Nuclear Associates 76-430

Mini CT QC Phantom

Users Manual

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Table Of Contents

Section 1
Operation

1.1 Suggested Monthly QA Protocol

The protocol suggested here corresponds to the Data Entry Form that appears on page 2-2. Photocopies of the form should be made to use for record keeping.

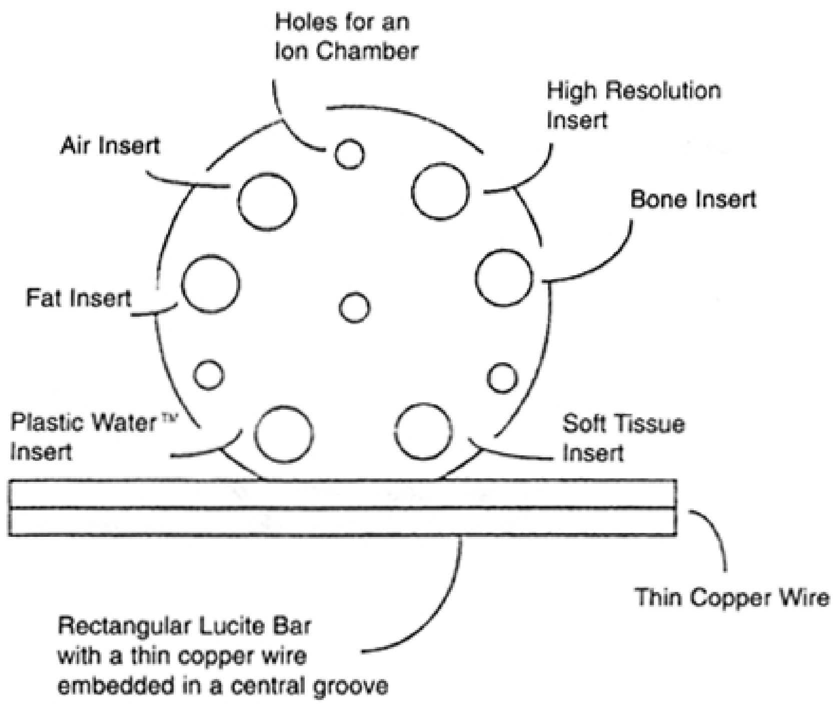

Figure 1-1. Typical Setup for Insert Placement

1.1.1 Safety Aspects and General Items

Check these items by visual observation and by questioning the technologist. Review all the daily and weekly tests that the technologists are required to perform in order to comply with the manufacturer's instructions.

1.1.2 Position Indicators

Check the accuracy of the various indicators at the table and the gantry by manipulating the controls as necessary.

1.1.3 Laser Beam Alignment, Slice Thickness Accuracy, Slice Spacing Accuracy, and Slice Contiguity Checks

Place a 14" x 17" plywood board or a 14" x 17" cassette (with no film inside) on the CT table and tape it securely to the table. Place a 10" x 12" non-screen film in a cardboard holder (Flex Film Cassette Model 07-800-1012) or a paper envelope. Secure it to the plywood board or the cassette with tape at the edges, so that it won't slide during the procedure. Now, place the phantom on top of the film holder with the axis of the phantom disc along the gantry axis. Use a level to ensure accurate positioning. Make sure that the phantom disc is about a third of the way from the top of the film. Perform the following steps in sequence.

1. Move the CT table up or down to bring the film to the level of the gantry axis.
2. Move the CT table in or out as necessary and make the laser beam coincide with the copper wire on the phantom.
3. Make an 8 mm cut. The technique (exposure factors) you use should be close to those that are typically used for a head scan (120 kVp and 250 mAs and 1.0 second scan time). Then make a 4 mm cut making sure that the table has not advanced. Do not remove the film yet. With a properly maintained unit, the 4 mm image will be superimposed exactly over the 8 mm image, and the image of the copper wire will appear at the center of the whole pattern (See Image 1, Figure 1-2).
4. Advance the table by 30 mm. Make a 2 mm cut using the same technique as in step 3. Advance the table by 2 mm and make another 2 mm cut. Do not remove the film yet. With a properly maintained unit, these two images will abut properly, with no gap or overlap. Set your own standards for acceptance based on the manufacturer's specifications (See Image 2, Figure 1-2). Notice that in this case, there is a slight gap between the scans, more so at the edges than in the middle.
5. Advance the table by another 30 mm. Make a 4 mm cut. Then advance the table by 4 mm and make another 4 mm cut. Do not remove the film yet. With a properly maintained unit, these two images will abut properly, with no gap or overlap. Again, set your own standards for acceptance based on the manufacturer's specifications. (See Image 3, Figure 1-2. Notice that in this case, there is a significant overlap between the scans in the middle and a slight gap at the edges.)
6. Advance the table by another 30 mm. This time make an 8 mm cut. Then advance the table by 8 mm and make another 8 mm cut. Do not remove the film yet. With a properly maintained unit, these two images will also abut properly, with no gap or overlap. Again, set your own standards for acceptance based on the manufacturer’s specifications (See Image 4, Figure 1-2). In this case, there is a significant overlap between the scans in the middle and a significant gap at the edges).
7. Remove the film and process it.
8. Examine the processed film and make entries for compliance in the appropriate places on the Data Entry Form on page 2-2.

