Spectrum Sciences Institute
RF Dosimetry Research Board

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Tissue Recipe and Calibration Requirements

SSI/DRB-TP-D01-033

PART of SAR Measurements Requirements

SSI/DRB-TP-D01-030

DRAFT

Prepared jointly with:

APREL Laboratories

Near Field Measurements Laboratory

March 1998

- NOTICE -

This draft was prepared to assist the Dosimetry Research Board of SPECTRUM SCIENCES INSTITUTE and specifically the Working Group on SAR Measurements. It is submitted as a basis for discussion only, and is not binding on APREL Inc. Subsequent study may lead to revisions of the document, both in numerical values and/or form, and after continuing study and analysis, APREL Inc. specifically reserves the right to add to, or amend the content of this contribution.

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1.0 INTRODUCTION

1.1 Purpose and Scope of the Standard

The purpose of this document is to standardize the recipe for simulated muscle and brain tissue, and the calibration of the simulated tissue. This Standard includes procedures to be followed in making and calibrating simulated biological tissues to be used for Specific Absorption Rate (SAR) measurements.

This Standard defines:

- the methodology and procedures to be followed in the laboratory calibration of the simulated tissues
- the hardware and software required, the test procedures, and, where applicable, the required limits for calibration of simulated tissues.

In addition to recipes for simulated brain and muscle tissues, this Standard also includes tests to determine the following parameters:

1. Density
2. Heat Capacity
3. Dielectric Constant and Conductivity

This Standard is part of a Certification Program Methodology as described in a separate document entitled "SSI/DBR TP-D01-030, Specific Absorption Rate (SAR) Standard For Portable Telecommunications Devices, March 1998". SSI/DBR TP-D01-033 contains specific criteria that must be met for SAR certification.

1.2 Test Facilities

All calibration work as described in this Standard shall be performed at an ISO/IEC Guide 25 accredited laboratory.

1.3 Test Personnel

Personnel performing the calibration will be experienced in relevant measurements (eg physical properties or RF characteristics) and supervised by a person proficient in SAR measurements.

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1.4 Test Equipment

The required test equipment, hardware and software, is identified is each individual procedure. Equipment may be substituted or updated from time to time. Should this occur, such change shall be noted in the test report. Equipment shall be calibrated to standards traceable to International Standards.

1.5 Standard Environmental Conditions

All measurements and calibration should be performed under normal laboratory conditions for physical properties and electrical characteristics as stipulated by ISO/IEC Guide 25. The nominal temperature for physical property measurements and for electrical characterization are 20°C and 23°C, respectively.

2.0 BACKGROUND

In order to perform measurements of specific absorption rates (SAR) of electromagnetic energy in human brain tissue, it is necessary to use models that simulate the electrical properties of real tissue. It is also important that those models are reproducible, long lasting, non-corrosive, and easy to produce and use. Mixtures have been developed that simulate the electrical properties of various biological tissues for various frequency ranges between 100 – 2,450 MHz. This mixture is a practical simulation of biological tissue, however, requires different proportions of sugar, water, salt, hydroxyethylcellulose (HEC) and a bactericide, for different frequency ranges. The solution is easy to produce, and fairly inexpensive. Its electrical properties can be altered to match many tissue types, at different frequencies. For certain frequency ranges, the conductivity of the mixture, even without the presence of salt, will be higher than some of the biological tissues. This will lead to a conservative overestimation of the SAR value. Another advantage of the solution is that its liquid form allows easy positioning of the E-field probe within the phantom. The shelf like of such simulated tissue is reasonably long (weeks) with the addition of the bactericide. Additional precautions (covering, stirring, filtering) may extend the useful to over six months.

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3.0 REFERENCES

- "Simulated Biological Materials for Electromagnetic Radiation Absorption Studies", G.W. Hartsgrove et al, Bioelectromagnetics, vol. 8, pp. 29-36, 1987.
- "Suggestions Prepared Following the CENELEC Document", N. Kuster et al, Attachment 9, Minutes IEEE Standards Coordinating Committee –34, Subcommittee –2, May 2, 1997 meeting.
- "Calibration for Implantable E-field Probes in Human Equivalent Material", Narda Microwave Corporation, Feb. 11, 1997.
- Private communication, Motorola, Fort Lauderdale, FL and Libertyville, IL, 1997.
- "Compilation of the Dielectric Properties of Body Tissue at RF and Microwave Frequencies", C. Gabriel, Brooks Air Force Technical Report AL/OE-TR-1996-0037.

