Deep RF Hyperthermia- Technical Historical Review

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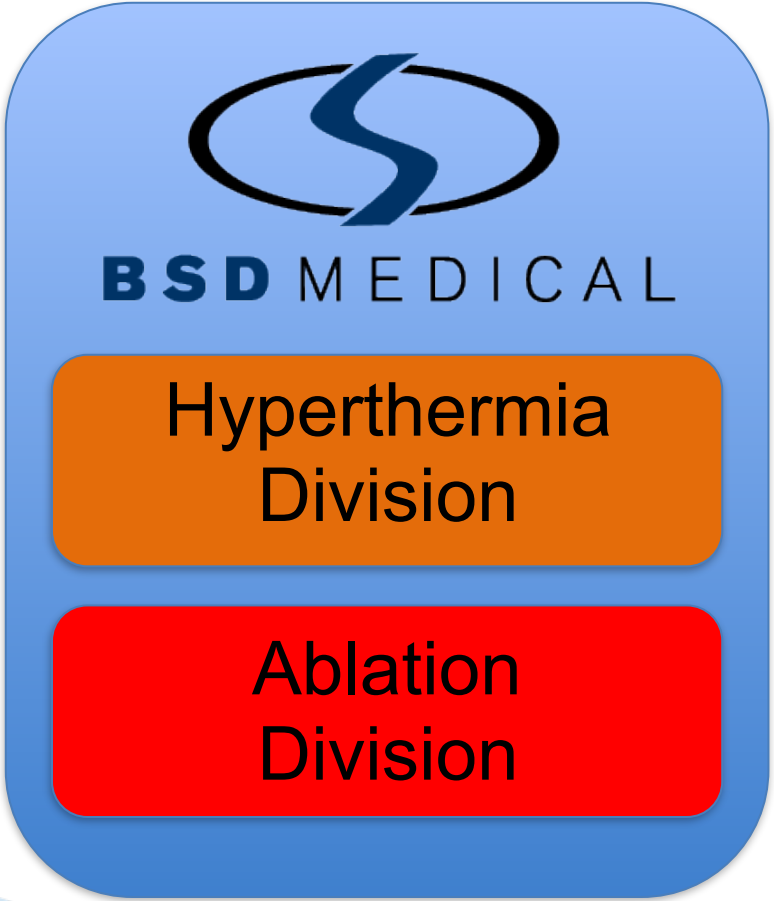
Pyrexar Medical Corporation

ESHO 2019 • May 22 – May 24 • Warsaw, Poland

Pyrexar Medical Turns 4



Pyrexar MEDICAL

perseon

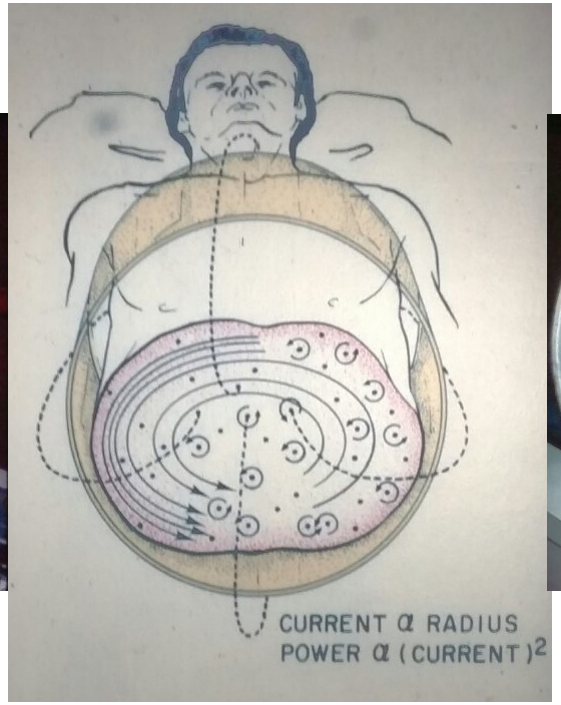
BSD Medical Corp Began1978

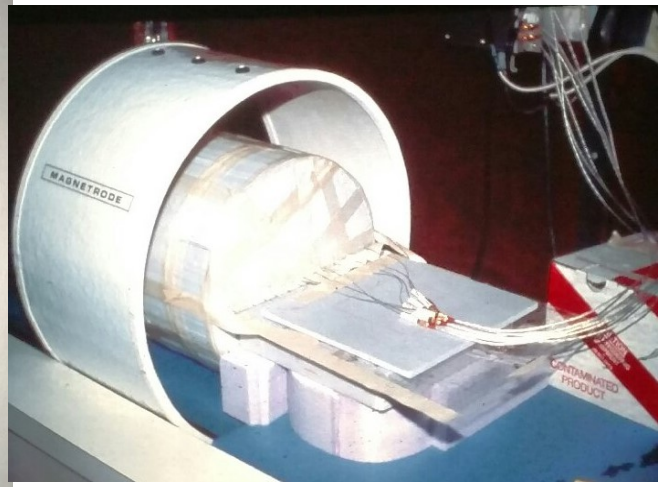
Pyrexar Medical Progress- 4 years old

Mark Falkowski CEO & Pyrexar Team

- BSD-500 Upgrade retrofit
  - New applicator arm
  - New large touch screen monitor
  - New software user interface
- Redesign BSD-2000-3D/MR- Universal
  - Pads with no sling
  - Reduce cost
  - Universal compatibility
- Hal.o phased array
  - Brain tumors
  - Possible stroke, Alzheimer's Disease, etc.

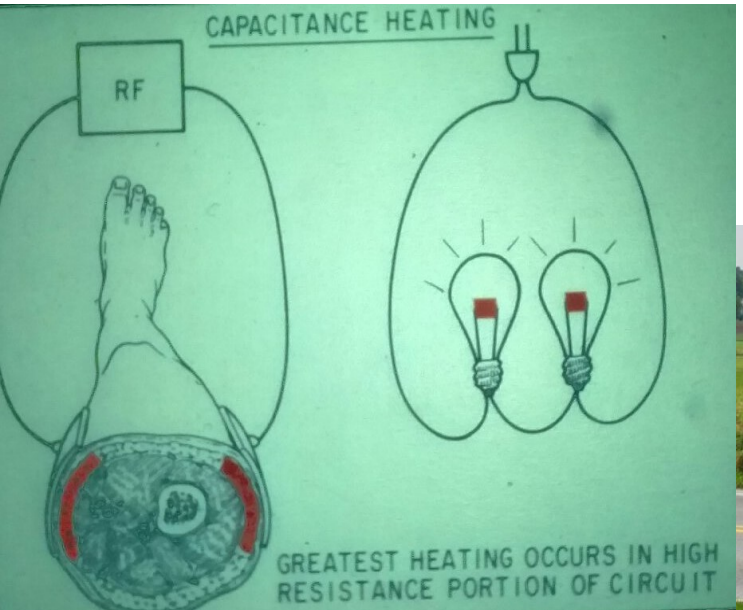
40 Years Ago Magnetrode Inductive RF Coil 13MHz- no deep heating



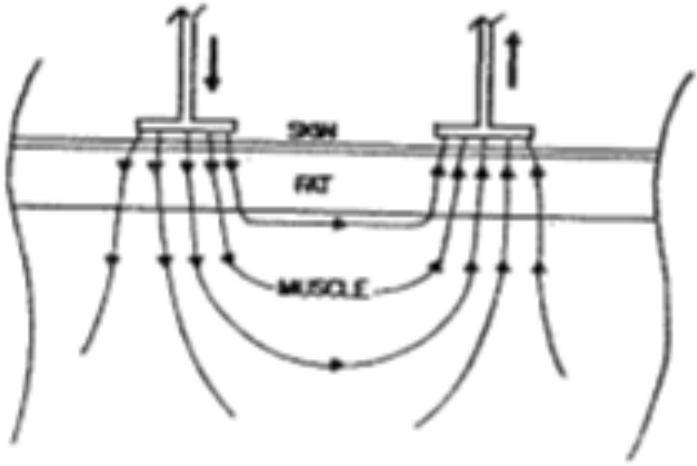


Capacitive RF Electrodes

Capacitive electrode cancer treatments were being used in 1917. Geyser (Philadelphia & IJ Surgery)



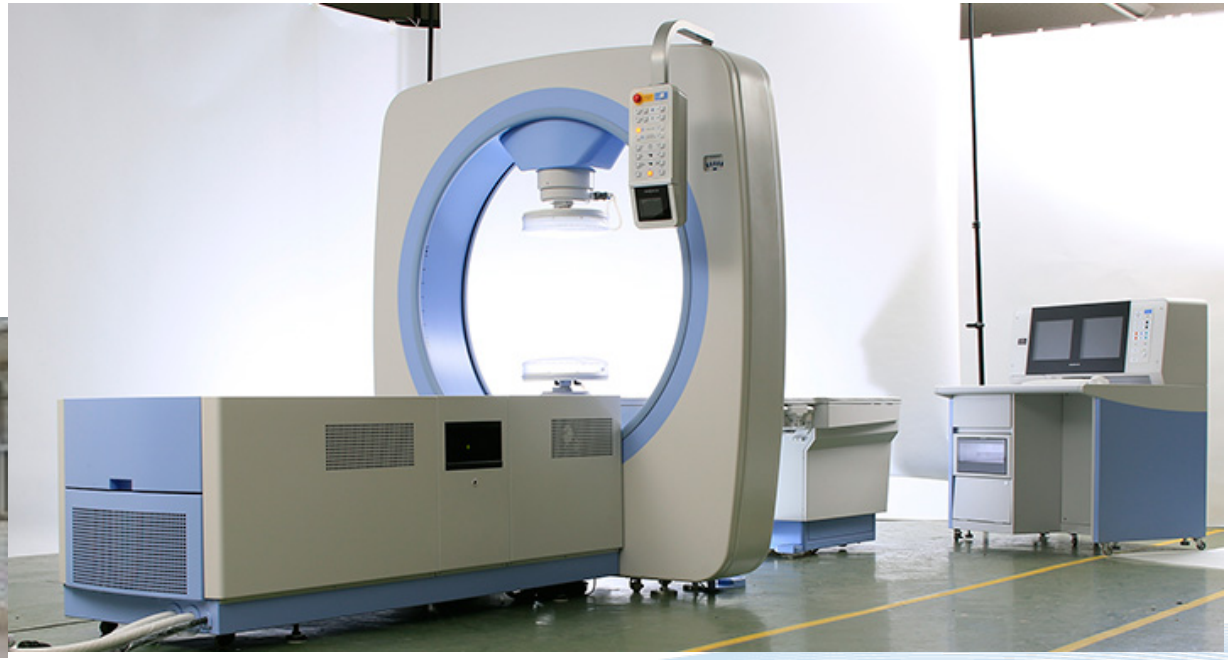
Capacitive heating “would produce a more than 17 times greater rate of temperature rise in the fat than in the muscle.” W. Guy, 1974 Proceedings IEEE



RF-8 Thermotron

RF-8 Two Capacitive Electrodes uses cooling water bolus to reduce excess fat heating with cooling depth limited to 1.5cm of fat.

Modern version of old Capacitive electrode technology.



2 Electrode Capacitive Numerical Study, D'Ambrosio,

Med Bio Eng Comput (2007) 45:459-466

Necrotic tumor BF @ ≥42°C
-BF 18% of muscle max
-57% of fat max
-Mean fat thickness 2.5cm

Concluded: ".., calculations show that extremely high temperatures, up to 60°C, are reached in normal tissue regions, if therapeutic temperatures are obtain in deep-seated tumors."