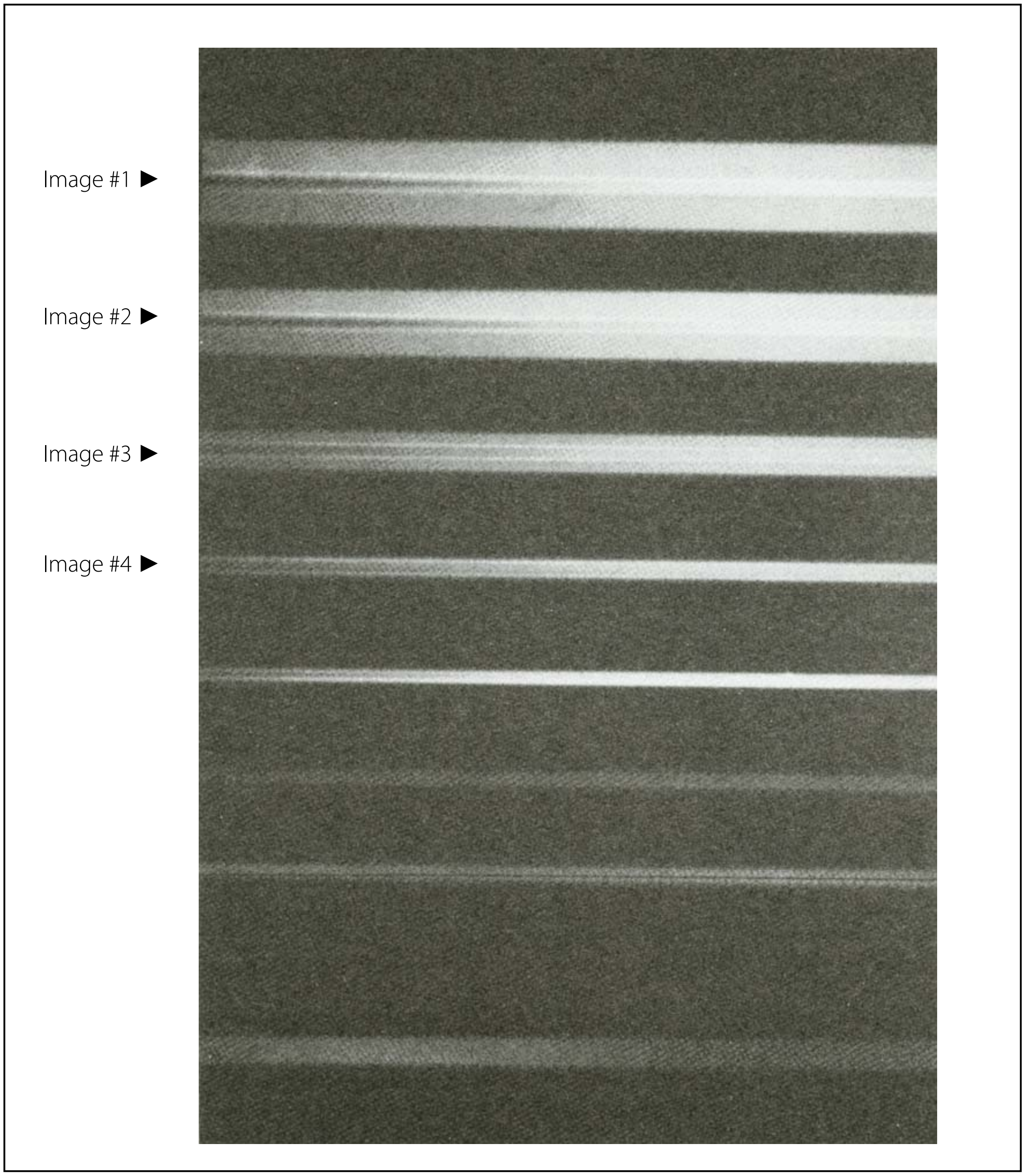

Figure 1-2. Film #1

1.2 Pilot Scan to Transverse Scan correspondence

Put the phantom back on the table, this time without the film. Perform the following steps in sequence:

1. Make a pilot scan of the phantom.
2. Looking at the monitor image, position the cursor at the middle of the phantom disc.
3. Make a 2 mm transverse cut and observe if the center mark on the phantom disc appears in the image. If not, move the table in or out, by 1 mm at a time, until the center mark appears in the image. Record the degree of misalignment, if any, on the Data Entry Form on page 2-2.

1.3 CT Number Uniformity

Using the same image as in the previous test, read the CT numbers and their standard deviations at three locations in the body of the phantom (center, 2 o'clock, 5 o'clock, 8 o'clock, and 11 o'clock). Record them on the Data Entry Form on page 2-2, and make a notation at the bottom of the form if corrective action is necessary. Use the same averaging area as in the previous test while reading the CT numbers (See Figure 1-3).

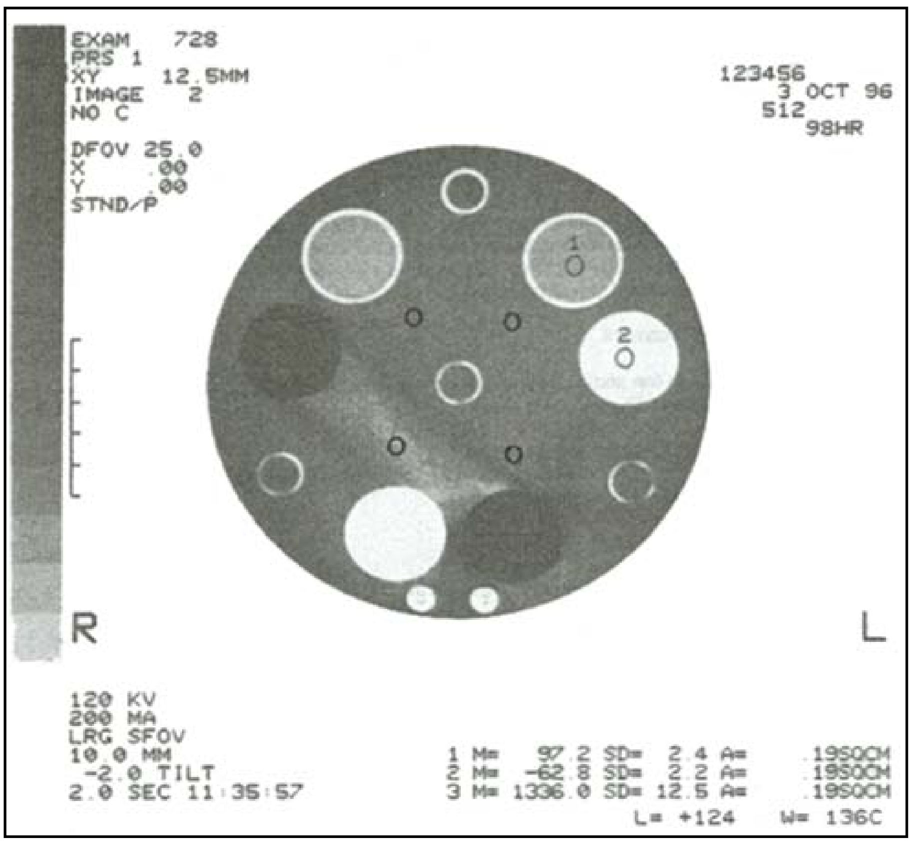

Figure 1-3. Film #2

1.4 Video Monitor

While reading the CT numbers as required in the previous two tests, closely observe the functioning of the monitor controls, image centering, aspect ratio and overall image quality. Make appropriate check marks on the Data Entry Form on page 2-2.

1.5 Multiformat or Laser Camera

Make hard copies of the transverse and pilot scans previously made and while doing so, closely observe the functioning of the camera controls, mechanical movements, image centering, aspect ratio and overall image quality. Make appropriate check marks on the Data Entry Form on page 2-2. Also review all the daily and weekly tests that the technologists are required to perform to comply with the manufacturer's recommendations.

1.6 Processor and Other Miscellaneous Items

Make appropriate visual observations of the processor, dark room and other auxiliary equipment in the facility, and make appropriate check marks on the Data Entry Form on page 2-2. Also, review all the daily and weekly tests that the technologists are required to perform to comply with the manufacturer's recommendations.

1.7 Dose Measurements

Dose measurements can be made with a CT chamber (Nuclear Associates' Model 30-301-1000) placed at different locations within the phantom. The readings will obviously be lower than the CTDI (Computerized Tomographic Dose Index) values measured with a standard CT Dose Phantom. However, appropriate calibration factors can be established if so desired. With the CT chamber positioned in the middle hole, one can check slice thickness accuracy and mAs linearity as shown at the bottom of the Data Entry Form on page 2-2.

1.8 CT Number and Noise Level Accuracy

Using the last image made, read the CT numbers and their standard deviations in the region of each of the inserts. Record them on the Data Entry Form on page 2-2. Note the averaging area used while reading the CT numbers. Use the same averaging area month after month.

