Nuclear Associates 18-222 and 18-223
Tissue-Equivalent Mammography Phantom

Instruction Manual

CardinalHealth

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Section 1

Introduction

1.1 Background

The American Cancer Society and American College of Radiology guidelines for the screening of asymptomatic women have made over 50 million women candidates for mammography. In view of the staggering numbers involved, it is critically important that simple but reliable methods be developed to assess system performance, to assure consistent system performance, and to assure consistent production of diagnostically useful images (1, 17).

1.2 The Development of the Standard of Reference

Phantoms for use in mammography should simulate a real breast as closely as possible (2). A list of desirable features for such a phantom can be found in Section 2, page 2-2. Note that the phantom should be able to test for both image quality and dose if system performance is to be evaluated. The phantoms must also be easy to use and yield images that may be unambiguously interpreted.

In developing the tissue-equivalent/realistically shaped phantom:

- Image Contrast may be measured quantitatively with standard densitometers though the use of the embedded step wedge.
- Dose may be calculated by "TLD" or by ion chamber placed on top of the phantom and converted to average glandular dose through conversion tables (3.6 and 3.7) in NCRP Report #985 (2). A suggested dose chart is shown in Figure 2-1.
- Resolution - Simulated tumors and microcalcifications of known size and location are embedded in the phantom for qualitative evaluation. The smallest microcalcifications and tumors are small enough that they will not normally be detected.

1.3 The Realistically Shaped, Tissue-Equivalent Series of Breast Phantoms

Shape

Standard dental modeling techniques were used to obtain molds of the compressed right breast of a volunteer female subject. This breast is 4.5 cm thick and 18 cm in width.

Materials

Tissue-equivalent resin molding techniques were used. The system of resins used have been developed over the past six years to permit mimicking of any body tissue at different diagnostic x-ray levels. The elemental composition of the simulating tissue as compared to Hammerstein's analysis (11) of human tissue is shown in Table 2-1. Also shown in Table 2-2 are comparisons of linear attenuation coefficients for actual and simulated tissue.

The basic phantom (Model 18-222) matches the composition of an average firm breast consisting of 50% adipose tissue and 50% glandular tissue and is realistically shaped. The phantom is suitable for evaluating the mammographic process in the laboratory as well as for monitoring system performance in the clinic. The phantom may be used for screen-film mammography or xeromammography. Each molded breast is surrounded with a .5 cm adipose-equivalent tissue. Thus, the glandular portion of the standard phantom is 3.5 cm in thickness.

The materials used in this phantom have been formulated for optimum response in the film-screen mammographic range of x-ray exposure (24 to 34 kVp), but will generally provide similar results at higher (xeromammographic) exposure ranges.

The resin materials mimic the photon attenuation coefficients of a range of breast tissues. The average elemental composition of the human breast being mimicked is based on the individual elemental compositions of adipose and glandular tissues as reported by Hammerstein (11). See Tables 2-1 and 2-2 for comparative data.

The attenuation coefficients are calculated using the "mixture rule" and the photon mass attenuation and energy absorption coefficients table of J.H. Hubbell (16).

Optional Size Phantoms

The Model 18-222 Phantom is 4.5 cm in compressed thickness. Other sizes available are 4 cm, 5 cm, and 6 cm thickness.

Optional Tissue Densities

Densities ranging from 20% glandular/80% adipose to 70% glandular/30% adipose are available on request.

Details

The Standard Phantom (Model 18-222) has embedded details (Figure 2-2) consisting of:

- Seven masses that are 75% glandular and hemispherical in shape.
- A wax insert with embedded nylon fibers.
- The Model 18-222 has an optical density reference zone. This allows OD measurements, which are position dependent, to be taken from the same area each time. This helps factor out OD variances.
- The Model 18-222 has two edges of beam targets. This enables precise localization of the x-ray beam's edge - for example, is the machine penetrating the chest wall, or is it not close enough to the chest wall such that something may be missed in a clinical setting?
- One line pair test target with line pair tests between 5 and 20 line pair/mm.

