom. The center of the phantom shall be placed at the center of rotation of scanner. Watertight inserts for TLD capsules may be provided (Figure 7).

(4) Artifacts:

The alignment phantom shall consist of a 1/4 inch Al pin placed in the noise phantom with its axis parallel to the axis of rotation of scanner (Figure 7).

The spatial uniformity phantom shall be the noise phantom.

Beam hardening and dynamic range artifacts should be investigated. Since these artifacts are usually related to a specific imaging task, the Task Force feels that it does not wish to recommend any particular "high-Z" artifact phantom at this time. Actually the best suggestions for these artifact phantoms usually originates from the investigator's clinical colleagues.

(5) Linearity Phantoms:

It is recommended that 2.5 cm diameter pins of Plexiglas, Lexan, nylon, polystyrene, and polyethylene be used (Figure 2). The physical densities of these plastics should be measured. These should be placed in the noise phantom or in phantom of Plexiglas with circular cross section with 18-20 cm diameter.

A potential problem in establishing sensitivity of CT scanners is related to the fact that all high precision CT scanners use a polychromatic x-ray source<sup>11-13</sup>. For non-water bath scanners, objects may be placed in the center of the field to insure each measurement with the same x-ray spectrum in all projections. If spatial uniformity has been verified, the linearity check pins can be placed off center, but should be at least 3 cm from the outside edge of the phantom.

Appropriate values of linear attenuation coefficient can be obtained from tables of  $\mu/\rho$  and the measurement (or specification by phantom manufacturer) of physical density once an appropriate "effective" energy of

measurement is ascertained. The Task Force recognizes the lack of rigor in using the “effective” energy concept, but for the recommended plastic the value of  $\mu(E_{\text{Effective}})$  will be equal to  $\mu$  averaged over the energy fluence spectrum, at least to the accuracy demanded by this test. McCullough and Payne<sup>16</sup> provide data which allows the investigator to select an “effective” energy of measurement.

(6) Size Independence:

The size independence phantoms shall be the 8 and 13 inch diameter noise phantoms (Figure 1).

DISCUSSION:

(1) Relationship of noise and spatial resolution.

The Task Force notes that several investigators<sup>7,15</sup> derived a formula have/for the variance in the reconstructed matrix element values with the following general

form 
$$\sigma^2(\mu) \propto \frac{B}{D_o \cdot h \cdot w^2} \quad (3)$$

where B is the fractional transmission of the object, w the true reconstruction pixel width, h the depth of the slice and D<sub>0</sub> the maximum patient entrance dose. Of immediate interest is the w<sup>3</sup> dependence on pixel width which causes the noise to increase dramatically with reduced width. For example, the decrease in pixel width from 1.5 to 0.75 mm will cause an increase in the noise to 283 percent of the original value, all other factors remaining constant. This can be offset by an eight-fold increase in dosage.

As a result of the above described trade-off, it has been suggested<sup>17</sup> that as an alternative to standard deviation (i.e., the precision in individual CT-numbers), that standard error of the mean for those numbers within a given area be used as a measure of CT-scanner performance. The impetus behind this approach is that, of two systems with identical noise, the one with more picture elements per unit area may be more satisfactory since the noise is easier to integrate out. However, there are at least two possible objections to this approach. First, there is no exact relationship between diagnostic value of the image and the noise/resolution ratio. For example, it is not clear that a system with four times the number of picture elements/cm<sup>2</sup> but twice the noise, is at least as good as the original system, even though both would have an identical estimated standard error of the mean. The size of the object, its contrast, and the viewing distance also are relevant to the discussion. Also, it is not clear that it is appropriate to use a measure which combines standard deviation with the display pixel sizes, since the display picture element sizes may not adequately reflect the true resolving power of the system. For these reasons it is probably judicious to use standard deviation as a measure of precision (noise) of a CT-scanner, although in cross-evaluating various units it should be kept in mind that additional resolution (measured, not inferred from pixel element size) may counteract increased noise. Because of these reasons, the Task Force recommends

that noise of a CT-scanner be expressed only in terms of attenuation coefficient standard deviation.