The CT numbers to be expected with each of the inserts provided depend on the kilovoltage at which scanning is performed, the amount of filtration in the beam and other characteristics. However, as a first approximation, one can expect the CT number "H" for any material to be given by the formula:

H = -1000 (1-)

where   is the physical density of the material. **NOTE**: The closer the material is to water in terms of its mass attenuation coefficient, the more accurate this formula is. See Appendix A for further CT number calculation instructions.

The physical densities of the materials of interest in the use of the Mini CT Phantom are as follows:

Air	0.001 g / cm^3	Acrylic	1.180 g / cm
Lung-Equivalent	0.240 g / cm^3	Polystyrene	1.050 g / cm^3
Polyethylene	0.950 g / cm^3	Nylon	1.150 g / cm^3
Water	1.000 g / cm^3	Polycarbonate	1.190 g / cm^3

Plastic Water™	1.030 g / cm^3	Bone-Equivalent	1.933 g / cm^3
		Teflon	2.214 g / cm^3

When using the Mini CT QC Phantom for treatment planning, the following electron densities may be used:

Bone-Equivalent = 5.95 x 10^{23}cm^3 Lung-Equivalent = 0.79 x 10^{23}cm^3

Water-Equivalent = 3.33 x 10^{23}cm^3

1.9 High Contrast Resolution

Observe the image with the best possible combination of the window width and level and determine the number of rows of holes in the image of the high-resolution insert that can be seen distinctly and separately. Enter that number on the Data Entry Form on page 2-2. Within parentheses, enter the notification factor and the algorithm used in observing the image. The hole diameters are 0.016", 0.020", 0.024" and 0.030" respectively in each of the rows. The space between the holes is the same as the diameter on the holes in any given row (See Figure 1-4).

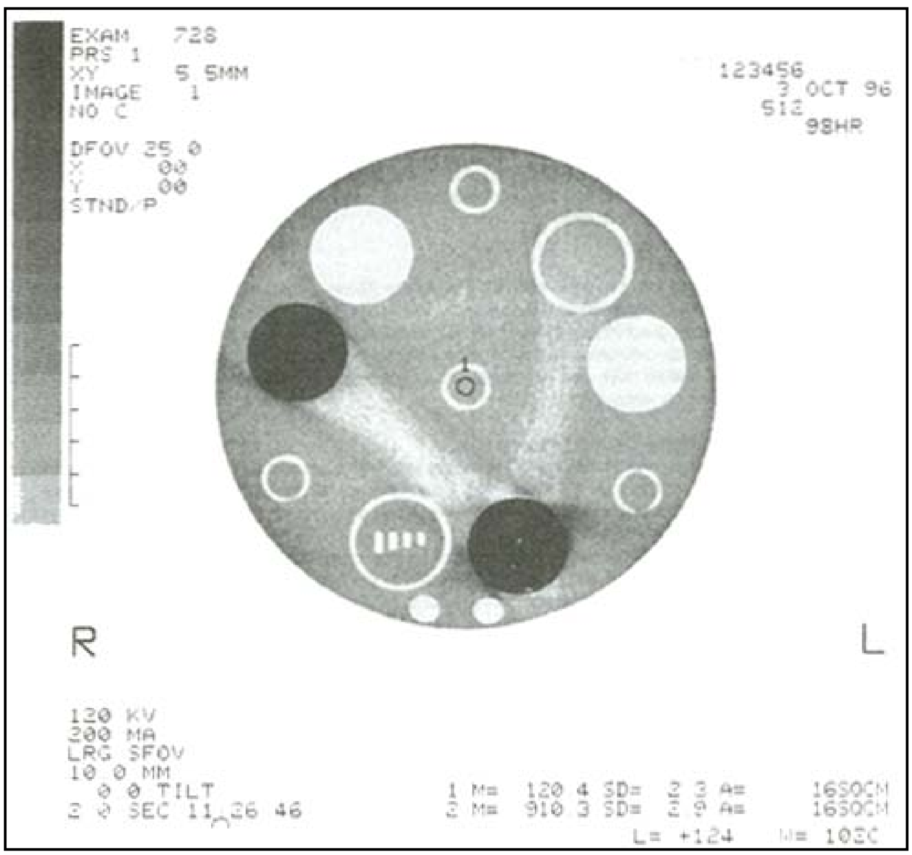

Figure 1-4. Film #3

1.10 Low Contrast Resolution

If you have purchased the optional Low Contrast Resolution Insert, use its image to assess the low contrast resolution capability of the unit. The low contrast insert contains three rods of Nylon each 5 mm in diameter. Each rod is placed 1 mm from the insert edge, centered 17 mm apart (See Figure 1-5).

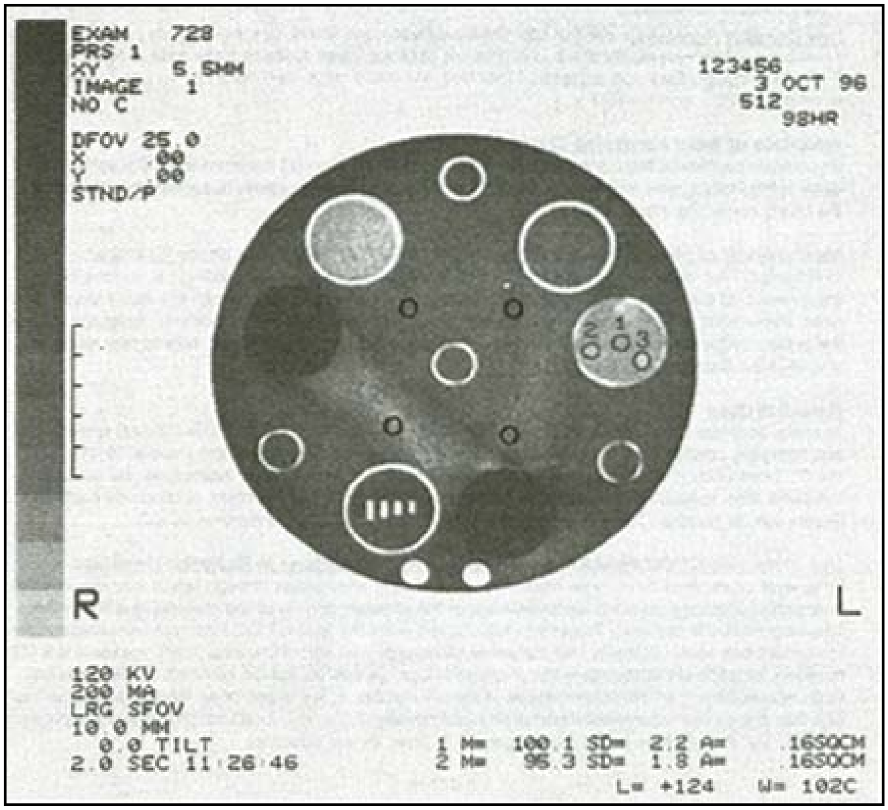

Figure 1-5. Film #4

1.11 Adequacy of Beam Hardening Correction

If you have purchased the optional Low Contrast Resolution Insert, use its image to assess the low contrast resolution capability of the unit. The low contrast insert contains three rods of Nylon each 5 mm in diameter. Each rod is placed 1 mm from the insert edge, centered 17 mm apart (See Figure 1-4).