The Physicist Research Model (Model 18-223) includes:

- Three tissue equivalent phantoms with removable outer fat layer and with embedded details similar to Model 18-222
  - 4 cm - 50/50 (dense)
  - 5 cm – 30/70 (normal) (or 4.5 cm - 50/50)
  - 6 cm - 20/80 (fatty)
- Three tissue equivalent slab combinations of plates ranging from .5 cm thickness to 2 cm. This permits test imaging in .5 cm increments from a thickness of .5 cm to 7 cm.
  - 30% glandular/70% adipose
  - 50% glandular/50% adipose
  - 70% glandular/30% adipose

- Each set has one removable detail plate (50% glandular) containing:
  - Step Wedge
  - Simulated tumors (100% glandular)
  - Microcalcifications ($CaCO_3$)
  - Tabular alumina specs (AL_2O_3)
  - Fibril (8.7 micron) plus cladding
  - Line pair test target (20 LP/mm)

1.4 Clinical Usefulness

The phantom approaches the desirable features see Section 2, page 2-2. The phantom is realistically shaped and has the tissue equivalency of an average, firm breast. Breast detail components closely mimic the radiographic properties and shapes of normal and pathological breast structures. The shape and configuration of the phantom makes it easy to use by both technologists and physicists. Since the phantom is both realistically shaped and tissue equivalent, it can be reliably used to test for radiation dose as well as image quality. A recently completed field study confirms this assumption (6). Finally, the phantom provides valuable image quality information. The subjective assessment of detail visibility is easy to use for routine clinical assessment while densitometric analysis provides necessary accuracy for laboratory work. Hence the phantoms may be used to assess the mammographic process as well as assuring consistent image performance.

Table 2-3 provides a comparison of composite attenuation for various mammographic phantoms currently commercially available. Also shown are similar calculations for breast tissue using Hammerstein's methodology (11).

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Section 2

Operation

2.1 How To Use the Mammographic Phantom

What To Do First

- Select the technique you would use on a normal 4.5 cm compressed breast of average glandular composition.
- Take one photo-timed image at the technique normally used for the average breast patient.
- With standard densitometer, read central background density in the center of the phantom image. This background density should be 1.0 to 1.2 optical density.
- If first film does not give OD of 1.0, then adjust technique to obtain a background OD of 1.0.
- Record technique and retain image. This now becomes your image control film.

Quantitative Procedures (at least once a week)

- Count the number of microcalcification groups visible and record the number.
- Count the number of simulated tumors and record the number.
- With optical densitometer, read fat and gland steps of the step wedge. Record the values, and the difference (i.e., contrast). The fat/gland (steps 1 vs. step 5) should be .28 or greater.
- With a magnification lens, identify the number of line pair/mm, which are discernible.
- Record values on the record sheet (Figure 2-3).

Long Term Comparisons

- Once a quarter, take one of the weekly test films and compare visually to the initial film. You should see identical images. If not, then corrective actions should be initiated.

Records To Keep

- Daily record of processor function (temperature and OD of step 10 or 11). This requirement is well understood and not discussed further herein.
- Weekly record of step wedge contrast and detail visibility.
- Retained films of weekly phantom checks.
- Keep the QA record sheets (see Figure 2-3) in a file. These records of system performance are valuable to you as a management tool and as proof of good "QA" should your system performance ever be challenged.

Care And Handling

These phantoms are manufactured from high quality materials but, like anatomy they represent, they can be broken. Please handle with care.

If you will treat these phantoms as you would any fragile piece of technical equipment, they will serve you well for many years.

When not in use, the phantom should be stored in a safe location. Store at normal room temperature. If subjected to temperatures above 110° for any extended period of time, return the phantom to Cardinal Health, Radiation Management Service for re-certification.

Cleaning may be accomplished by using mild soap and water solution. It has been reported that some detergents cause the surface of the to become tacky. We use "Armor-All" vinyl protectant and experience no difficulty with tacky surfaces.

Avoid contact with corrosive substances and with radiographic contrast media. Wash thoroughly if such contact occurs.

Desirable Features of A Breast Phantom

1. Structural characteristics of the phantom:
   a. Phantom should be realistically shaped.
   b. Phantom should be tissue equivalent.
   c. Phantom should have a realistic background
   d. Phantom components should mimic features of breast disease (calcifications, tumors.).
2. Phantom should be easy to use.
3. Phantom should test relevant parameters including absorbed dose and image quality.
4. Phantom images should be easy to interpret and provide an accurate, unambiguous measure of image quality.