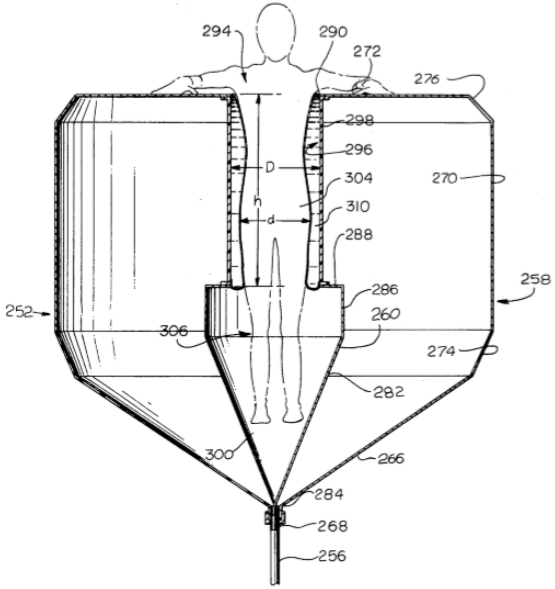
2 Electrode Capacitive Numerical Study, Kok IJH 2018

“Although this study showed that capacitive heating is in general much less effective compared with radiative heating for deep-seated tumors, capacitive heating can be of clinical value for some specific patient categories.”

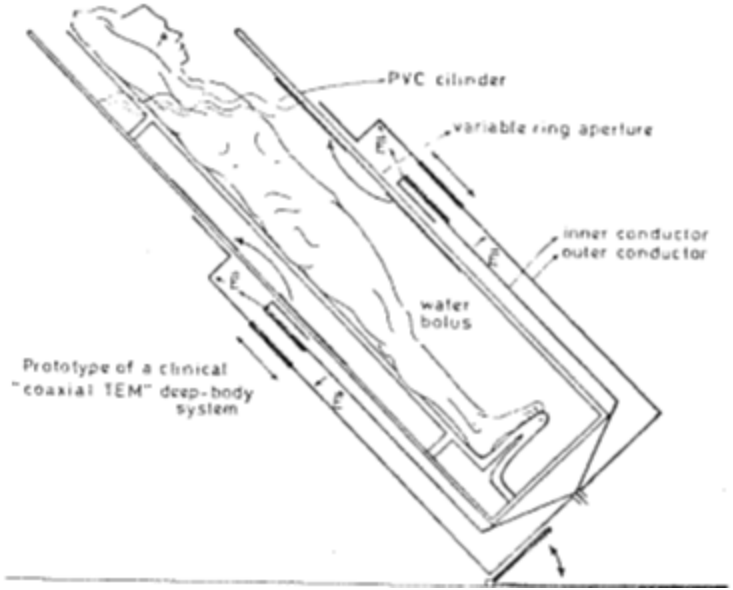
“This simulation study showed that therapeutic temperatures are predicted for capacitive heating in patients with (almost) no fat. Nevertheless, radiative hyperthermia generally yields much more favorable heating patterns for deep-seated pelvic tumors, compared with capacitive heating.”

BSD-1000 Introduced in 1979

TEM Cell Concepts

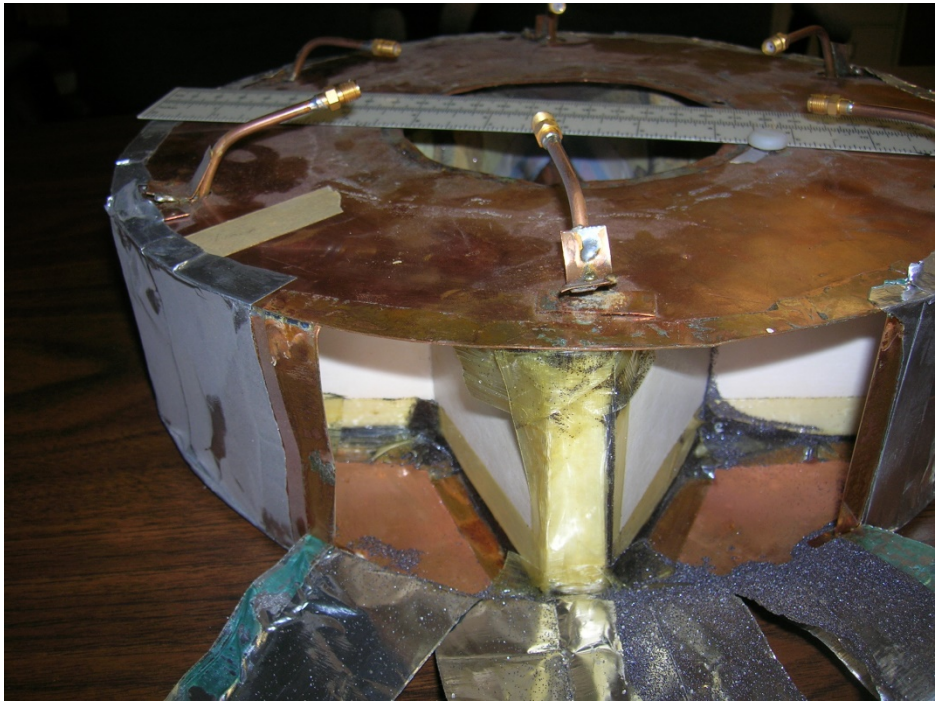


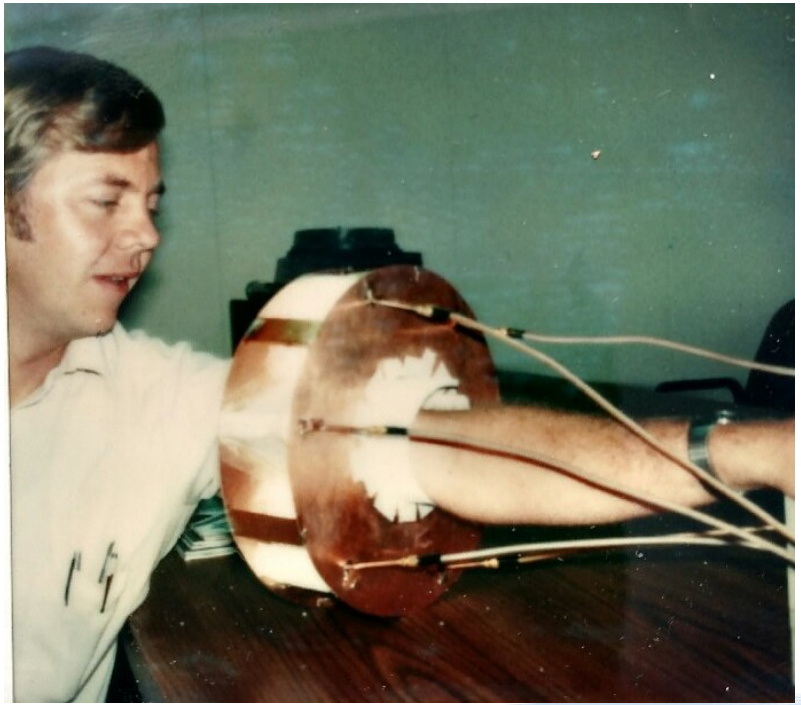
Turner, 1980, Prototype
US Pat. 4,462,412



Lagendijk 1983

First Deep Phased Array Concept- 6 Pyramid Waveguides 1979

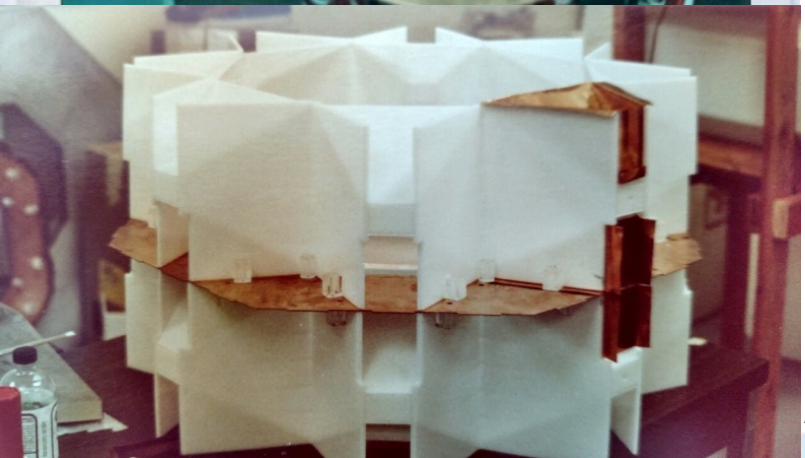


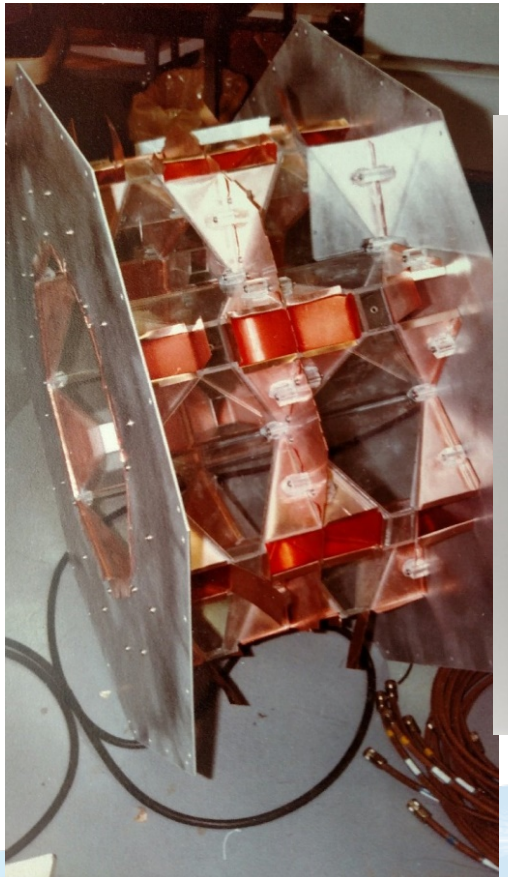


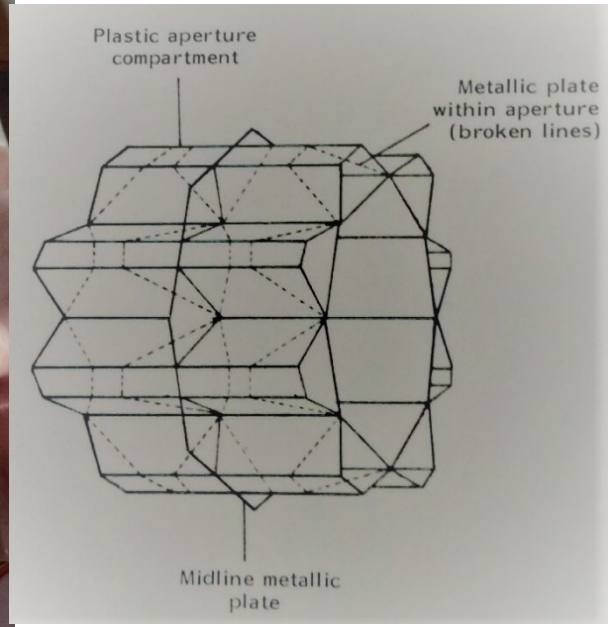
Full Size Annular Phased Array 1980

- 16 TEM mode pyramid waveguides
- 2 rings of 8 apertures
- High dielectric filled apertures
- 60 to 120MHz
- 3 separate water bolus bags