4.0 RECIPE AND PREPARATION

4.1 Ingredients

The following table contains recipes for simulated muscle and brain tissues for 100 MHz – 1GHz. This gives approximate quantities required to achieve electrical parameters specified in section in Section 5

Table 4.1

Simulated Tissue Ingredients		
Ingredient	Muscle Mixture	Brain Mixture
Water	52.4 %	40.6 %
Sugar	45.0 %	58.0 %
Salt	1.5 %	1.0 %
HEC	1.0 %	0.3 %
Bactericide	0.1 %	0.1 %

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The following table contains recipes for simulated muscle and brain tissues for 1.5 –2.5 GHz. This gives approximate quantities required to achieve electrical parameters specified in section in Section 5

Table 4.2

Simulated Tissue Ingredients	
Ingredient	Brain & Muscle Mixture
Water	45.3 %
Sugar	54.3 %
Salt	0.0 %
HEC	0.3 %
Bactericide	0.1 %

Common household salt and sugar are typically used.

4.2 Equipment

The following equipment will be needed to make the simulated tissue.

Table 4.3

Description	**Manufacturer**	**Model**
Graduated Cylinder	BOMEX	2000 ml
Storage Container	Various sources	20 l
Weight Scale	Pennsylvania Scale Co.	2 kg
Handling Containers	Various sources	various
Corrosion Resistant Mixing Device		

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4.3 Preparation

1. Select the appropriate simulated tissue type: Muscle or Brain.
2. From the Tables 4.1 or 4.2 above, determine the percentage of each ingredient for the volume of 20 liters, calculate the mass of each ingredient assuming that the density of the final solution is 1300 kg/m^3.
3. Verify that the storage container in which the ingredients will be mixed is clean.
4. Obtain the calculated amount of reverse-osmosis or de-ionized water.
5. Pour about 25% of the water into a glass beaker, heat it on a hot plate to almost boiling, and then add it to the cold water. The objective is to increase the temperature of the water to approximately 40" C (100-105°F).
6. Prepare the appropriate quantities of the dry ingredients in separate containers.
7. When the water is ready, slowly add salt and bacteriacide while stirring at low speed.
8. After the salt and bactericide is dissolved start adding sugar to the container while stirring continuously at low speed until totally dissolved.
9. Add the HEC slowly to avoid clumping. Continue to stir until the solution thickens.
10. Total stirring time should be 30-35 minutes.

5.0 MEASUREMENT OF THE DIELECTRIC CONSTANT AND CONDUCTIVITY OF SIMULATED TISSUE

5.1 Test Purpose

Before a batch of simulated tissue can be used for SAR measurements, its electrical characteristics (dielectric constant and conductivity) must be determined to ensure that the simulated tissue was properly made and will simulate the desired human characteristics. A coaxial slotted line with probe is used to measure RF amplitude and phase changes versus distance in the simulated tissue as shown below.

5.2 References

- "A Comparative Study of Four Open-Ended Coaxial Probe Models for Permittivity Measurements of Lossy Dielectric/Biological Materials at Microwave Frequencies" D.Berube, F.M.Ghannouchi, and P.Savard, 1996, IEEE Transactions on Microwave Theory and Technique 44:1928-34.
- "Broadband Calibration of E-Field Probes in Lossy Media." K.Meier, M.Burkhardt, T.Schmid, and N.Kuster, 1996, IEEE Transactions on Microwave Theory and Techniques. 44:1954-1962.

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- “Coaxial Line Reflection Methods for Measuring Dielectric Properties of Biological Substances at Radio and Microwave Frequencies – A Review”, M.A. Stuchly and S.S. Stuchly, 1980, IEEE Transactions of Instrumentation and Measurement, 29:176-183.
- SAR Measurement Operational Guide, O.M. Garay and Q. Balzano, 1995, Motorola, Florida Corporate Electromagnetics Research Laboratory, Fort Lauderdale, Florida.
- FCC Dielec.exe computer program.
- CRC Handbook of Chemistry and Physics , R.C.Weast, M.J.Astle, and W.H.Beyer (Eds.), 1996, CRC Press Inc., Boca Raton, Florida.