1.12 Measurement of Slice Thickness Accuracy and mAs Linearity Using an Ion Chamber

Insert any CT ion chamber into the central slot of the phantom and take readings at various slice thicknesses, at the same mAs. Next, take readings at various mAs values with the same slice thickness. Remember to reposition the phantom in the gantry after each measurement. Enter the data at the bottom of the Data Entry Form on page 2-2 and assess linearity by taking appropriate ratios as shown in the Sample Data Entry Form on page 2-1.

1.13 Radiation Dose

To make accurate measurements of the CTDI (Computerized Tomographic Dose Index) under various operating conditions, it is recommended that the CT Dose Head Phantom (Model 76-414) and the CT Dose Body Phantom (Model 76-415), both available from Fluke Biomedical, Radiation Management Services, be used. If at the same time, measurements are also made with the Mini CT QC Phantom, appropriate calibration factors can be obtained for dose measurement with the Mini CT QC Phantom as well.

1.14 Use of the Mini CT QC Phantom for Inhomogeneity Corrections in Radiation Oncology

Whenever corrections have to be made for altered beam attenuation through tissue inhomogeneities in radiation oncology, an accurate knowledge of the physical density of the material in each of the inhomogeneities is required. To get this information, scan the Mini CT QC Phantom immediately after the patient has been scanned. Use the same kilovoltage and slice thickness. Then, measure the CT numbers for each of the inserts in the phantom image, as well as the CT numbers at the center of each inhomogeneity in the patient image. If the CT number in the region of an inhomogeneity is "H_P" and that in a closely equivalent insert of physical density " ${}_I$" is "H_I", it can be shown that the physical density " ${}_P$" of the tissue in the inhomogeneity is given by the equation:

This procedure assumes that the CT unit is properly calibrated and that the CT numbers for water and air are indeed 0 and -1000 respectively. If this is not the case, the numbers can first be derived using a simple procedure.

$${}_P = {}_I \; \frac{1 + 0.001\, H_p}{1 + 0.001\, H_I}$$

The true CT numbers "H_P" and "H_I" can be determined using the observed CT numbers "H_p^0" and "H_I^0" and the equations:

$$H_p = 1000 \; \frac{H_p^0 - H_w^0}{H_w^0 - H_a^0}$$

$$H_I = 1000 \; \frac{H_I^0 - H_w^0}{H_w^0 - H_a^0}$$

where H_w°" and H_a°" are the observed CT numbers for water and air, respectively. When using this formula, the CT number for water can be assumed to be that observed for Plastic Water™ minus 30. This assumption is necessary, since the Mini CT QC Phantom does not contain a liquid water insert. If greater accuracy is desired, the difference in CT numbers for liquid water and Plastic Water™ (Model 74-600 series) can be experimentally ascertained for any given CT unit operated at any given kilovoltage, by scanning the Mini CT QC Phantom and a water phantom at the same time.

Section 2
Data Entry Form

SAMPLE DATA ENTRY FORM

Quality Assurance / Acceptance Testing of CT units

Date: Oct 4, 1996. Unit I.D : CT # 1

	Safety Aspects
✓	All door interlocks operating properly
✓	All radiation warning signs lighting up properly
✓	All emergency shut-off buttons operating properly
✓	Patient intercom system working properly

	General Items
✓	All manufacturer recommended daily and other periodic tests performed regularly and action taken when necessary
✓	Boot-up function and initial software checks okay
✓	All image processing algorithms properly functioning
✓	All disc drives and archiving systems okay
✓	Processor sensitometry performed regularly and action taken when necessary
✓	Safe light brightness adequate but not too intense
✓	Darkroom clean and free from leaks
✓	All physiological and other auxilary equipment functioning okay
✓	Controls, switches and lights at console okay
✓	Controls, switches and lights at table okay
✓	Controls, switches and lights at gantry okay
✓	Table movement smooth
✓	Table position indicators accurate and reproducible
✓	Gantry movements smooth
✓	Gantry position indicators accurate and reproducible

	Beam Alignment and Image Sequencing Aspects
✓	Laser beam to scan beam correspondence okay
✓	Slice width accuracy okay
✓	Slice spacing accuracy okay
×	Slice contiguity satisfactory (See Remarks)
	Pilot scan to transverse scan correspondence okay

	Video Monitor
✓	All controls properly adjusted
✓	Imge centered properly on the monitor
×	Aspect ratio satisfactory (8/8.2)
✓	Beam Hardening Correction satisfactory
✓	All image processing algorithms satisfactory
✓	No. of gray scales seen satisfactory (13)

	Multiformat or Laser Camera
✓	Transports films easily
✓	Makes correct exposures
✓	Images properly positioned on film
✓	Cassettes and/or magazines in good condition
✓	All controls and indicators functioning properly
✓	Controls set properly
✓	Film images correspond closely to monitor images
✓	Films do not show any light leaks or other artifacts
✓	Magazines go in and out freely
✓	Aspect ratio satisfactory (8/8)
✓	Number of gray scales seen satisfactory (13)
✓	Camera optics clean

CT Numbers and Noise Level Adequacy

Protocol : 120 kVp, 200mA, 2.0 Sec

Air	−985 ± 21	Polystyrene	25 ± 1.8
Lung-Equivalent	−782 ± 20	Nylon	94 ± 2.3
Polyethylene	−63 ± 2.2	Polycarbonate	97 ± 2.4
Water	——	Bone-Equivalent	1336 ± 12
Plastic Water	−1 ± 2.0	Teflon	——

Uniformity of CT Numbers

Center	120 ± 2.3	8 o' Clock	125 ± 1.9
2 o' Clock	123 ± 2.5	11 o' Clock	125 ± 2.1
5 o' Clock	126 ± 2.0	Averaging Area	1.8 cm²

High Contrast and Low Contrast Resolution

High Contrast Resolution (# of rows clearly seen) 3
Low Contrast Resolution Satisfactory
Window Level Used: 124 Window Width Used: 102

Radiation Dose at 120 kVp

Mid-line Dose (mGy/mAs) 0.127
Surface Dose (mGy/mAs) 0.142

Measurement of slice thickness accuracy with an ion chamber

Slice thickness	Reading	Ratio	Expected
2 mm	101	1.0	1.0
5 mm	255	2.5	2.52
10 mm	509	5.0	5.03

Evaluation of mAs linearity with an ion chamber

mAs	Reading	Ratio	Expected
64	108	1.00	1.0
309	509	4.83	4.71
411	680	6.42	6.30

Remarks and Recommendations for Corrective Action

1. Image on Monitor of circular Phantom was oblong. Rectified Subsequently
2. Slice contiguity should be improved. Show film to Service Engineer
3. Manufacturer recommended daily tests are not being performed.