APAS Construction 16 Waveguides



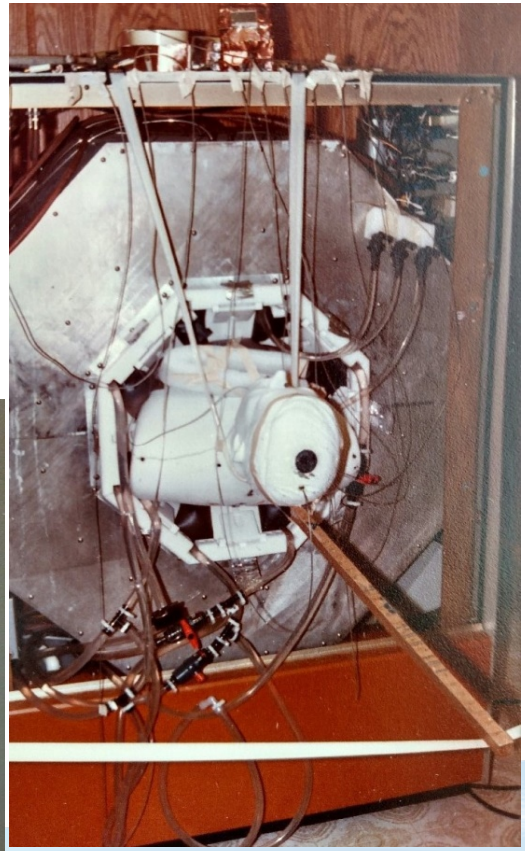


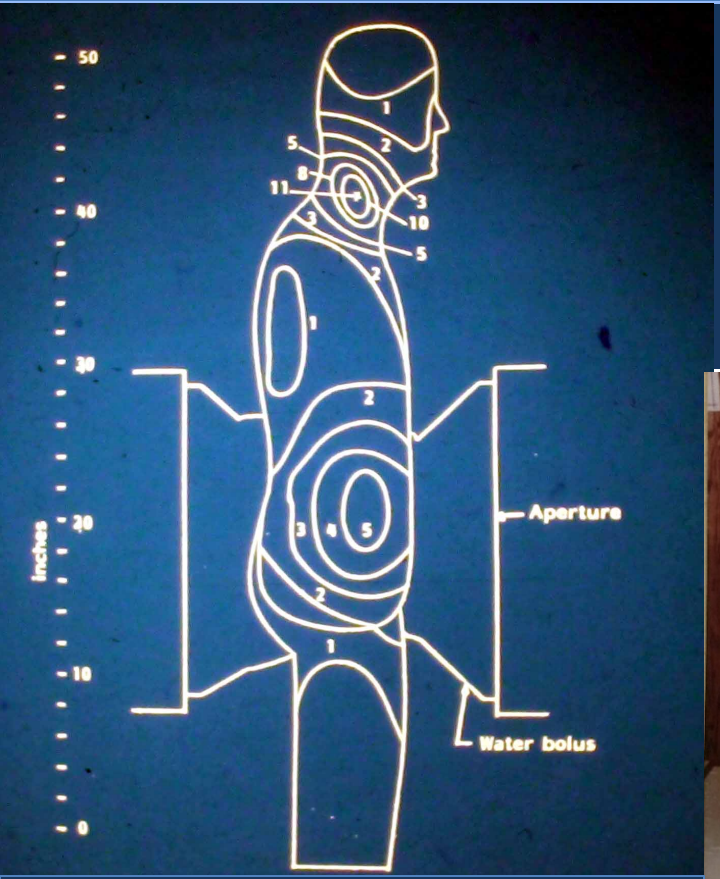


A

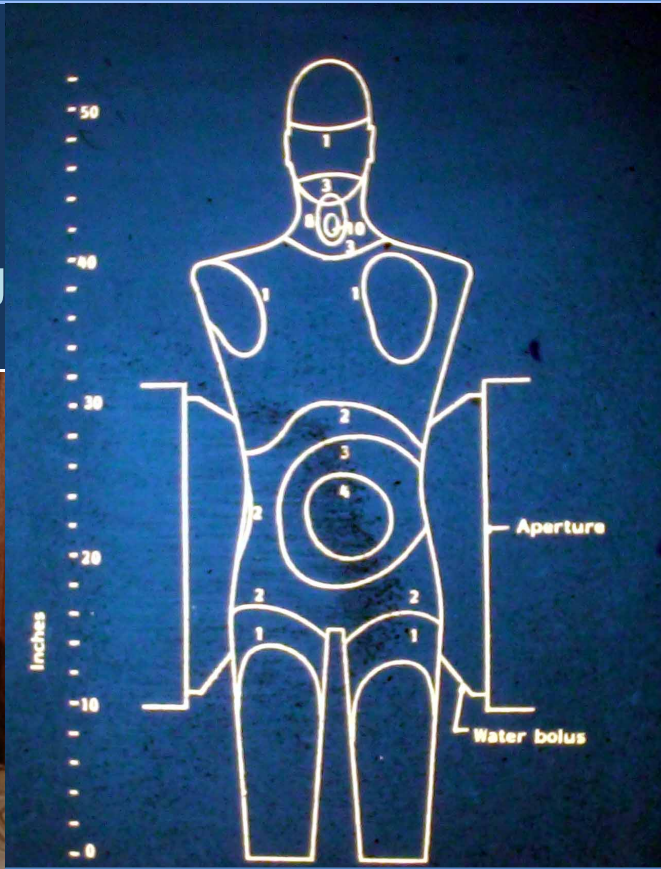
Pyrexar MEDICAL

APAS Initial Phantom Testing 1980

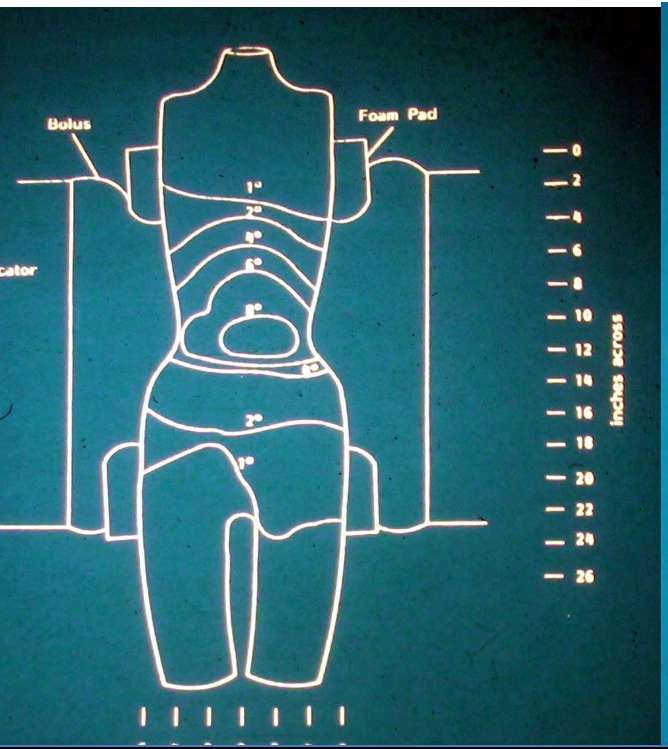


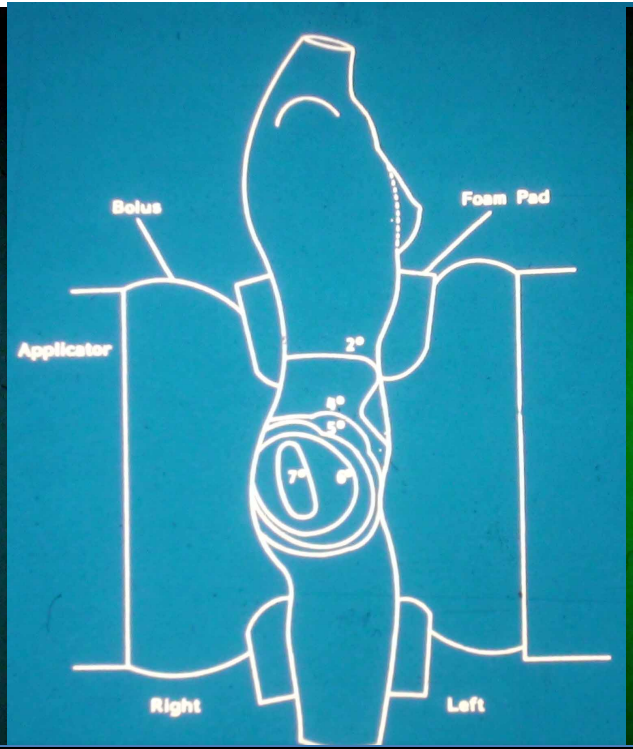


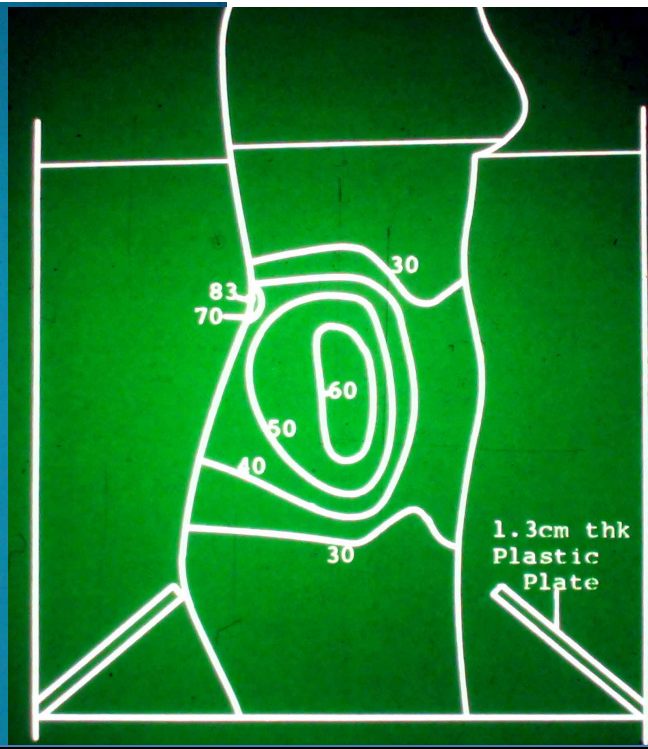
74MHz
Metal waveguides
increase fringe fields
leading to neck heating