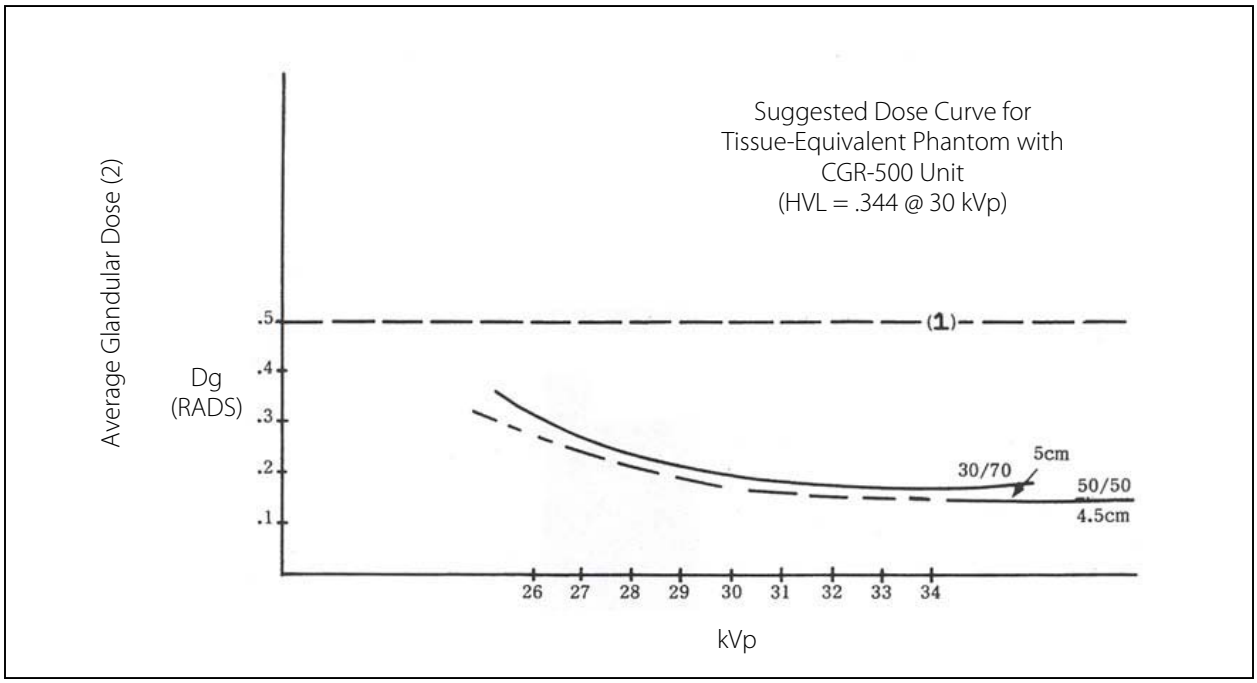


Figure 2-1. Suggested Dose Chart

(1) ½ RAD is considered the maximum acceptable dose for 1 view mammogram of the average patient per the National Council on Radiation Protection and Measurements (NCRP-80).

(2) NCRP-85; Pages 40 – 56.

(3) Measurements were taken at exposure settings that produced background photographic density of 1.0 using Ortho-M Film, Min-R screen, Grid, and General Purpose film processor.

Table 2-1. Actual vs. Simulated Tissue (Weight Fractions)

Tissue	C	O	H	N	Ca	P	Al	G1	Specific Gravity
30% Glandular									
Actual Tissue	48.850	46.400	10.700	2.150		.200			.930
Simulated	75.510	9.960	11.730	1.230	.350			1.180	.930
50% Glandular									
Actual Tissue	40.150	46.400	10.700	2.450		.300			.982
Simulated	75.070	10.160	11.670	1.230	.670			1.170	.982
70% Glandular									
Actual Tissue	31.150	54.920	2.750		.380				1.004
Simulated	74.650	10.350	11.620	1.230	.970			1.170	1.004
100% Glandular									
Actual Tissue	18.400	67.700	10.200	3.200		.5000			1.040
Simulated	70.210	12.510	10.930	1.150	.610		3.460	1.100	1.040
100% Adipose									
Actual Tissue	61.900	25.100	11.200	1.700		.100			.930
Simulated	75.950	9.820	11.760	1.230				1.170	.924