13

Figure 2-1. Sample Data Entry Form

Data Entry Form

Quality Assurance/Acceptance Testing of CT Units

Date:

Safety Aspects	
	All door interlocks operating properly
	All radiation warning signs lighting up properly
	All emergency shut-off buttons operating properly
	Patient intercom system working properly

General Items	
	All manufacturer recommended daily and other periodic tests performed regularly and action taken when necessary
	Boot-up function and initial software checks ok
	All image processing algorithms properly functioning
	All disc drives and archiving systems okay
	Processor sensitometry performed regularly and action taken when necessary
	Safe light brightness adequate but not too intense
	Darkroom clean and free from leaks
	All physiological and other auxilary equipment functioning okay
	Controls, switches and lights at console okay
	Controls, switches and lights at table okay
	Controls, switches and lights at gantry okay
	Table movement smooth
	Table position indicators accurate and reproducible
	Gantry movements smooth
	Gantry position indicators accurate and reproducible

Beam Alignment and Image Sequencing Aspects	
	Laser beam to scan beam correspondence okay
	Slice width accuracy okay
	Slice spacing accuracy okay
	Slice contiguity satisfactory
	Pilot scan to transverse scan correspondence ok

Video Monitor	
	All controls properly adjusted
	Image centered properly on the monitor
	Aspect ratio satisfactory
	Beam Hardening Correction satisfactory
	All image processing algorithms satisfactory

Unit ID:

Multiformat or Laser Camera	
	Transports films easily
	Makes correct exposures
	Images property positioned on film
	Cassettes and/or magazines in good condition
	All controls and indicators functioning properly
	Controls set properly
	Film images correspond closely to monitor images
	Films do not show any light leaks or other artifacts
	Magazines go In and out freely
	Aspect ratio satisfactory
	Number of gray scales seen satisfactory
	Camera optics clean

CT Numbers and Noise Levels Adequacy			
Protocol:			
Air		Polystyrene	
Lung-Equivalent		Nylon	
Polyethylene		Polycarbonate	
Water		Bone-Equivalent	
Plastic Water		Teflon	

Uniformity of CT Numbers			
Center:		8 o'clock:	
2 o'clock:		11 o'clock:	
5 o'clock:		Averaging Area:	

High contrast and Low Contrast Resolution			
High contrast Resolution -# of rows clearly seen:			
Low Contrast Resolution:			
Window Level Used:		Window Width Used:	

Radiation Dose	
Mid Line Dose (mGy/mAs):	
Surface dose (mGy/mAs):	

	No. of gray scales seen satisfactory

Measurement of slice thickness accuracy with an ion chamber				Evaluation of mAs linearity with an icon chamber			
Slice Thickness	Reading	Ratio	Expected	MAs	Reading	Ratio	Expected

Remarks and Recommendations for Corrective Action:

Appendix A
Addendum to Instructions

A.1 General Information

Note that this procedure makes the idealized CT numbers for air and water to be always -1000 and 0 respectively regardless of what their measured values are on a given day, with a given scanner, in a given location and a given algorithm. In practice, for greater accuracy, one can measure the water and air CT numbers in approximately the same location within the phantom as the Region of Interest (ROI) within a patient.

A.2 Reformulation of the Definition of CT Number

The CT number H of a material is defined traditionally by the equation

$$H = -1000\ (1 - \mu/\mu_w) \qquad (2)$$

where μ is the linear attenuation coefficient of the material in question and μ_w that of water. The quantity μ/μ_w can be rewritten as

$$\mu/\mu_w = \frac{(\mu/\ )}{(\mu_w/\ _w)} = (\ /\ _w) = \ F \qquad (3)$$

where $\mu/$ and $\mu_w/\ _w$ are the mass attenuation coefficients of the material and water respectively. The 's are their physical densities. F is the ratio of the mass attenuation coefficient of the material in question to that of water.

Since $_w = 1.0\ g / cm^3$, it follows that

$$H = -1000\ (1 - \ F) \qquad (4)$$

$$F = (1/\ )\ (1+.001H) \qquad (5)$$

$$= (1/F)\ (1+.001H) \qquad (6)$$

For the sake of dimensional compatibility, one can think of as the specific gravity of the material or the physical density relative to that of water.

Using published values for the mass attenuation coefficients from the National Institute of Science and Technology (NIST), we calculated the F ratios for selected tissues and tissue substitutes at effective beam energies ranging from 60 keV to 100 keV and used them to calculate the expected CT numbers with the help of equation (4) above. The results are given in the form of a table attached to this addendum.

With the advent of spiral CT, reduced scan times and improved data processing algorithms, interest in the use of actual CT numbers (pixel values) for the quantitative evaluation of CT scans is growing. CT numbers are also increasingly being used for making inhomogeneity corrections in Radiation Oncology Treatment Planning. However, as is well known, measured CT numbers are subject to many types of systematic variations due to system malfunction from time to time (AAPM Report No. 39). For this reason, regular monitoring of their consistency using a standard phantom such as our CT Performance Phantom or our portable Mini CT QC Phantom is extremely important.

This will ensure that hidden systematic errors due to system malfunction are promptly recognized and corrected. One cannot still expect all CT scanners to give the same CT number for the same material. This is because; measured CT numbers are also subject to a number of inherent physical and design variations and limitations. The selection of beam quality and beam hardening algorithms is among the more important ones. Another is the day-to-day stability of the measured CT numbers for water and air. Measured CT numbers can also be different in different regions of a scan for identically the same material due to beam hardening and partial volume effects. In this addendum to our basic instruction manuals, we provide users of our CT Performance Phantom and our Mini CT QC Phantom some additional information that will help to minimize the errors involved in the use of CT for quantitative purposes.

One way to improve the accuracy of measured CT numbers is to idealize them using a procedure first proposed by Brooks (1). This procedure corrects for variations in the CT numbers for water and air from time to time and from location to location. The procedure itself is simple and has already been described in our instruction manual for the Mini Phantom. It is included in this addendum also for the benefit of those that may only have the performance phantom. In addition, we will present a reformulation of the definition of the Hounsfield or CT number, based on earlier work by Rao et al (2,3) and use this formulation to provide a chart of expected CT numbers for selected tissues and tissue substitutes at varying values of the effective beam energy in keV. In addition, an improved procedure for determining the effective beam energy in keV will be suggested as an alternative to the linearity measurements proposed by Kriz and Strauss (4) and Judy et al (5). Finally, two alternate methods for tissue characterization by CT and for making- inhomogeneity corrections in Radiation Oncology will be suggested.

A.3 Idealization of CT numbers

The idealized CT number H is related to the observed CT number H(O) by the formula

$$H = 1000 \frac{H(O) - H_w(O)}{H_W(O) - H_a(0)} \qquad (1)$$

where H_w (O) and H_a(O) are the observed CT numbers for water and air respectively.

It must be emphasized that the CT numbers provided in this table are based on theoretical calculations only and cannot therefore be regarded as absolute standards. Besides, CT numbers vary considerably with the physical density and the exact molecular composition of the material involved, in the case of tissue equivalent materials. These can change from batch to batch and from manufacturer to manufacturer. Further more, as stated before CT numbers vary not only with beam energy but also with beam filtration, "cupping" effects due to beam hardening, the algorithms used for beam hardening corrections, detector non-linearity, partial volume effects etc.

A.4 Determination of Effective Beam Energy

Also attached to this addendum are a number of plots of the F value for different materials against effective beam energy in keV. Knowing the physical density of the material of a given insert in the phantom and the measured CT number (properly idealized), one can determine the F value for the material experimentally using equation (4) above and then use that number to estimate the effective beam energy at the location of the insert using the appropriate calibration graph provided. For greater accuracy, one can use aluminum or magnesium inserts since the theoretically calculated F numbers for them can be expected to be more accurate than for the inserts made of tissue equivalent materials whose composition can vary from batch to batch and from manufacturer to manufacturer. Secondly, the measured CT numbers are much more sensitive to beam energy with Al and Mg than with the others because of their higher Z values.