5.3 Definitions

dielectric constant: the ratio of the capacity of a condenser with that substance as dielectric to the to the capacity of the same condenser with a vacuum for dielectric. It is a measure of the amount of electrical charge a given substance can withstand at a given electric field strength.

conductivity: the quantity of electricity transferred across unit area, per unit potential gradient, per unit time.

5.4 Standard Values Required

The dielectric constant and conductivity of simulated brain tissue should be 46.1 and 0.74 S/m^2, respectively.

Table 5.1

Tissue Ingredients			
Frequency (MHz)	Tissue Type	Dielectric Constant ε_r	Conductivity σ (S/m)
835	Brain	41.2	0.90
	Muscle	54.7	1.38
915	Brain		
	Muscle		
1900	Combined	41.0	1.70
2450	Combined		

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5.5 Test Equipment

Table 5.2

Description	Manufacturer	Model
Network Analyzer	Hewlett Packard	8510B
Slotted Line Carriage	Hewlett Packard	809B
Coaxial Termination	Hewlett Packard	908B
Slotted Line Probe	APREL	SLP-001
Miscellaneous Cables and Adapters	N/A	N/A

5.6 Test Configuration

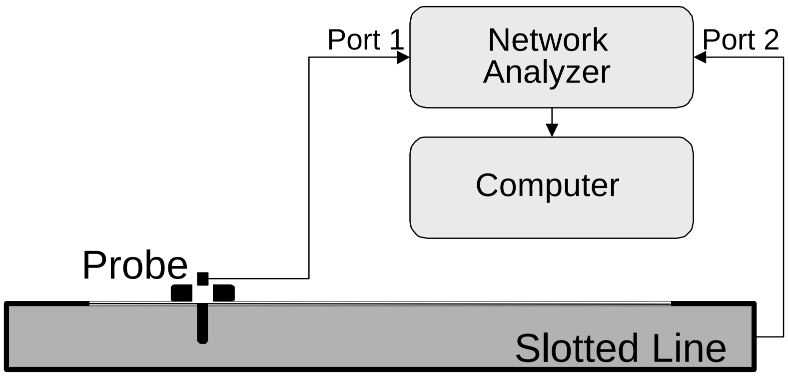

Figure 5.1

5.7 Test Procedure

1. Before using the slotted line, inspect it carefully to be sure the inside is clean and free of foreign matter.
2. Clean the area about 1 cm wide along each side of the slot. Similarly, clean the underside of the probe outer structure to ensure a good noise-free contact with the slotted line. Take care to avoid damage to the probe center conductor.

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3. Using a large syringe, draw up a sample of room temperature simulated tissue. Ensure that the sample is as free as possible of air bubbles, and inject the simulated tissue into the slot. Make sure that the slot is full of simulated tissue and free of air bubbles.
4. Connect Port 1 of the network analyzer to the probe, and Port 2 to the slotted line.
5. Insert the slotted line probe into the probe holder and tighter the thumbscrew.
6. Move the holder to the end nearest the input connector, making sure that the simulated tissue is flush with the outside surface of the line. Align one end of the probe marker with a line on the centimeter scale.
7. Set the network analyzer's frequency range to cover the measurement frequencies and select the S_{12} parameter.
8. Select port-to-port loss measurement and select averaging over a sufficient number of samples.
9. After averaging, place the marker at a frequency of interest and record the level in the table (one table per frequency) to the nearest 0.1dB.
10. Select phase measurement (averaging should be left on). Place the marker at a frequency of interest and record in the phase in the table (one per frequency) to the nearest 0.1°.
11. Move the probe 0.5cm toward the far end of the line.
12. Repeat steps 7 through 11 until 13 data points (corresponding to 6 cm) have been measured.