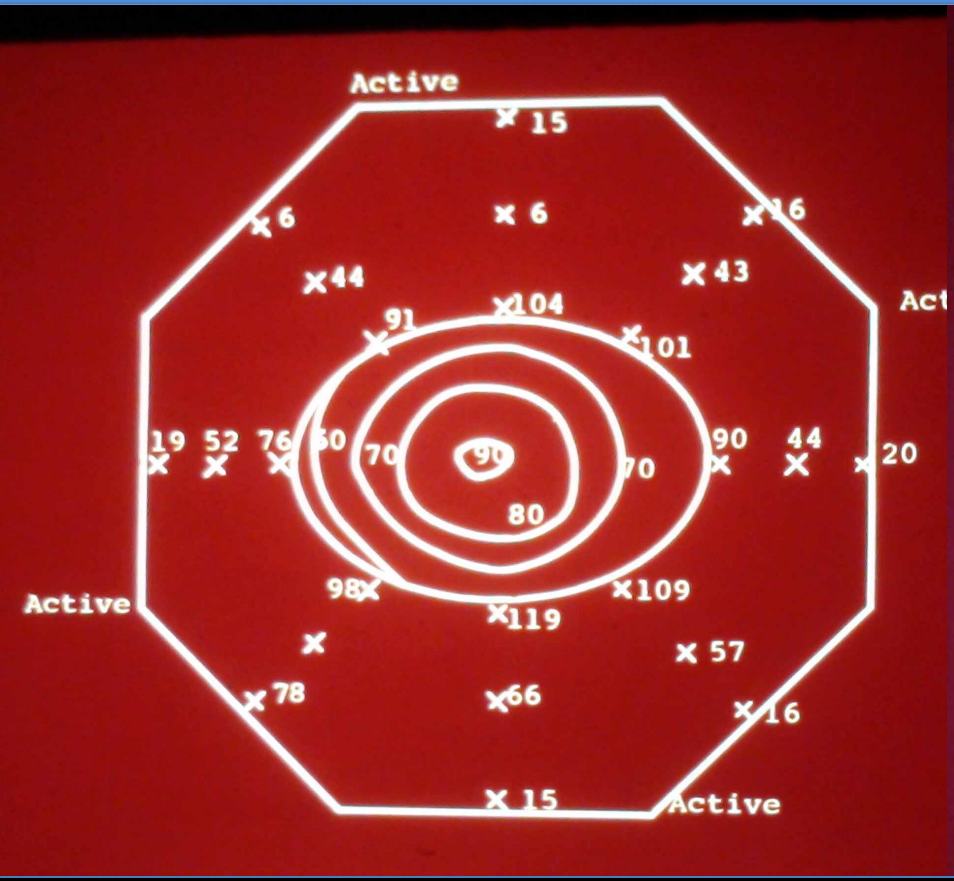


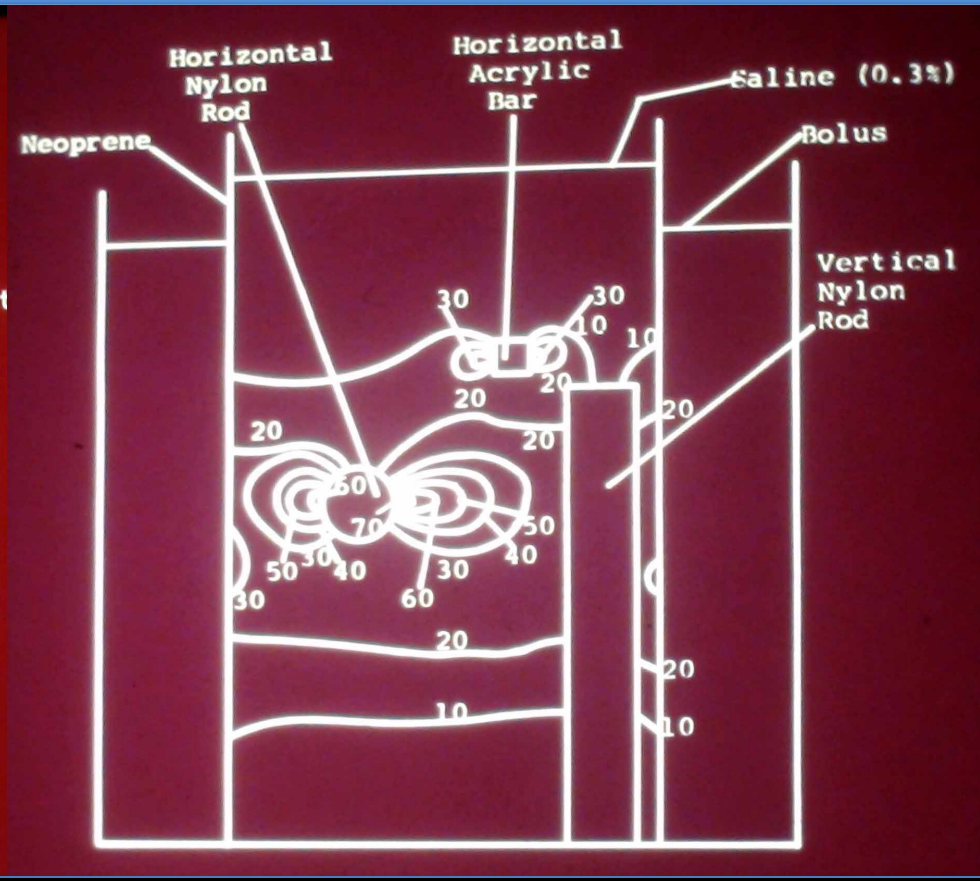
APAS Testing Female 0.3% Saline Phantom








Active
15
6
6
16
44
43
91
104
101
19
52
76
80
70
90
70
90
44
20
80
98
109
119
Active
57
78
66
16
15
Active


Horizontal
Nylon
Rod
Horizontal
Acrylic
Bar
Saline (0.3%)
Neoprene
Bolus
Vertical
Nylon
Rod
30
30
10
10
20
20
20
20
20
50
70
50
50
30
40
30
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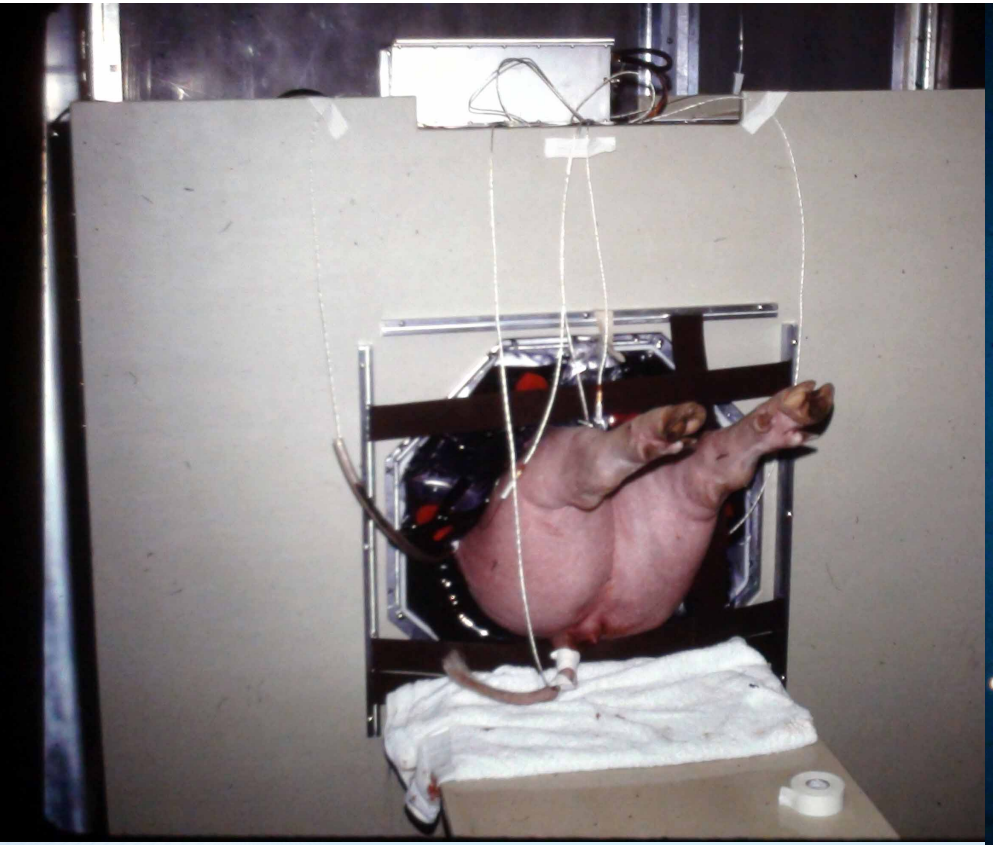
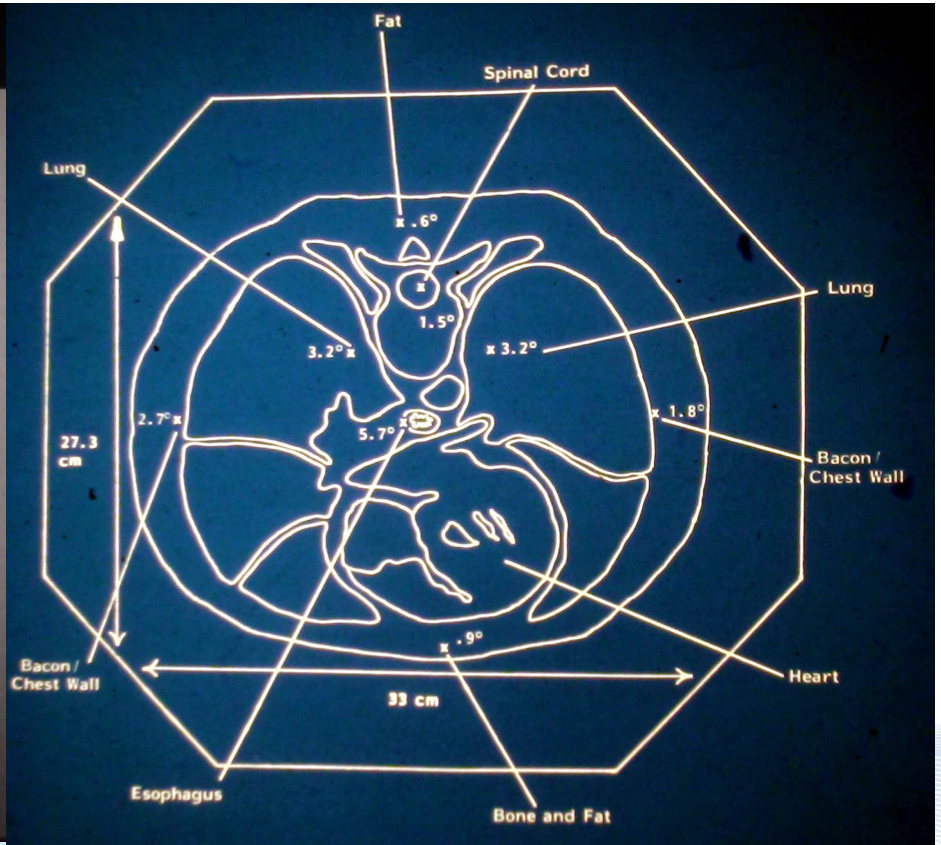
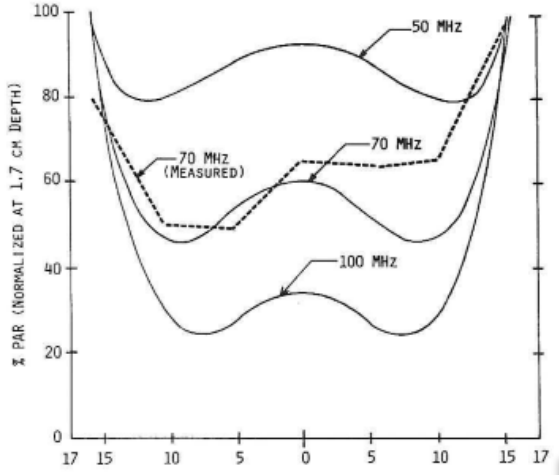
60
20
20
10
10