In using this procedure for determining the effective beam energy, it is once again emphasized that the measured CT numbers should be idealized first as described earlier. For greater accuracy, the water and air numbers may be measured at the same location within the Mini CT QC or Performance Phantom as the calibration insert.

A.5 Tissue Characterization and Inhomogeneity Corrections by CT

Instead of using CT numbers per se, one can calculate the physical density in any given Region of Interest (ROI) in a clinical scan by scanning the Mini CT QC or the Performance Phantom immediately after a patient has been scanned. If the CT number in the ROI is H (Pt) and that at the center of an insert of similar atomic composition placed in a similar location within the phantom is H (Ph), it follows from equation (6), since the F values for the insert and the material in the ROI can be approximated to be the same, that the physical density (Pt) in the ROI is related to the physical density (Ph) of the insert material by the equation

$$(Pt) = (Ph) \frac{1 + 0.001\, H\,(Pt)}{1 + 0.001\, H\,(Ph)} \qquad (7)$$

This formulation may offer a more accurate way of tissue characterization in quantitative CT than the use of CT numbers alone. It may also be useful for making inhomogeneity corrections in Radiation Oncology.

Another way is to develop a matrix of effective beam energy values for different size simulated body contours during a calibration procedure, assume the atomic composition of the material in the region of interest (whether it be body tissue or a prosthetic material) from published literature, calculate its F value at the particular beam energy and then determine the density of the material in the ROI knowing the measured CT number, appropriately idealized. We are considering the development of envelopes to our Mini CT phantom to meet the requirements of this section.

References

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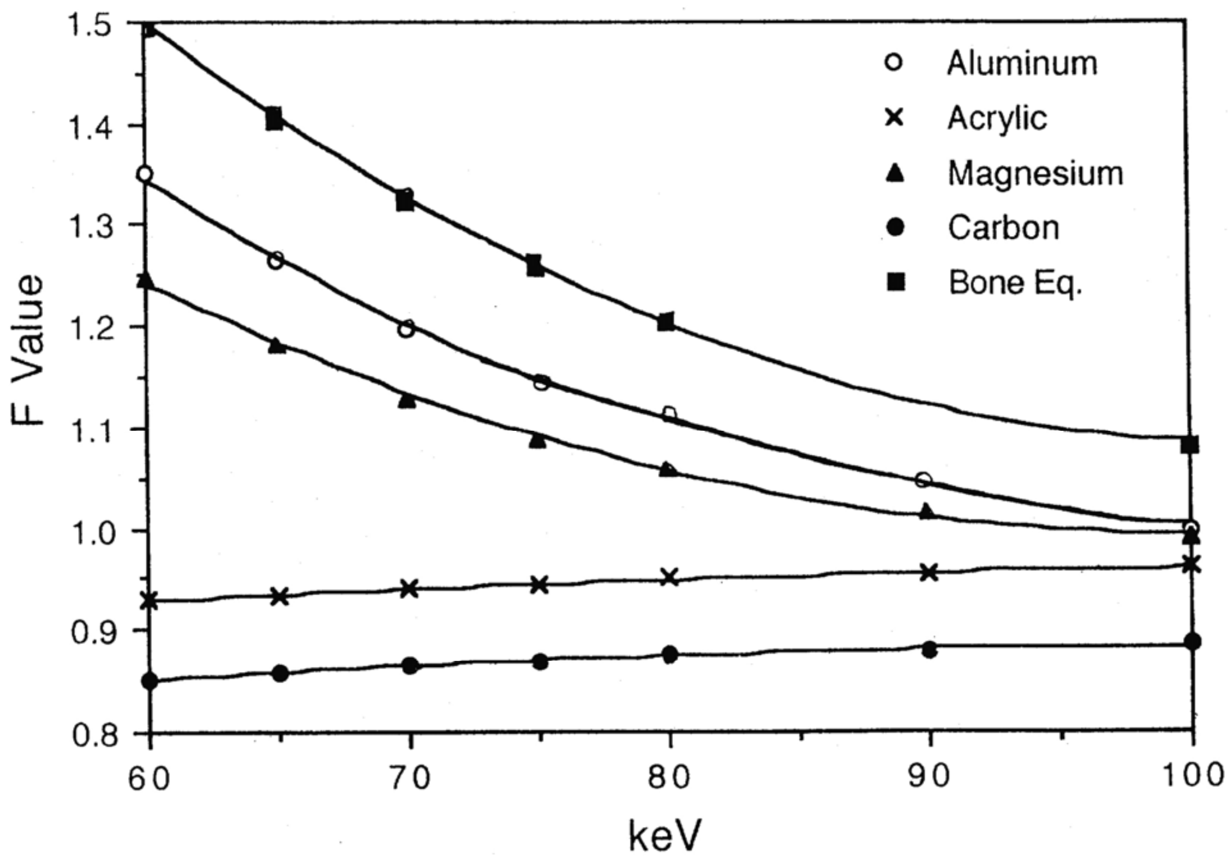
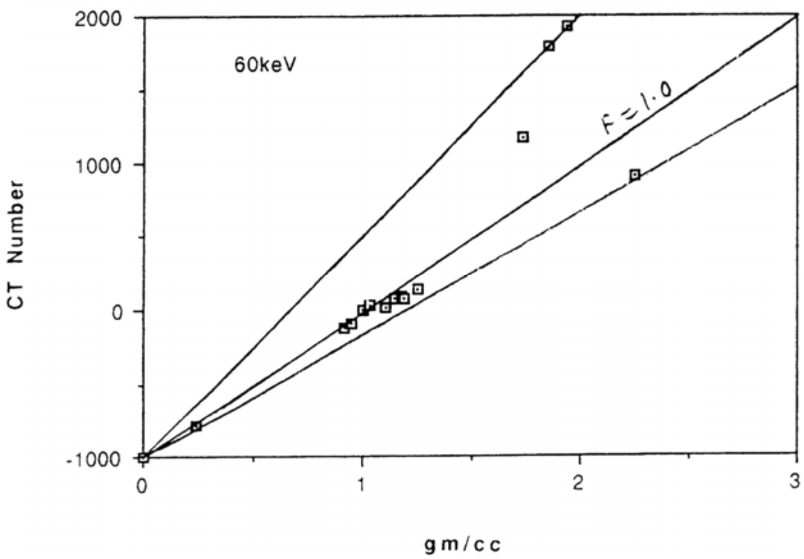