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5.8 Test Data Table

1. The level and phase can be recorded in the following table (use one copy per frequency):

Table 5.3

Frequency:		**Date:**	

Position (cm)	**Level (dB)**	**Phase (°)**
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		
4.5		
5.0		
5.5		
6.0		

2. Execute the Fluid Calibration with Slotted Line.xls spreadsheet and enter the measured amplitude and phase data as recorded in the table(s). When the data are plotted (eg Figure 5.2), examine the linearity of the curves to judge the validity of the calculated dielectric constant and conductivity (eg Table 5.4). If only one point on a curve is out of line, re-measure just that point. If more than one point is wrong, repeat the entire measurement. Once the data are satisfactory, the calculated values should be compared with the values in Table 5.1.
3. The measured data, calculated values, and plot must be identified with the type of simulated tissue, date it was prepared, frequency, date and name of person conducting the measurements, and kept in a file.
4. The simulated tissue should be used soon after preparation and characterization of the dielectric properties, and stored so as to prevent evaporation of the water. After prolonged use, a sample should be taken for dielectric measurement to assure there has been no change in properties. In the absence of biological degradation and significant evaporation, the simulated tissue can be used for several months.

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Table 5.4

02-Feb-98 *Rob Acorn*
Brain Mixture @ *835* *MHz*

Position [cm]	Amplitude [dBm]	Phase [deg]
0	-37.9	-74.4
0.5	-39.2	-106.6
1	-40.6	-140.8
1.5	-41.9	-174.3
2	-43.2	152.4
2.5	-44.6	117.7
3	-45.9	83.8
3.5	-47.2	51.4
4	-48.6	18
4.5	-50.1	-16.2
5	-51.5	-49.5
5.5	-52.7	-84.6
6	-53.9	-115.7
ε_r	41.73	
$\sigma_{effective}$ [S/cm]	1.103E-02	

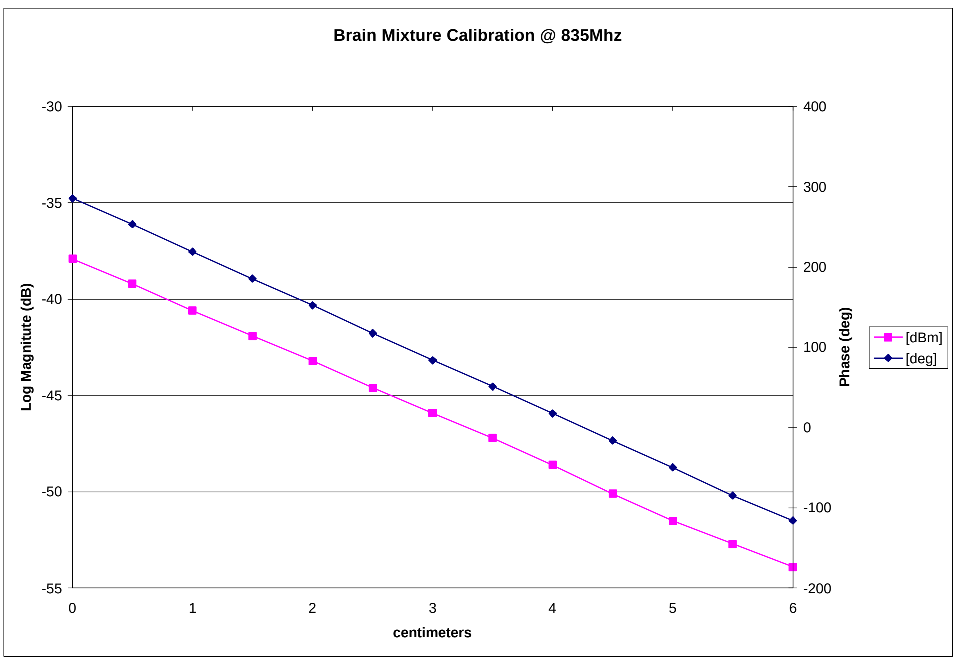

Figure 5.2

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5.9 Test Data Analysis

The data from the slotted line are used to determine the relative dielectric constant and effective conductivity (that includes contributions from both dielectric and ohmic processes) from the following relationships:

$$e_{\mathrm{r}} = \frac{b^2 - a^2}{w^2 m e_0} \tag{1}$$

$$s_{\text{effective}} = \frac{2ab}{wm} \tag{2}$$

α and β are determined by averaging, respectively, the attenuation (dB/cm) and phase shift (deg/cm) over the length of the slotted line. The attenuation and phase shift are each determined for seven pairs of points. Each of the pairs of points is from measurements separated by 3 cm. For example (using the data in Table 5.4), the attenuations and phase shifts at z=1 cm and z=6 cm define ΔdB_1 and Δdeg_1:

ΔdB_1 = Mag (z = 3 cm) - Mag (z =0 cm)

= -45.9 dB_m, - (-37.9 dB_m) = -8.0 dB, and

Δdeg_1 = Phase (z = 3 cm) - Phase (z =0 cm)

=83.8 deg - (285.6) deg = -201.8 deg.