Pig testing confirmed deep focus

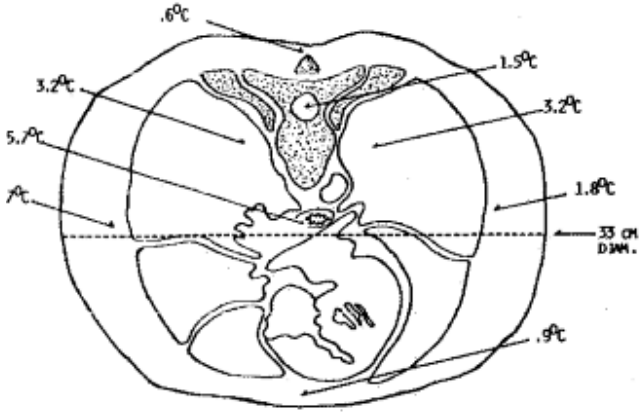


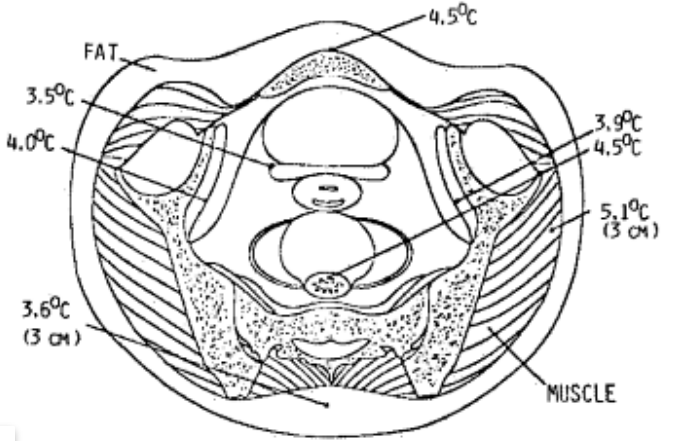


3D Numerical Model in muscle phantom

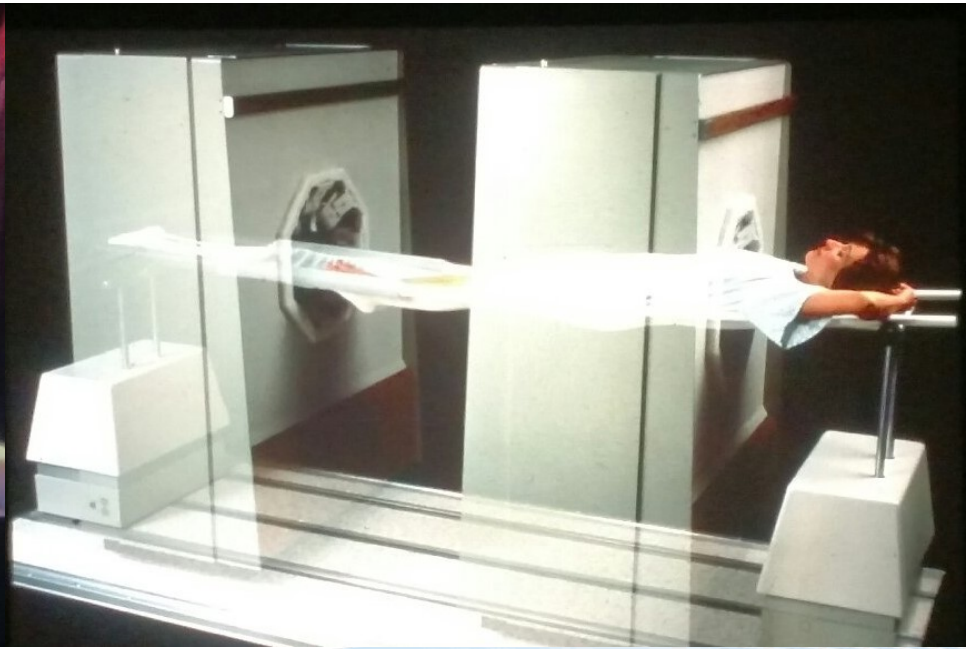


APAS Heating of Pig In No-bloodflow condition

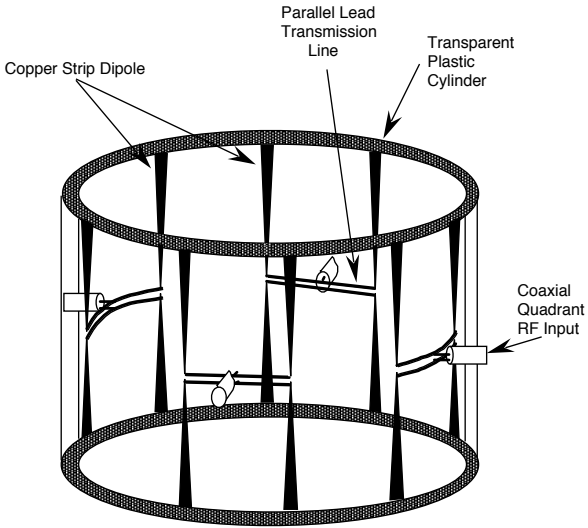




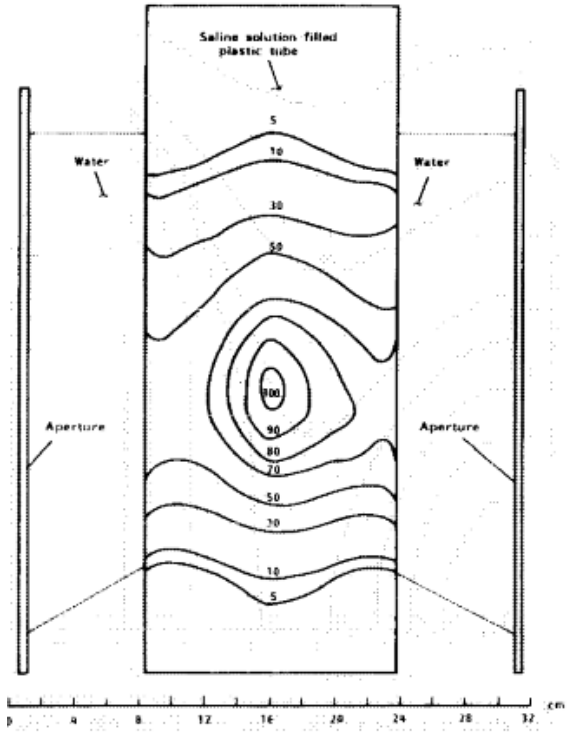
APAS Clinical Introduction 1981



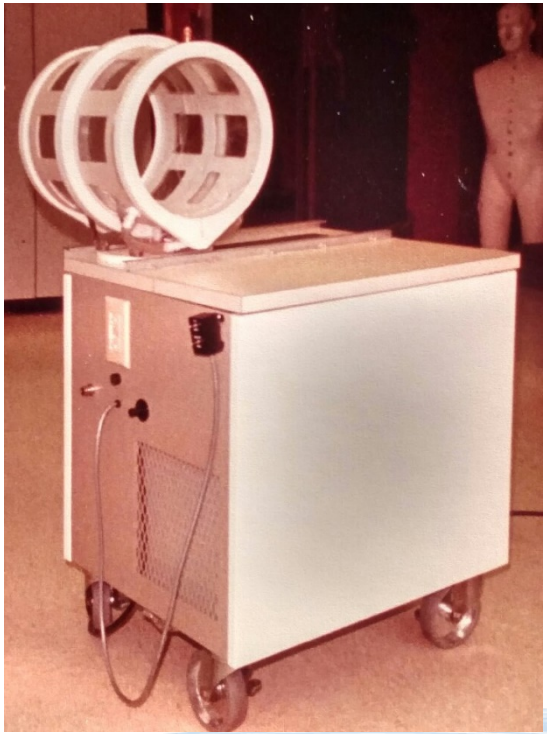
Dipole phased array mini-annular phased array (MAPA) 100-180MHz



Turner 1984



120MHz



AMC-4 system 1987
70MHz 4 RF Channels

AMC-8 system
70MHz 8 RF Channels

Discussions With Experts, What to do next??

Phased Array BSD-2000 1988

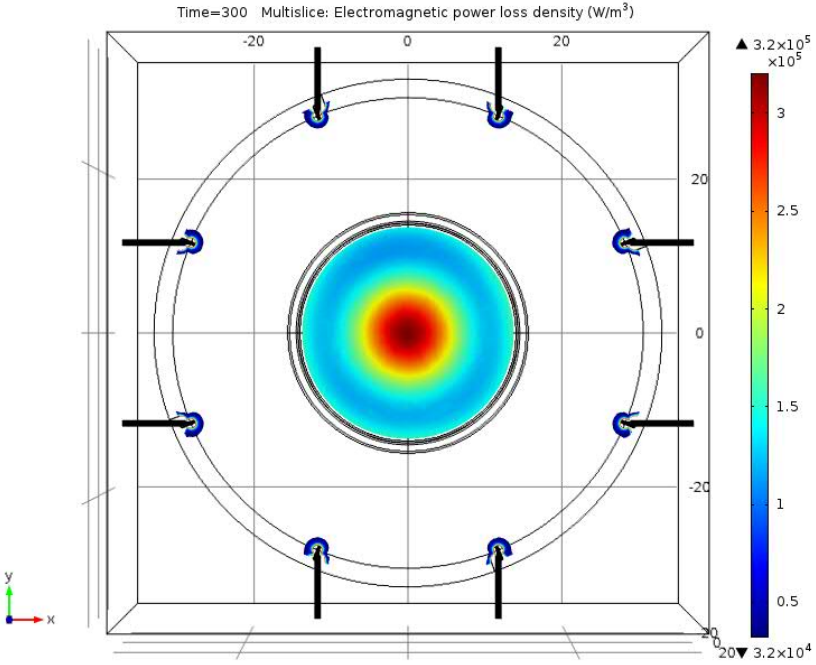
Deep Heating Numerical Study

- COMSOL 3D Multiphysics Model
- Homogeneous phantom cylindrical and elliptical saline or muscle dielectric and 2/3rds muscle conductivity with 1cm layer of superficial fat.

Sigma 60-8 dipole array@ **100MHz** using a COMSOL numerical model of a 28cm diameter phantom 74cm long & 48cm long water bolus.

This study showed more selective central heating
with low fat heating near the bolus outer edges.
Maximum SAR is shown in the tissue center.

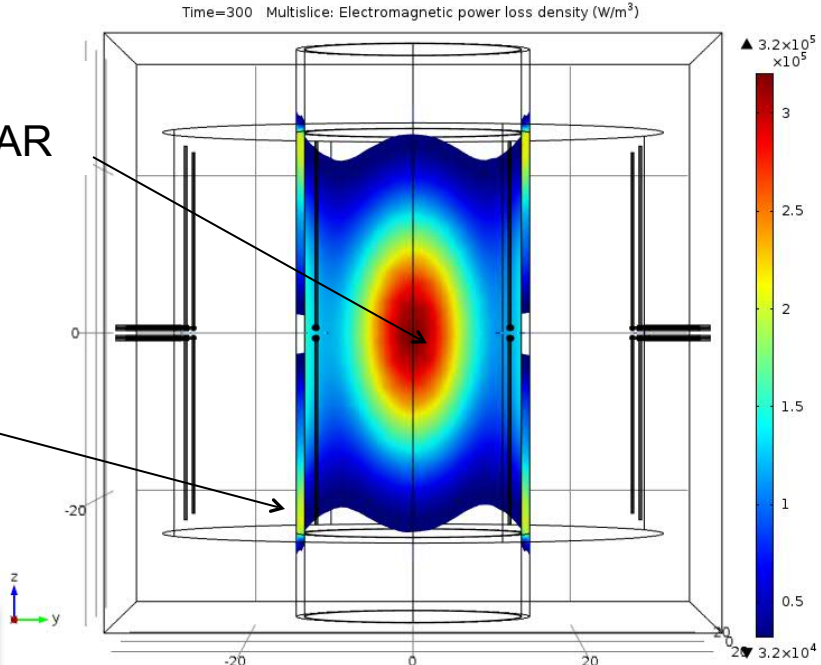
Axial Slice View



Coronal Slice View

100%
Central SAR

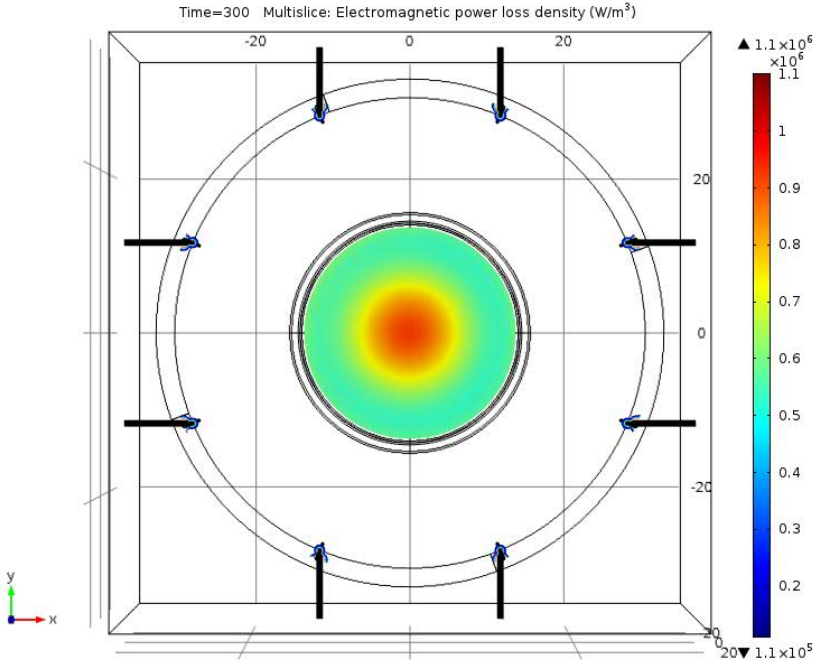
50%
Fat SAR



Sigma 60-8 dipole array@ **75MHz** using a COMSOL numerical model of a 28cm diameter phantom 74cm long & 48cm long water bolus.

This study showed stable and uniform surface and central heating with and increase of fat heating near bolus outer edges as compared with the heating at the center.