(2) Expected Sensitivity:

It might appear reasonable to expect any CT scanner to resolve an object with  $\Delta\mu$  equal 1 percent / diameter twice the matrix element size, anywhere in the clinically useful field in all subject sizes of clinical interest, e.g. if the element width is 1.5 mm, one should be able to see a 3.0 mm (1.8") Lexan pin in nylon. In practice, various factors compromise this goal and it appears that one should consider the low contrast sensitivity to be acceptable if a Lexan pin of diameter 3-4 times the pixel dimensions is resolved in a background of nylon, for a scanner with noise value about  $0.001 \text{ cm}^{-1}$ .\* For body size subjects it appears that the minimum Lexan pin that can be seen in a background of nylon will be 1/2 to 3/4 of an inch, for moderate patient exposure (3-4 rads).

(3) Linearity:

The investigator should consider that clinically relevant linearity is not observed if any CT-number mean value deviates by more than two times the standard deviation from a best fit straight line describing the relationship of CT-numbers mean values to linear attenuation coefficient over the range of polyethylene to Plexiglas. The Task Force suggests the expected mass attenuation calculated using the concept of effective monoenergetic energy, but notes difficulty with the concept when both the Compton effect and photoelectric effect contributes to the attenuation process. The error is less than 1% for the plastic listed above.

(4) Accuracy and phantom size independence:

Accuracy requirements (i.e., when the measurement of the x-ray linear attenuation coefficient by a CT-scanner agrees with the expected value related

\*  $\% \sigma_{\mu_w} = 0.5 \text{ percent}$

to the condition of measurement) may not be important since there appears to be a non-negligible variation in CT-numbers for the same pathological and normal tissues. What appears to be reasonable is to expect that there only be modest variations in CT-numbers with changes in operating conditions (subject size, kilovoltage). It would seem reasonable to expect that the mean value of water, when either scan size or kVp of operation is changed, should not change by more than the standard deviation of the central area of a uniform water bath on the smallest scan size for the same scan time.

FUTURE EFFORT:

This report has sought to summarize the important performance features of CT scanners and to outline phantoms for their evaluation. This Task Force and/or others will continue to meet to discuss needs in the field. In the near future the Task Force hopes to address some of the following topics; (a) exposures to patients, (b) room shielding, (c) character of noise, (d) viewer/display optimization studies, (e) image processing, (f) automated analysis and (g) role of CT in radiation therapy treatment planning. Comments on this report or any other topic of CT physics would be most welcome and should be addressed to:

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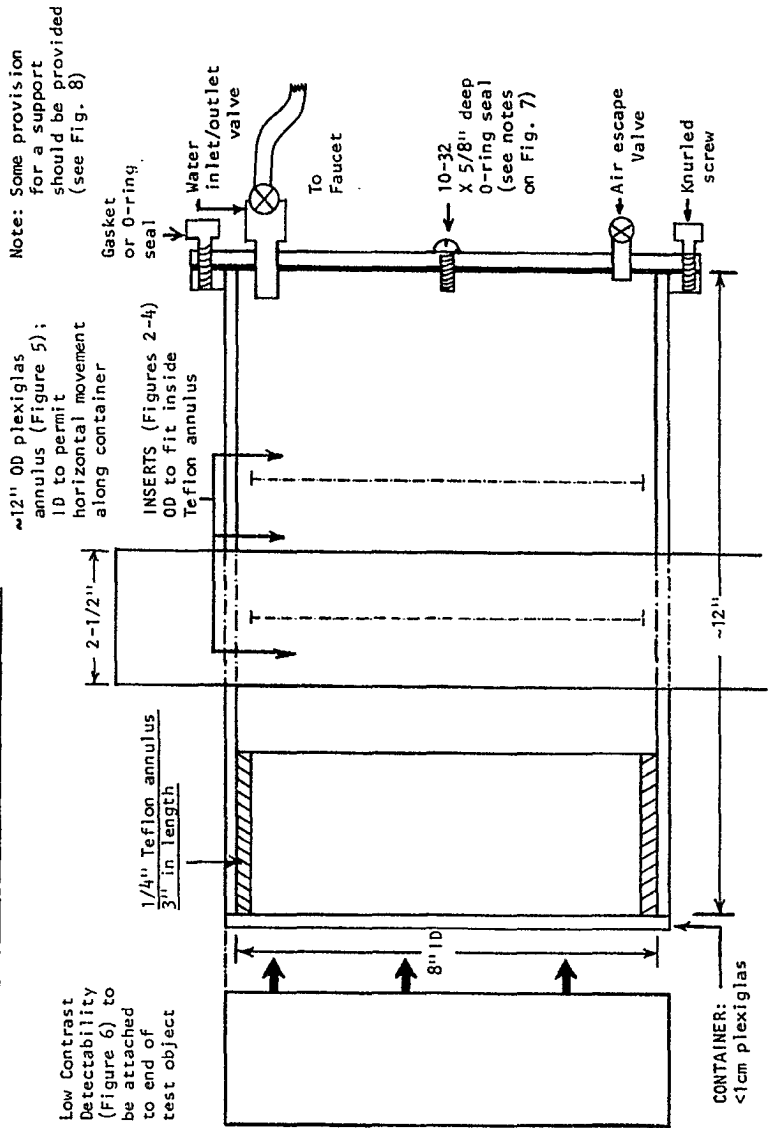
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- 

#### Appendix

##### A Typical Phantom Configuration for Evaluating Performance of X-ray Transmission computed Tomography (XCT) Scanners\*

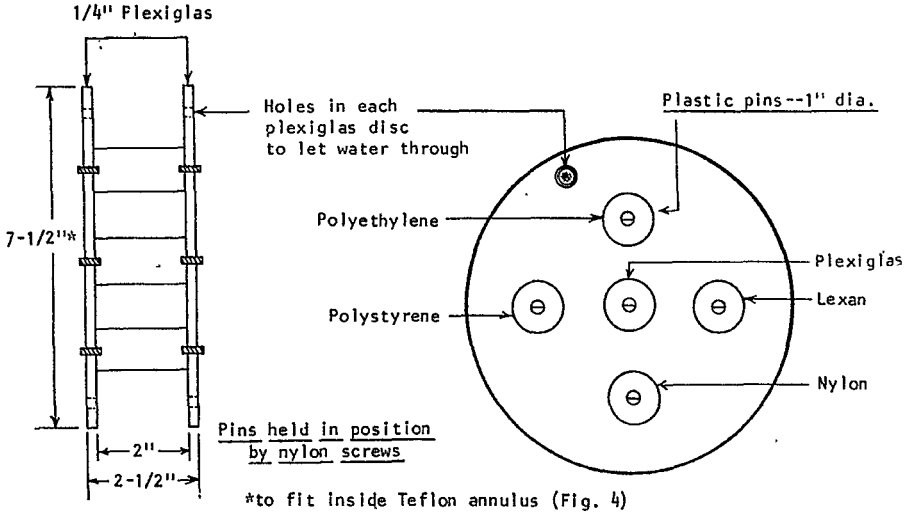
\*NOTE: The phantom contained in this Appendix is only one of a number of configurations to permit the evaluation of XCT scanners. Even though this configuration is presented to assist AAPM members in carrying out the evaluations outlined in this report, this phantom design should not be construed as being recommended over other equally useful designs.