In a similar fashion, obtain data for ΔdB_2 to ΔdB_6 and Δdeg_2 to Δdeg_6 and then average each series to get

$$a_{\text{avg}}(\text{dB/cm}) = \frac{\sum_{n=1}^{7} \Delta \text{dB}_n}{7 \cdot 3}, \text{ and}$$

$$b_{\text{avg}}(\text{deg/cm}) = \frac{\sum_{n=1}^{7} \Delta \text{deg}_n}{7 \cdot 3}$$

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The values of α_{avg} and β_{avg} must be converted to units of (Np/cm) and (rad/cm) using these relations:

$$\alpha_{avg}\left(\text{Np/cm}\right) = \frac{\ln(10)\cdot \alpha_{avg}\,(\text{dB/cm})}{20}\text{, and}$$

$$\beta_{avg}\left(\text{rad/cm}\right) = \frac{\beta_{avg}\,(\text{deg/cm})\cdot \pi}{20}$$

Finally, use (1) and (2) to obtain ε_r and $\sigma_{effective}$ from α_{avg}, β_{avg}, and $\omega = 2\pi f$, where f is the frequency of the RF field.

6.0 MEASUREMENT OF THE SPECIFIC HEAT CAPACITY OF SIMULATED TISSUE

6.1 Test Purpose

The specific heat capacity of the synthetic tissue liquid is required in the calibration of the miniaturized isotropic E-field probes used to measure the Specific Absorption Rate (SAR). A sample of the liquid is exposed to the known field of an RF radiation for a specific length of time. The liquid will be heated and this heat can be propagated by conduction, convection, and radiation. In the case of liquids heated from below, gravity convection is the main and predominant heating mechanism of the fluid mass.

6.2 References

- Introduction to Physics for Scientists and Engineers, F.J. Bueche, McGraw-Hill Book Company, New York, 1980.
- "The Specific Heats of Aqueous Sucrose Solutions", F.T. Gucker and F.D. Ayres, 1937, American Journal of Chemistry, 59:447-452.
- "Electromagnetic Energy Exposure of Simulated Users of Portable Cellular Telephones", Q. Balzano, O.M. Garay, and T.J. Manning, 1995, IEEE Transactions on Vehicular Technology, 44:390-403.
- "Broadband Calibration of E-Field Probes in Lossy Media", K. Meier, M. Burkhardt, T. Schmid, and N. Kuster, 1996, IEEE Transactions on Microwave Theory and Techniques, 44:1954-1962.
- SAR Measurement Operational Guide, O.M. Garay and Q. Balzano, 1995, Motorola, Florida Corporate Electromagnetics Research Laboratory, Fort Lauderdale, Florida.

6.3 Definition

specific heat capacity: the quantity of energy needed to raise the temperature of a unit mass by one degree.

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6.4 Standard Value

For brain tissue simulating liquids the heat capacity should be 2.8 J/K/g ±5%.

6.5 Test Equipment

Table 6.1

Description	**Manufacturer**	**Model**
Differential Thermometer		
Containers (2)		500 ml
Thermally Insulated Vessel		
Weigh Scale	Pennsylvania Scale Co.	2 kg
Graduated Cylinder	BOMEX	2000 ml
Data Recorder		

6.6 Test Procedure

1. Obtain two containers that can be rapidly heated (e.g., glass or suitable plastic).
2. Fill one container with 250 ml of water; the other with the same mass of simulated tissue. The initial temperature of the water should be the same as that of the simulated tissue (±1°C). Since we are dealing with heating by electromagnetic sources at ambient temperature, it is essential that we eliminate the chance of any direct infrared heating of the temperature sensor.
3. To ensure this, position the tip of the sensor 2mm from the bottom of the center of the container.
4. Turn on the heat source and wait at least 5 minutes for its temperature to stabilize.
5. Record the initial temperature of the water.
6. Place the container of water 5mm above the center of the hot plate and monitor the temperature increase.
7. After 30 seconds of heating, the water temperature should have increased by at least 5°C. Record the time and temperature.
8. Remove the container from the heat source and place it in the thermally insulated vessel.