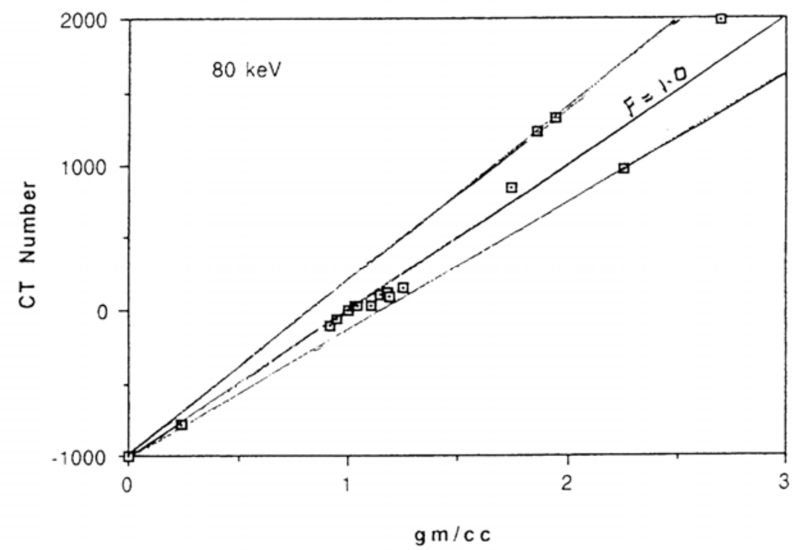
Plots of F Value Against keV for Selected Insert Materials

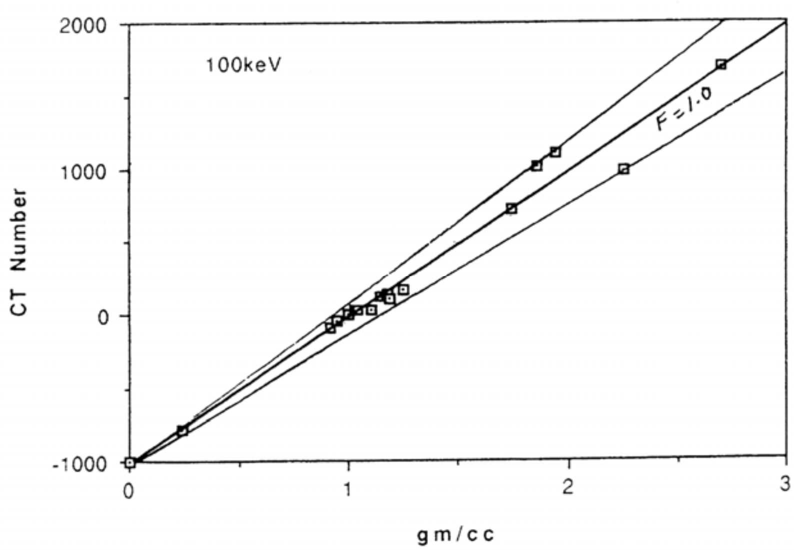
CT Relevant Data for Selected Tissues and Tissue Substitutes

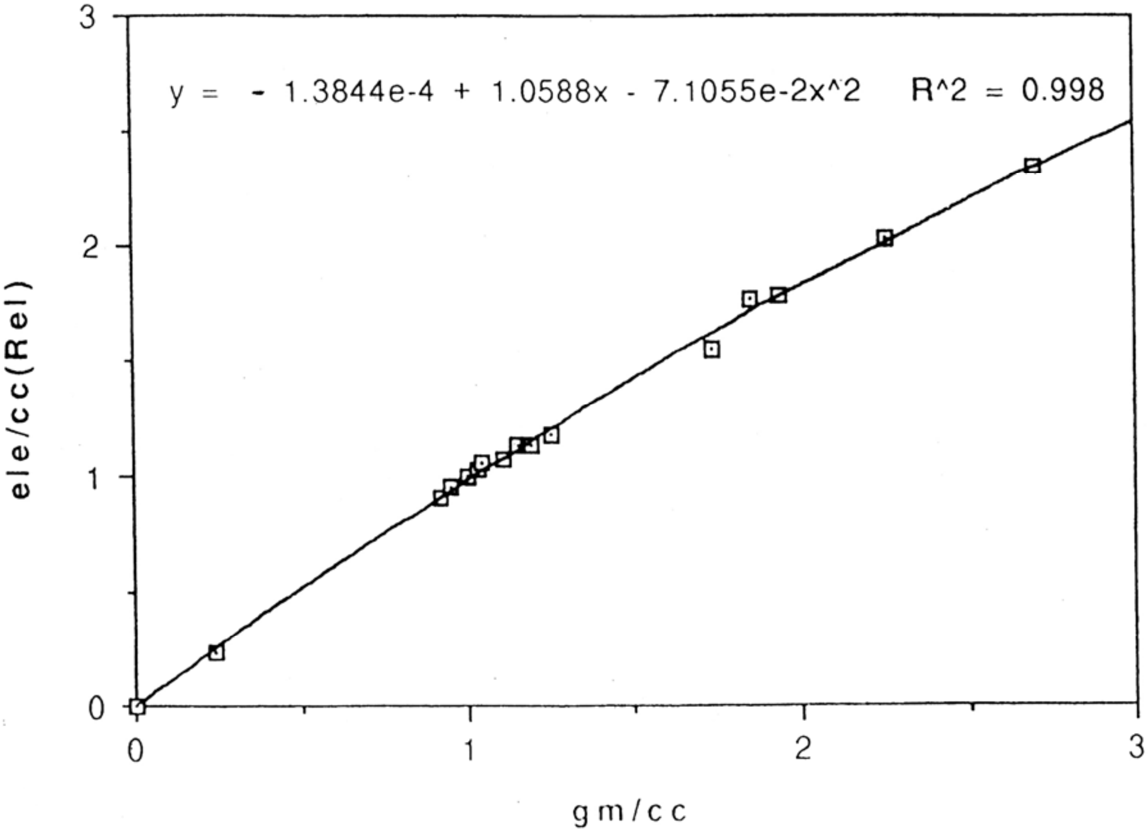
	Gm/cc	Elec/gm	Elec/cc.	Elec/cc.	F Ratios						Expected Nominal CT numbers					
Material or Tissue		X10E-23	X10E-23	Relative	60keV	65keV	70keV	75keV	80keV	100keV	60keV	65keV	70keV	75keV	80keV	100keV
Air	0.0010	3.0060	0.0030	0.0009	0.9033	0.9028	0.9023	0.9017	0.9011	0.8927	-999	-999	-999	-999	-999	-999
Lung Equivalent	0.2400	3.2860	0.7886	0.2359	0.9033	0.9028	0.9023	0.9017	0.9011	0.8927	-783	-783	-783	-784	-784	-786
Fat	0.9160	3.3400	3.0594	0.9151	0.9603	0.9668	0.9743	0.9771	0.9806	0.9871	-120	-114	-108	-105	-102	-96
Polyethylene (C2H4)	0.9500	3.3400	3.1730	0.9491	0.9550	0.9668	0.9800	0.9829	0.9924	1.0010	-93	-82	-69	-66	-57	-49
Water (H2O)	1.0000	3.3433	3.3433	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0	0	0	0	0	0
Polystyrene (C8H8)	1.050	3.2430	3.5997	1.0767	0.9057	0.9200	0.9270	0.9374	0.9429	0.9502	-49	-34	-27	-19	-10	-2
Plastic Water	1.0300	3.3343	3.4343	1.0272	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	30	30	30	30	30	30
Soft Tissue	1.0400	3.4200	3.5568	1.0639	0.9962	0.955	0.9930	0.9926	0.9923	0.9915	36	35	33	32	32	31
Nylon (C6H11NO)	1.1500	3.3200	3.8180	1.1420	0.9365	0.9472	0.9537	0.9556	0.9619	0.9702	77	89	97	99	106	116
Polycarbonate (C16H14O3)	1.1900	3.1770	3.7806	1.1308	0.9061	0.9129	0.9197	0.9220	0.9239	0.9302	78	86	94	97	99	107
Acrylic (C5H8O2)	1.1800	3.2480	3.8326	1.1464	0.9291	0.9343	0.9395	0.9447	0.9500	0.9608	96	102	109	115	121	134
Bakelite (C43H38O7)	1.2500	3.1790	3.9738	1.1886	0.9049	0.9126	0.9202	0.9234	0.9261	0.9384	131	141	150	154	158	173
Carbon	2.2500	3.0080	6.7680	2.0243	0.8495	0.8593	0.8657	0.8700	0.8750	0.8850	911	933	948	958	969	991
Teflon (C2F4)	2.2140	3.0110	6.6664	1.9939	0.9117	0.9071	0.8983	0.8935	0.8927	0.8808	1019	1008	989	978	976	950
Magnesium	1.7380	2.9905	5.1975	1.5546	1.2475	1.1809	1.1295	1.0904	1.0598	0.9906	1168	1052	963	895	842	722
Bone (Compact)	1.8500	3.1920	5.9052	1.7663	1.5088	1.4016	1.3219	1.2565	1.2045	1.0869	1791	1593	1446	1324	1228	1011
Bone equivalent	1.9330	3.0800	5.9536	1.7808	1.5088	1.4016	1.3219	1.2565	1.2045	1.0869	1916	1709	1555	1429	1328	1101
Aluminum	2.6990	2.9020	7.8325	2.3427	1.3520	1.2637	1.1975	1.1466	1.1031	1.0000	2649	2411	2232	2095	1977	1699