**FIGURE 1: BASIC PERFORMANCE EVALUATION TEST OBJECT**

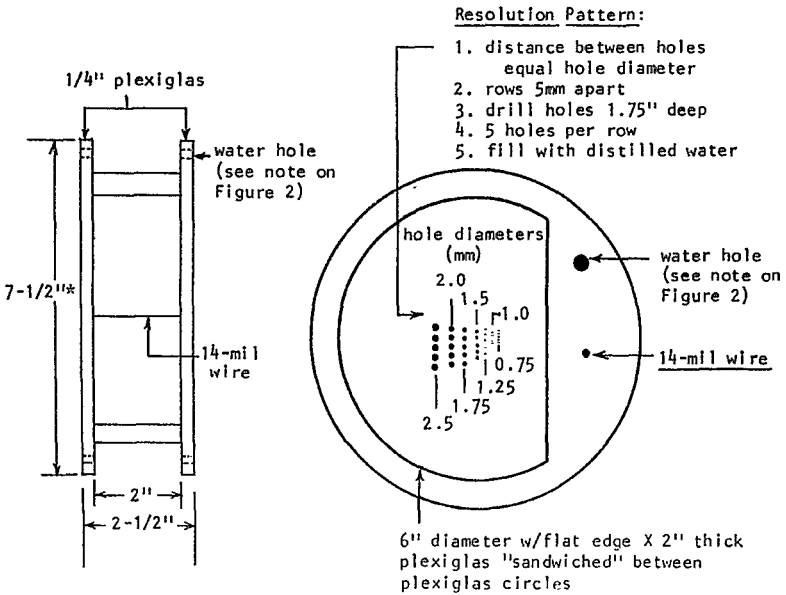




**FIGURE 2: CONTRAST SCALE/LINEARITY INSERT**



**FIGURE 3: IMAGE PLANE HIGH-CONTRAST RESOLUTION INSERT**



\*to fit inside Teflon annulus (Fig. 1)

FIGURE 4: SLICE WIDTH INSERT

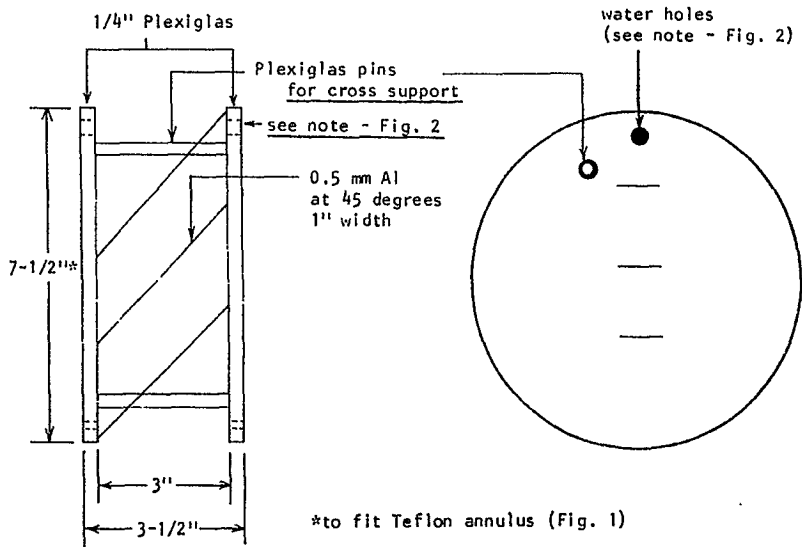
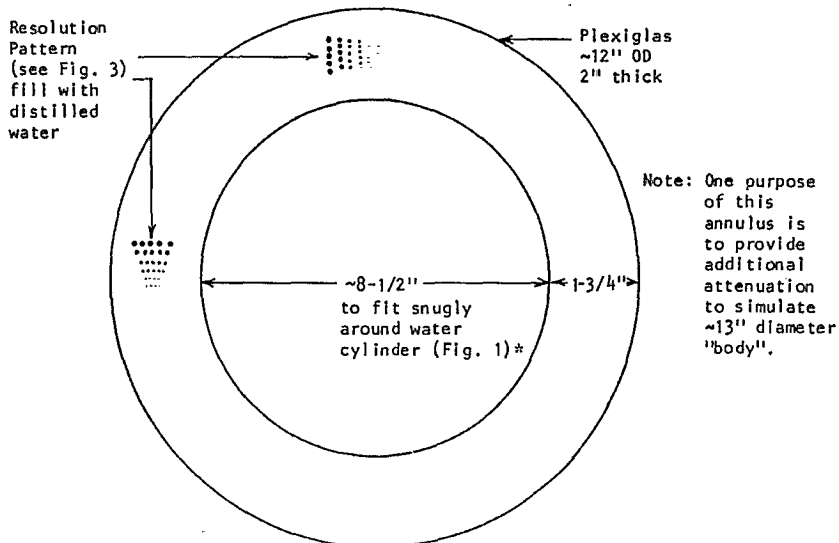
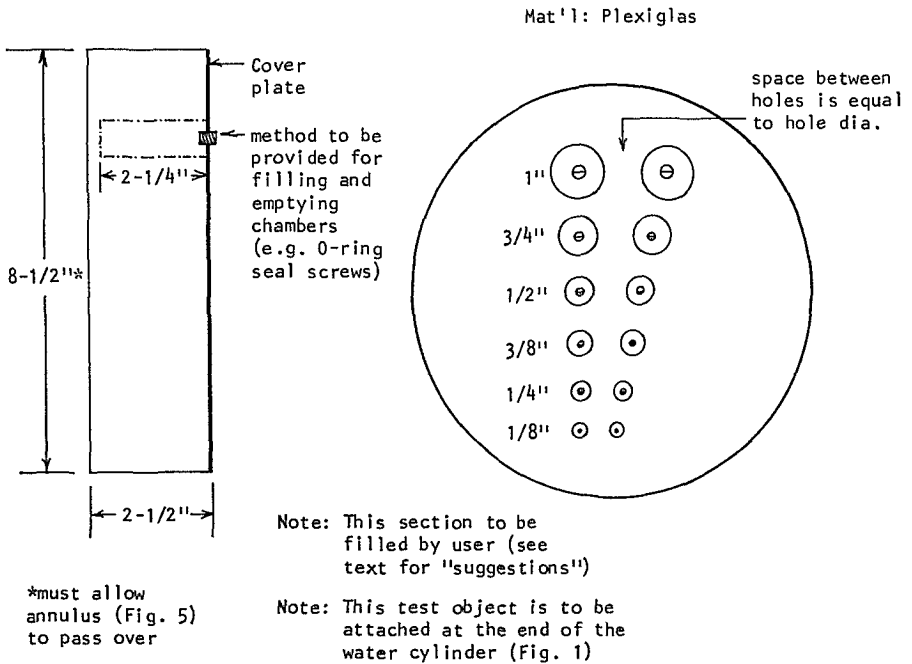