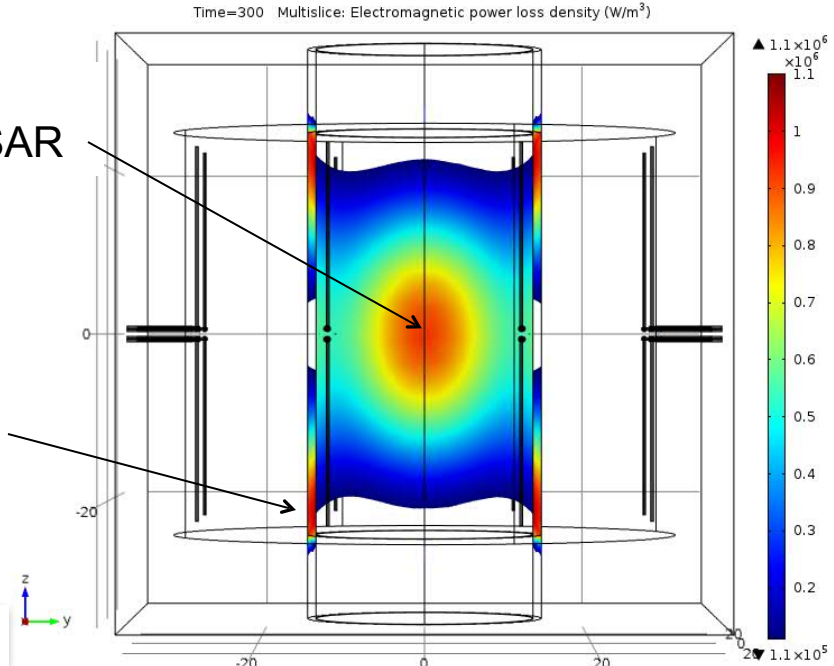
Axial Slice View



Coronal Slice View

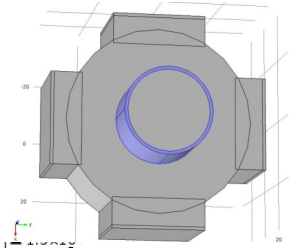
85% Central SAR

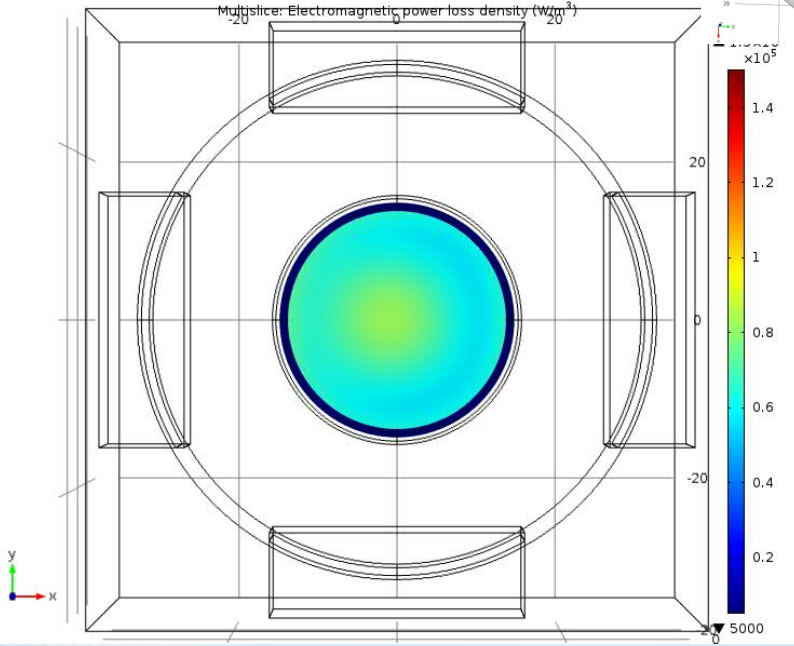
100% Fat SAR



Four Waveguide array@ **70MHz** using a COMSOL numerical model of a 28cm diameter phantom 74cm long & **40cm** long water bolus. This study showed high superficial fat SAR potential.

Axial Slice View

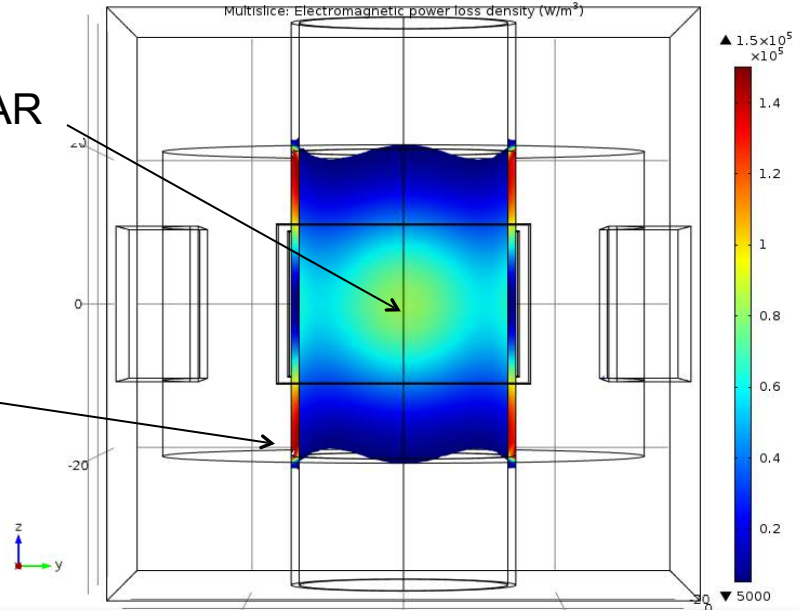




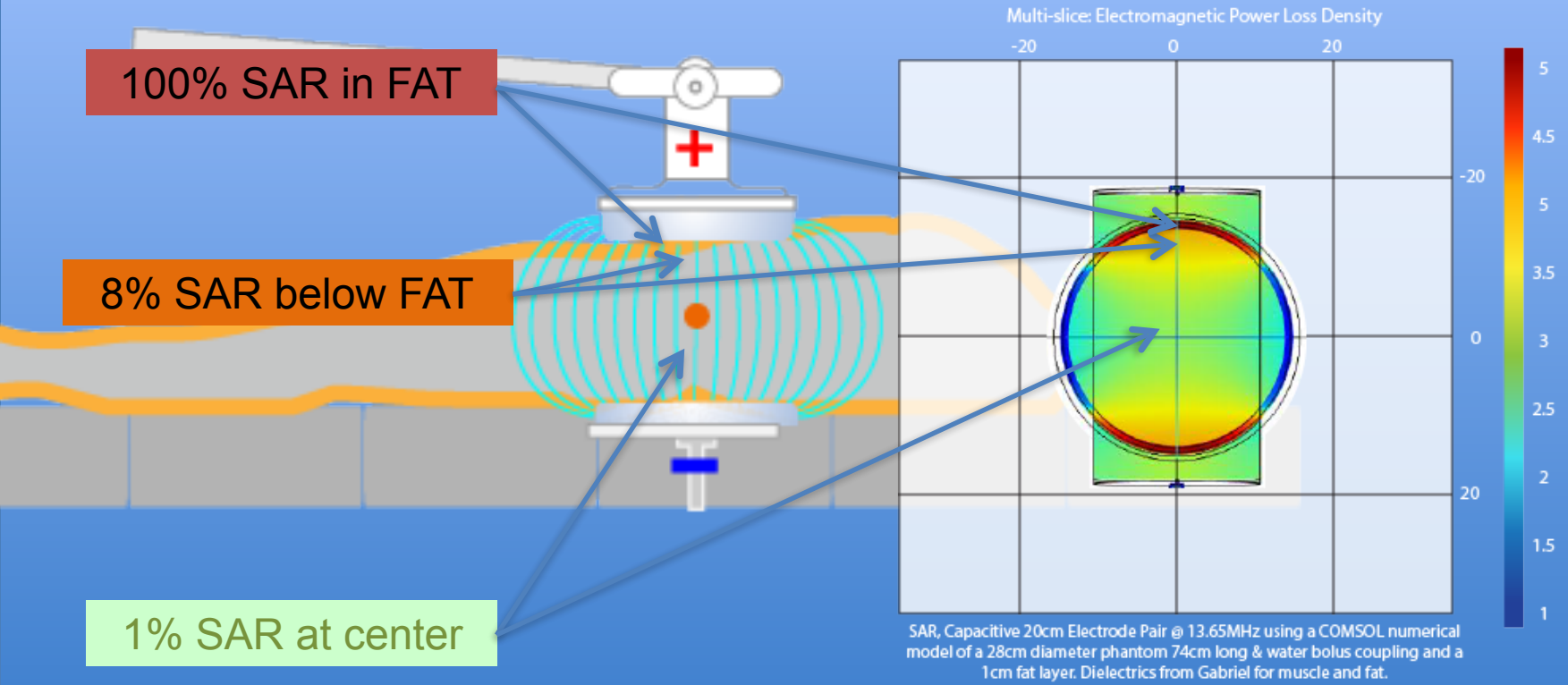
50%
Central SAR

100%
Fat SAR

Coronal Slice View



Capacitive Electrodes Have No Deep Energy Focus
1917 Technology

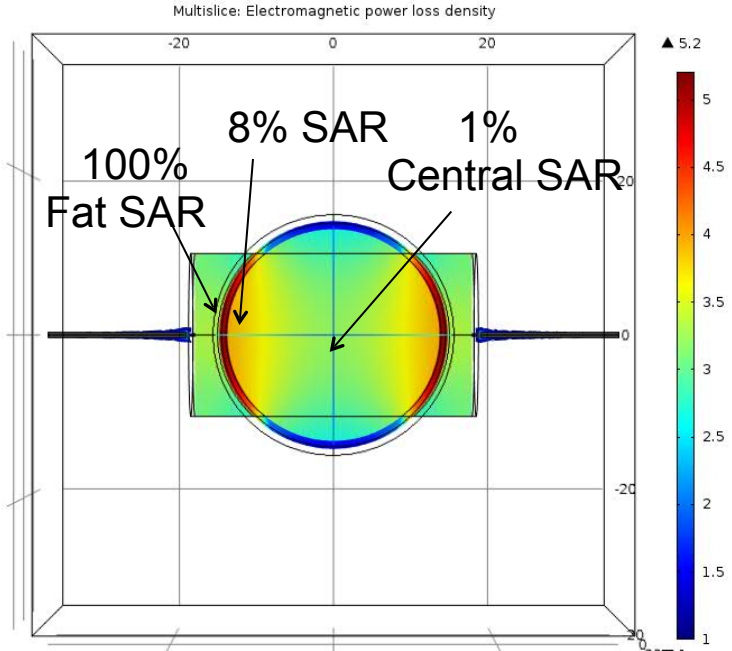


SAR, Capacitive 20cm Electrode Pair @ 13.65MHz using a COMSOL numerical model of a 28cm diameter phantom 74cm long & water bolus coupling and a 1cm fat layer. Dielectrics from Gabriel for muscle and fat.

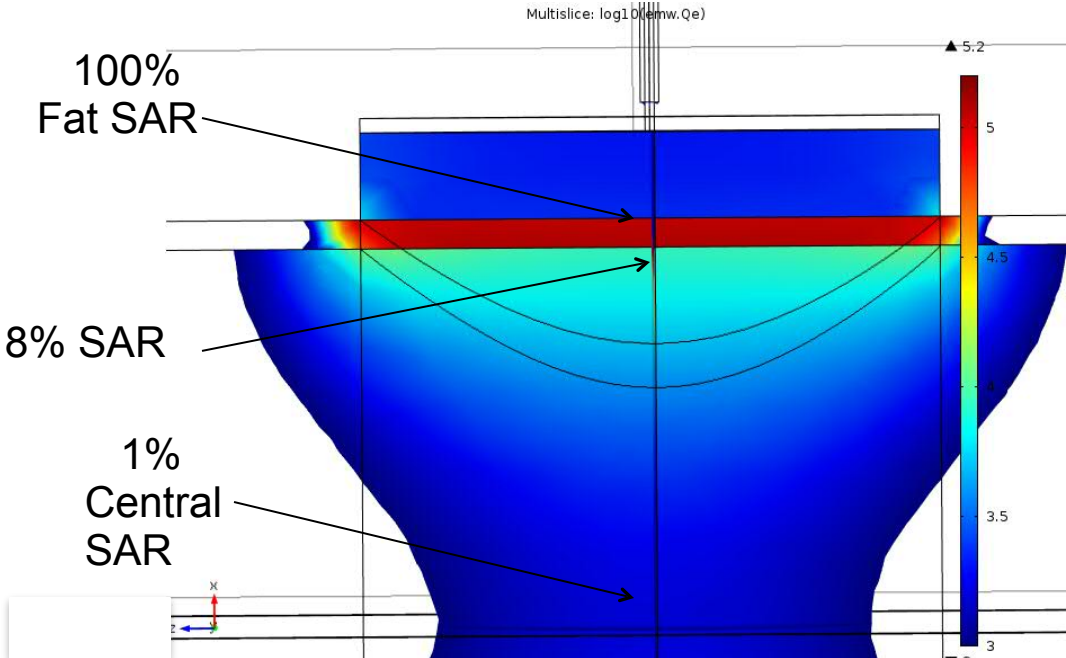
Capacitive 20cm Electrode Pair @ **13.65MHz** using a COMSOL numerical model of a 28cm diameter phantom 74cm long & water bolus coupling and a 1cm fat layer.