9. Stir the liquid thoroughly and record the steady-state temperature 1-2 minutes after stirring.
10. Repeat the above procedure using the container of simulated tissue. Ensure that the container is placed on the same area of the hot plate, is heated for the identical length of time, and the steady-state temperature is recorded after the identical time interval.

6.7 Test Data Table

The temperatures can be recorded below.

Table 6.2

	Water (°C)			Tissue (°C)		
Trial	**Initial Temp**	**30 seconds**	**120 seconds**	**Initial Temp**	**30 seconds**	**120 seconds**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

6.8 Test Data Analysis

Since the heat capacity of water is C_w = 1 cal/°C/g with excellent approximation (~ 1 %) in the temperature range of interest, the heat capacity (C_s) of the solution is given by

$$C_S = C_W \frac{\Delta T_W}{\Delta T_S}$$

where ΔT_W is the temperature increase of water and ΔT_S the temperature increase of the solution. The ratio of the values, $\Delta T_W/\Delta T_S$, should be the same (within the sensitivity of

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the thermometer) at the end of the heating and stirring. This ensures that the liquids have been uniformly heated.

6.9 Rationale

$C\ \Delta T$ = Heat flow x time = Total Heating Energy

If the heat flow, sample mass, and absorption (heat transfer) are the same for both liquids, then

$C_W\ \Delta T_W = C_S\ \Delta T_S$

The heat flow and total heating are kept constant by using the same source for the same amount of time. If the heat transfer mechanisms for the two liquids are about the same, with insignificant differences in convective and conductive characteristics, then any differences in temperature increase are a direct measure of the specific heat capacity, C.

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7.0 MEASUREMENT OF THE DENSITY OF SIMULATED TISSUE

7.1 Test Purpose

Before a batch of simulated tissue can be used for SAR measurements, its density must be determined to ensure that the simulated tissue was properly made and will simulate the desired human characteristics.

7.2 References

- Introduction to Physics for Scientists and Engineers, F.J. Bueche, 1980, McGraw-Hill Book Company, New York.
- "Electromagnetic Energy Exposure of Simulated Users of Portable Cellular Telephones", Q. Balzano, O.M. Garay, and T.J. Manning, 1995, IEEE Transactions on Vehicular Technology, 44:390-403.
- "Broadband Calibration of E-Field Probes in Lossy Media", K. Meier, M. Burkhardt, T. Schmid, and N. Kuster, 1996, IEEE Transactions on Microwave Theory and Techniques, 44:1954-1962.

7.3 Definition

density: a measure of the mass contained in a unit volume of the substance.

7.4 Standard Value

For brain tissue simulating liquids the density should be 1.28 g/cm^3 ±2%.

7.5 Test Equipment

Description	**Manufacturer**	**Model**
Weigh Scale	Pennsylvania Scale Co.	2 kg
Graduated Cylinder	BOMEX	2000 ml

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7.6 Test Procedure

1. Obtain a clean, dry graduated cylinder.
2. Place the cylinder on a scale and record its mass when empty.
3. Pour a sample of the simulated tissue into the cylinder.
4. Weigh the cylinder with the simulated tissue to obtain a total mass.
5. Subtract the cylinder mass from the total mass to obtain the mass of the tissue.
6. Record the tissue volume and mass in the table below.
7. Clean and dry the cylinder and repeat this process for a total of 10 trials.

7.7 Test Data Table

1 The volume and mass can be recorded in the following table:

Mixture Frequency (MHz):		**Date:**	
Empty Measuring Container Mass (g):			
Trial	**Volume (ml)**	**Mass (g)**	**Density (g/ml)**
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

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7.8 Test Data Analysis

The data are used to determine the density of the simulated tissue by means of the following relation:

$$r = \frac{m - m_c}{v}$$

where ρ is the density (g/cm^3, Note:1 g/cm^3 = 1000 kg/m^3)
m is the mass of the container filled with simulated tissue (g)
m_c is the mass of the empty container (g)
v is the volume of the simulated tissue (1 cm^3 ≡ 1 ml).

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