FIGURE 5: WHOLE-BODY ANNULUS/PERIPHERAL HIGH-CONTRAST RESOLUTION

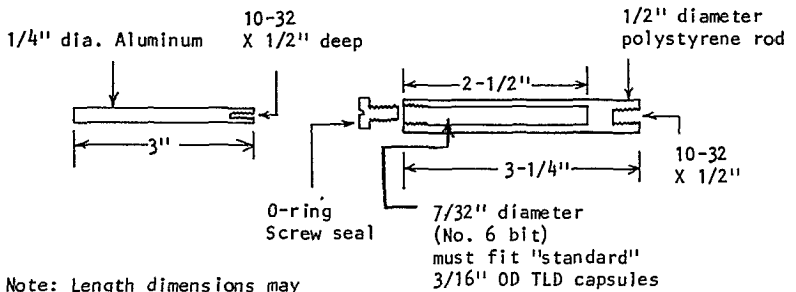


\*must be able to move along water cylinder including low-contrast detectability section (Fig. 6) that is attached to end of cylinder (Fig. 1).

**FIGURE 6: LOW-CONTRAST DETECTABILITY**



**FIGURE 7: ALIGNMENT AND DOSIMETRY INSERTS\***



Note: Length dimensions may have to be altered to suit method of insertion.

\*The three inserts (Figs. 2-4) when moved to the left in the water cylinder (Fig. 1) will leave about 3-1/2 inches for noise/uniformity determinations. The two "inserts" on this Figure should be able to be inserted without removing the entire lid of the water container.