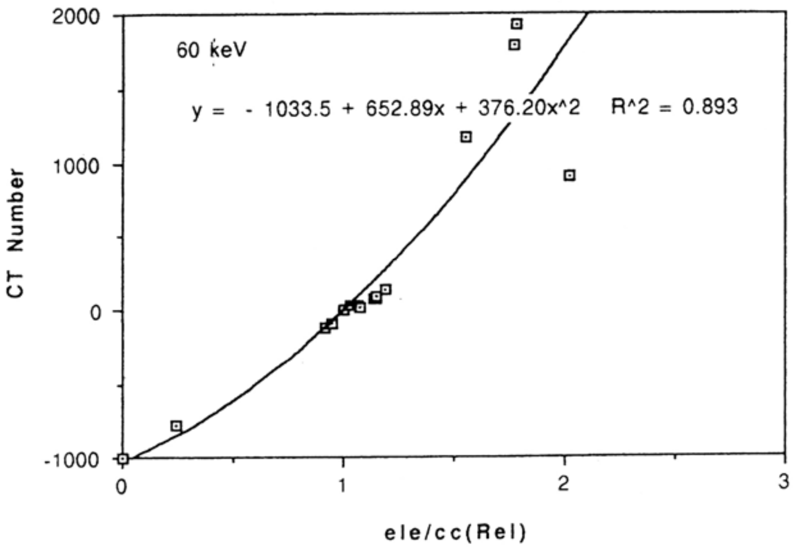
CT Relevant Data for Selected Tissues and Tissue Substitutes

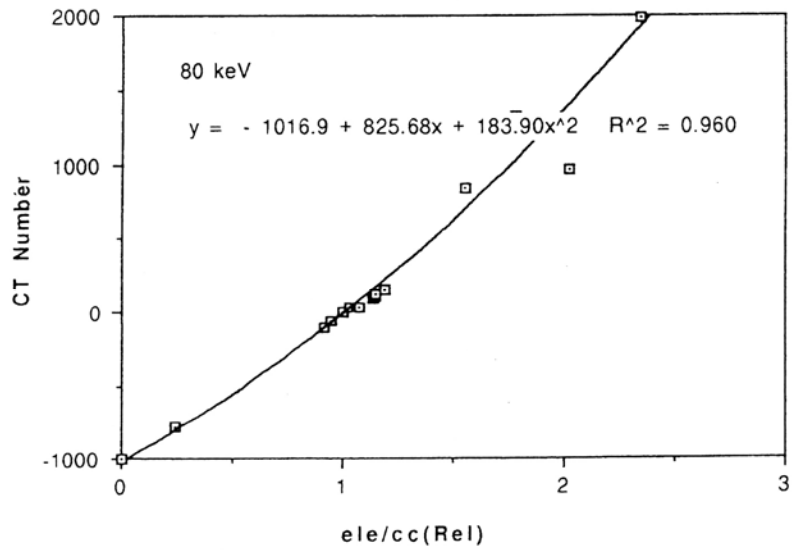

2000
1000
0
-1000
60keV
F = 1.0
CT Number
0
1
2
3
gm/cc

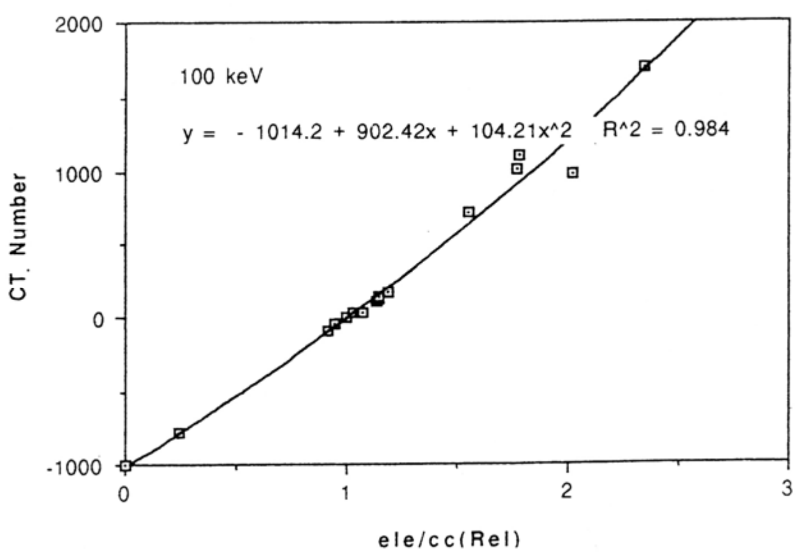

2000
1000
0
-1000
80 keV
F = 1.0
CT Number
0
1
2
3
gm/cc


2000
1000
0
-1000
100keV
F = 1.0
CT Number
0
1
2
3
gm/cc


y = - 1.3844e-4 + 1.0588x - 7.1055e-2x^2 R^2 = 0.998
ele/cc(Rel)
gm/cc
0
1
2
3
0
1
2
3


60 keV
y = - 1033.5 + 652.89x + 376.20x^2   R^2 = 0.893
CT Number
ele/cc(Rel)
2000
1000
0
-1000
0
1
2
3


80 keV
y = - 1016.9 + 825.68x + 183.90x^2   R^2 = 0.960
CT Number
ele/cc(Rel)
2000
1000
0
-1000
0
1
2
3


100 keV
y = - 1014.2 + 902.42x + 104.21x^2   R^2 = 0.984
CT Number
ele/cc(Rel)
2000
1000
0
-1000
0
1
2
3

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