This study showed extremely high superficial fat SAR heating.

Axial Slice View
SAR Log10 Plot Scale



SAR Zoom View
SAR Log10 Plot Scale

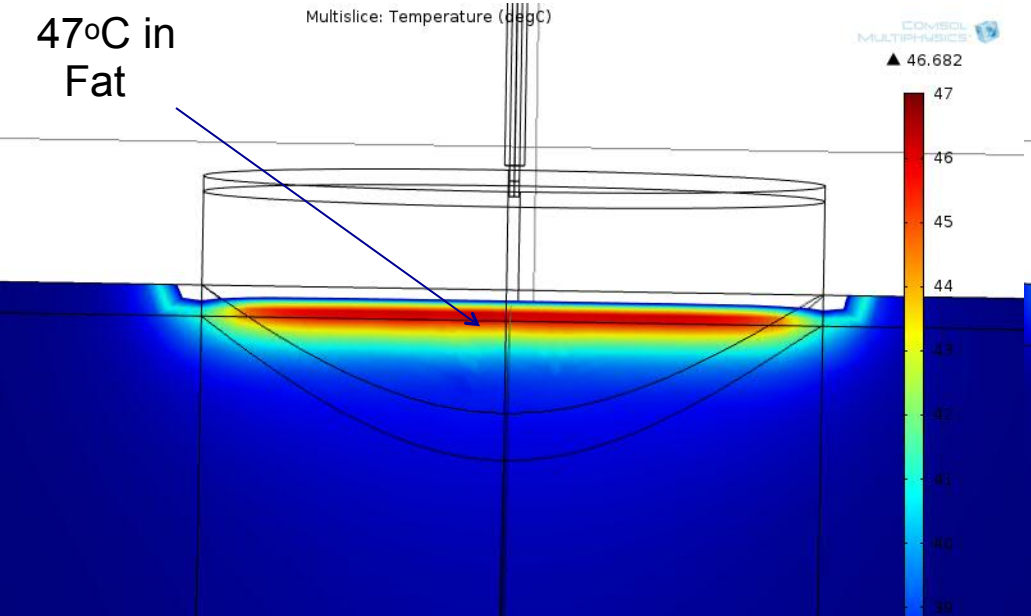


Capacitive System 13.65 MHz

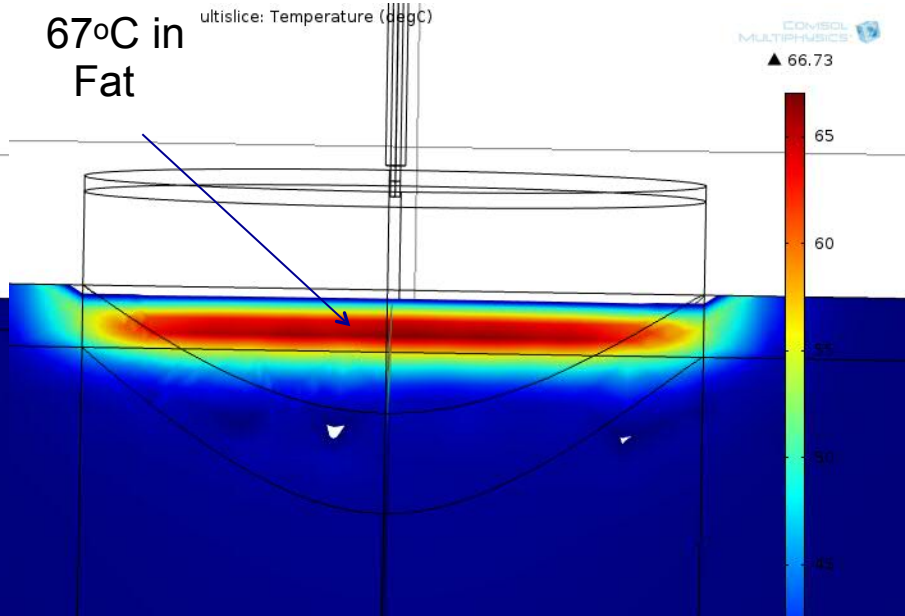
If patient has 1 cm of Fat Layer, 5 minutes of heating produces surface temp ~ 47˚C

If patient has 2 cm of Fat Layer, 5 minutes produces surface temp ~ 67˚C

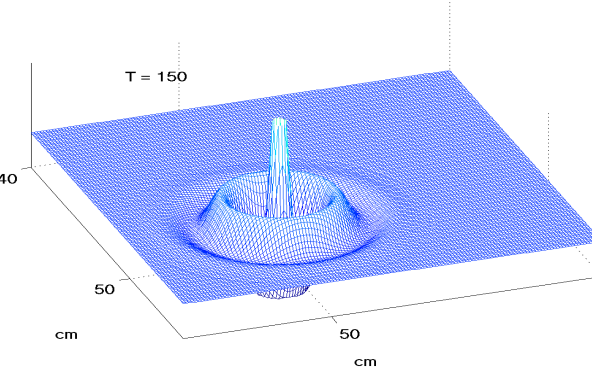
47°C in Fat

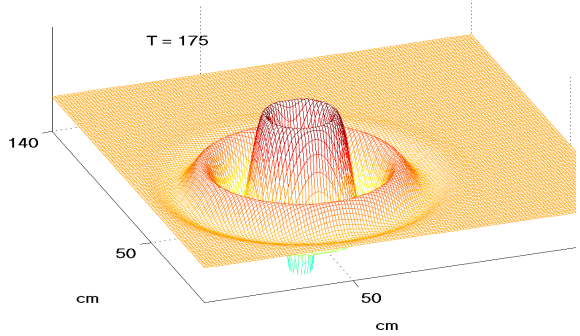


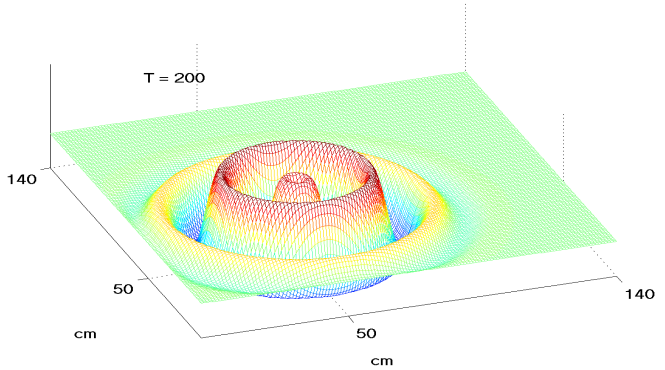
67°C in Fat

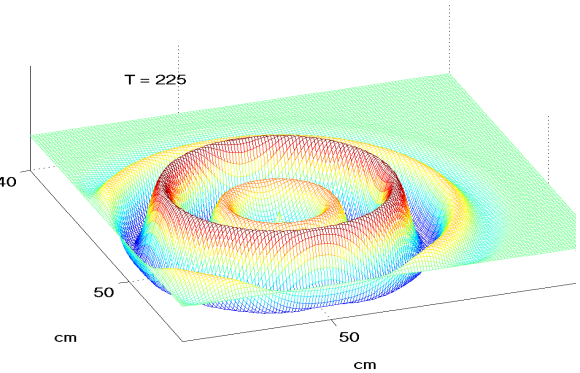


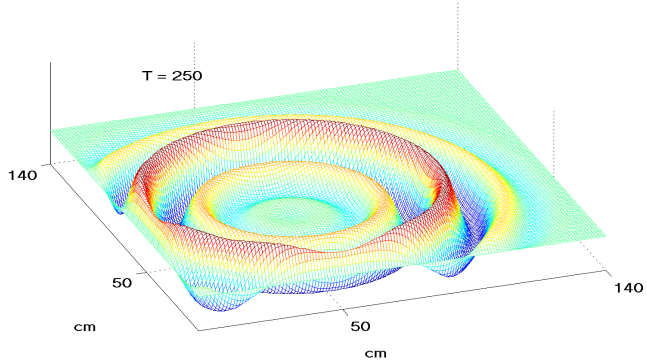
Dipole Radiated EM Wave Time Progression

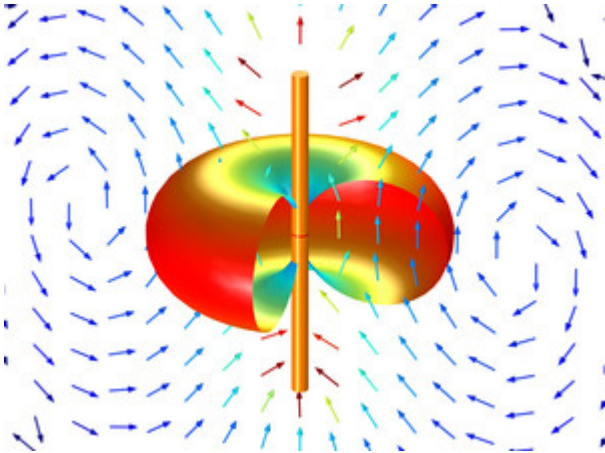












A Dipole Directive Design

- 1. Antenna short length radiation effect
- 2. Antenna water vs air intrinsic impedance loading effect

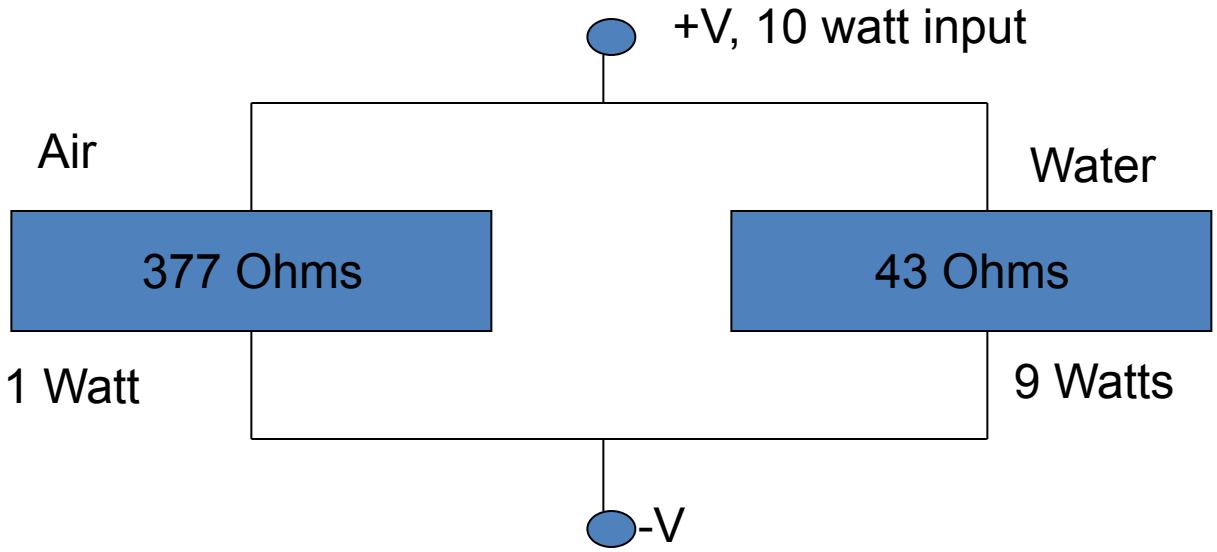
1. The BSD-2000 radiation field is selectively directed into the water bolus region and not into the outer air region because the dipole lengths are too short for efficient radiation into the low dielectric plastic and air.