Table 2-2. Actual vs. Simulated Linear Attenuation Coefficients (u)

30% Glandular			**100% Glandular**		
keV	**Actual**	**Simulated**	**keV**	**Actual**	**Simulated**
10.0	3.400820	3.262850	10.0	4.919490	4.685870
15.0	1.112980	1.098010	15.0	1.560170	1.535910
20.0	0.574784	0.574784	20.0	0.768012	0.768012
30.0	0.302201	0.304501	30.0	0.368387	0.371520
40.0	0.232988	0.234800	40.0	0.268827	0.270928
50.0	0.205005	0.206445	50.0	0.229969	0.231386
60.0	0.189907	0.191118	60.0	0.209919	0.210931
80.0	0.172653	0.173673	80.0	0.188308	0.189033
100.0	0.161710	0.162638	100.0	0.175442	0.176050
50% Glandular			**100% Adipose**		
keV	**Actual**	**Simulated**	**keV**	**Actual**	**Simulated**
10.0	3.812000	3.622000	10.0	2.975010	2.837940
15.0	1.234110	1.213450	15.0	0.995056	0.960624
20.0	0.627163	0.627163	20.0	0.530186	0.511345
30.0	0.320188	0.323307	30.0	0.294058	0.280331
40.0	0.242758	0.245163	40.0	0.233268	0.220533
50.0	0.211829	0.213702	50.0	0.208080	0.195861
60.0	0.195389	0.196938	60.0	0.194093	0.182268
80.0	0.176952	0.178232	80.0	0.177546	0.166402
100.0	0.165485	0.166639	100.0	0.166690	0.156112
70% Glandular					
keV	**Actual**	**Simulated**			
10.0	4.231200	3.984430			
15.0	1.357150	1.329930			
20.0	0.679992	0.679992			
30.0	0.337905	0.342249			
40.0	0.252103	0.255583			
50.0	0.218186	0.220987			
60.0	0.200393	0.202773			
80.0	0.180781	0.182797			
100.0	0.168807	0.170643			

NOTE

Our simulated materials are formulated to maximize simulation properties at 20 keV for the mammographic energy range and 70 keV for the diagnostic energy range.

Table 2-3. Attenuation Comparison (μx) for Uses in the Well Known Relationship Various Phantom Densities and Sizes $\frac{I}{I_O} = e^{-\mu x}$

Tissue:	Acrylic	Acrylic	Acrylic	BR-12	50/50	30/70	50/50	30/70	50/50	20/80
Thickness:	4.4 cm	5.0 cm	4.55 cm	4.5 cm	4.0 cm	4.5 cm	4.5 cm	5.0 cm	5.0 cm	6.0 cm
MFGR:	ACR	MFR #1	MFR #2	NAD	NAD	NAD	NAD	NAD	NAD	NAD
Fat Layer:	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
keV										
10	15.542	17.769	16.995	15.942	13.703	14.257	15.514	15.889	17.325	18.294
15	5.127	5.891	5.608	5.298	4.601	4.803	5.207	5.352	5.814	6.175
20 (28 kVp)	2.705	3.103	2.936	2.728	2.392	2.523	2.706	2.811	3.021	3.251
30	1.477	1.691	1.582	1.402	1.251	1.346	1.412	1.498	1.573	1.758
40	1.162	1.328	1.236	1.062	.956	1.042	1.078	1.159	1.201	1.371
50	1.033	1.179	1.095	.925	.836	.918	.944	1.021	1.051	1.211

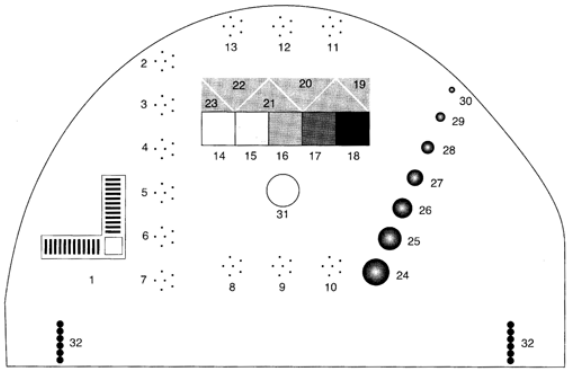
This chart compares the composite attenuation for various phantom size/density compositions.

The linear attenuation coefficient (μ) for each type of material (wax/lucite/gland/fat/etc.) applied to the thickness of the material in each phantom design permits calculation of total attenuation for each phantom design.

Actual Breast Tissue per Hammerstein

Tissue	70/30	50/50	50/50	50/50	30/70	20/80
Thickness:	4.0 cm	4.0 cm	4.5 cm	5.0 cm	5.0 cm	6.0 cm
MFGR:	Actual	Actual	Actual	Actual	Actual	Actual
Fat Layer:	Yes	Yes	Yes	Yes	Yes	Yes
keV						
10	15.689	14.411	16.317	18.223	16.578	18.996
15	5.066	4.697	5.314	5.931	5.446	6.271
20 (28 kVp)	2.571	2.411	2.725	3.038	2.829	3.279
30	1.307	1.254	1.414	1.574	1.502	1.762
40	.989	.961	1.082	1.204	1.165	1.375
50	.862	.843	.949	1.055	1.028	1.217

Figure 2-2. Embedded Details (Model 18-222 Specifications)



- **Line Pair Target**
  20 lp/mm
- **Ca Co_3 Specs**
  Grain Size (mm)
  2. .130
  3. .165
  4. .196
  5. .230
  6. .275
  7. .400
  8. .230
  9. .196
  10. .165
  11. .230
  12. .196
  13. .165
- **Step Wedge**
  1 cm thick
  14. 100% Gland
  15. 70% Gland
  16. 50% Gland
  17. 30% Gland
  18. 100% Adipose
- **Nylon Fibers**
  Diameter size (mm)
  19. 1.25
  20. 0.83
  21. 0.71
  22. 0.53
  23. 0.30
- **Hemispheric Masses**
  75% Glandular/ 25% adipose, thickness (mm)
  24. 4.76
  25. 3.16
  26. 2.38
  27. 1.98
  28. 1.59
  29. 1.19
  30. 0.90
- **Optical Density**
  31. Reference zone
- **Edge of Beam**
  32. Localization target

Quality Assurance Record Mammography

Location: Week/Month

Mammo Unit: QC Phantom No.

Processor Type:

Processor Cycle: 90 sec/2.5 min/3.0 min

	Baseline	Day/WK-1	2	3	4	5		Remarks
Film Type								Record film type and record serial number of film box in use.
kVp (with photomtimer)								Record kVp used for phantom test measurement. Use kVp normally used for an average density 4.5 cm breast.
Processor Temperature °F								Record processor temp at 9:00 A.M. each day.
Processor Speed (Sensitometry – Step 10)								Keep a box of film set aside - sensitize and process. Read step 10 with optical densitometer – record value.
Processor Contrast (Step 9 – 11)								Again, read steps 9 – 11 on the sensitized film. Subtract step 9 value from step 11. Record contrast.
Phantom Contrast (Step 1 – 5)								On the phantom test image, read stepwedge step 1 and step 5. Subtract values. Record contrast.
Phantom Central Background Density								On phantom test image, read background density in the middle of phantom with optical densitometer. Record value.
Phantom Calcifications								On phantom test image, count the number of micro calcification groupings visible. Record value.
Phantom Low Contrast Masses								On the phantom test image, count the number of low contrast masses visible. Records value.
Phantom Line Pair Visible								On phantom test image, view line pair test target with microscope. Record the number of line pairs/mm visible.
Dose (Mean glandular dose for a 4.5 cm 50% Glandular Breast)								Calculate the exposure monthly with ion chamber and convert to mean glandular dose or, contact CIRS for QC kit.

For daily readings, use 1 sheet/week

For weekly readings, use 1 sheet/month

Figure 2-3. Quality Assurance Record

2.2 References

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Radiation Management Services

For additional information, please contact Radiation Management Services business of Cardinal Health at 440.248.9300, or 516.870.0100.

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