Water has a dielectric of 78, thus at 100MHz the wavelength in water is (33cm) shortened by a factor of 9, compared to air (300cm). An efficient dipole radiator should be at least ½ of a wavelength of the media. The Sigma60 has 44cm dipoles, 45cm water bolus, and SigmaEye has 14cm dipoles and 45cm bolus.

2. The free space radiation impedance of air is 377 ohms/square and water is 43 ohms/square.

This means that the side of the dipoles with water represents a low impedance load that is like a parallel circuit. The loading of the high impedance air side and the dipoles are too short to be a good radiating antenna into the air.

A radiated electric field is created by the dipoles. One side is loaded by the plastic and air (both low dielectrics) and the other is loaded by the water (high dielectric). In this type of parallel circuit the impedance loading alone would direct about 9 times more power to the water side for low stray RF power.



Sigma30 (MAPA), SigmaEye, Sigma60

BSD-2000

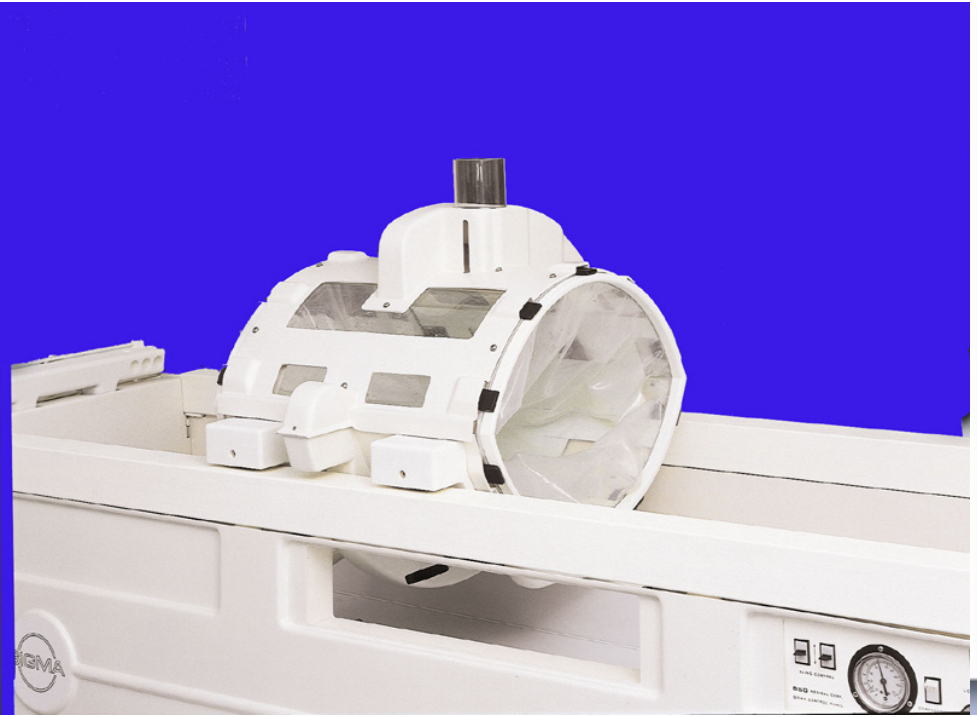
Basic BSD-2000 Modules
(each have been redesigned from the original 1988 design)

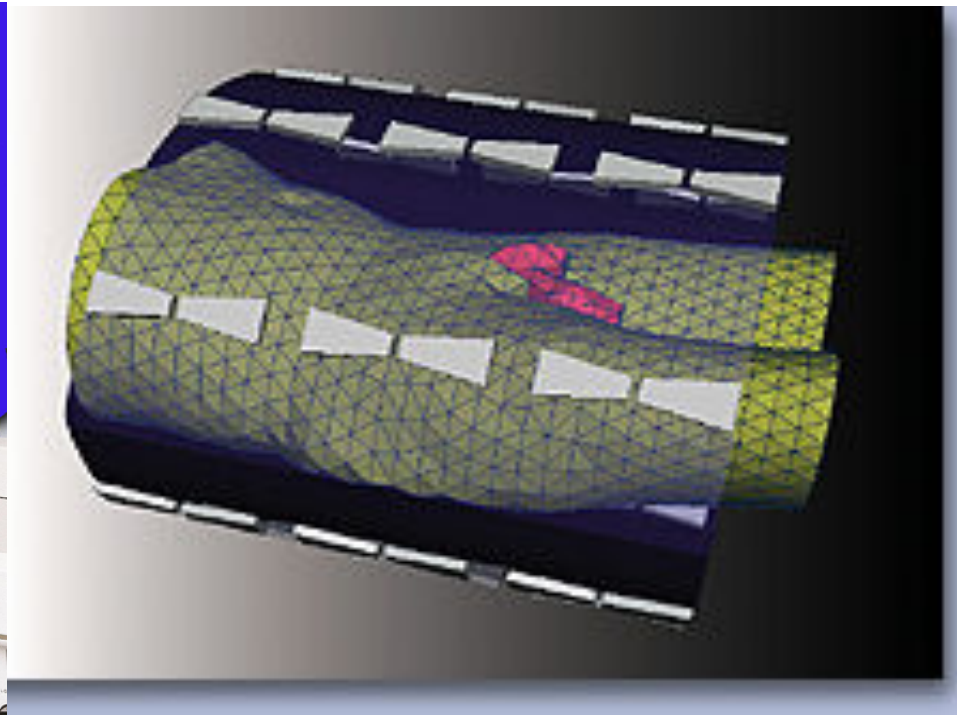
SigmaEllipse

Re-Design of the SIGMA 60 Applicator

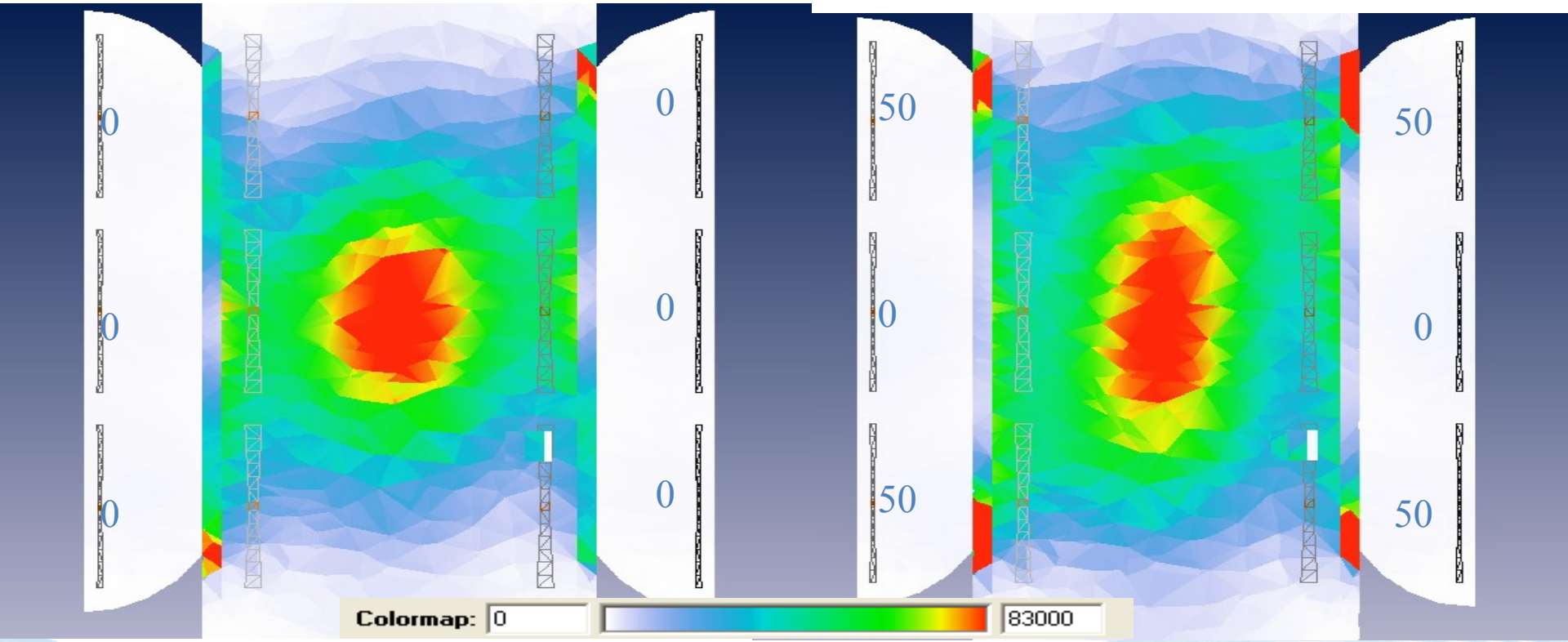
-Improved Handling
-Larger Bolus Membrane
-End-ring Bolus Seal
-Improved Servicing
-Larger Top Air Purge Zone
-Continue Rapid Water Drain

SigmaEye 24 dipoles in 3 annular rings
Electronic 3D Steering Along Body Axis





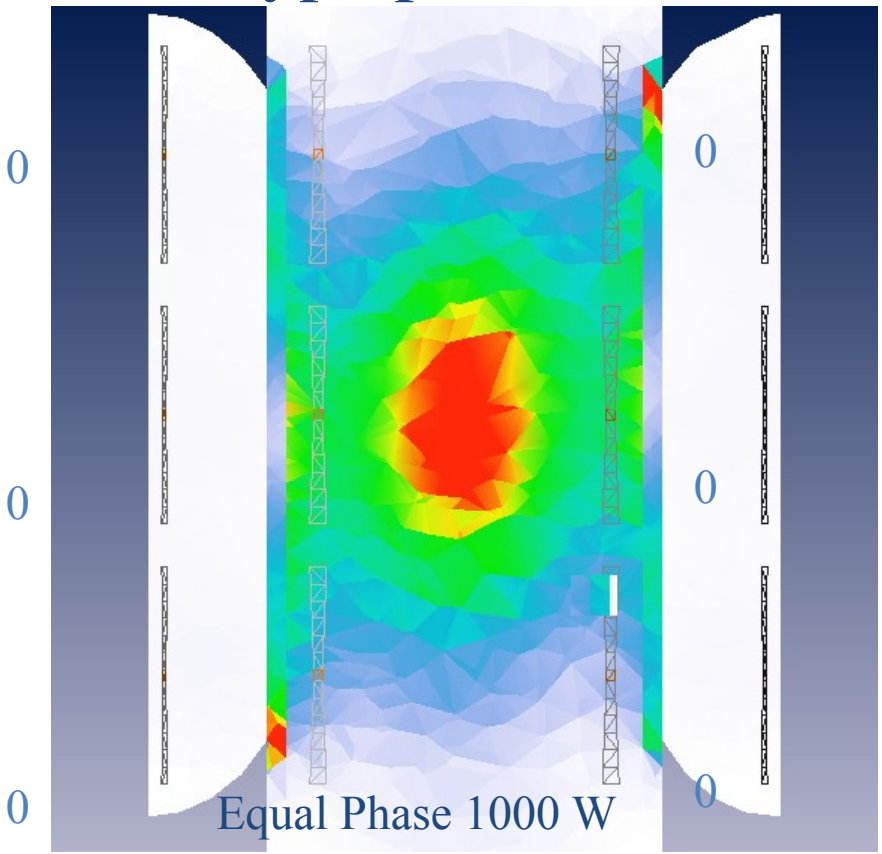
SigmaHyperplan Simulation of Heating Pattern Steering

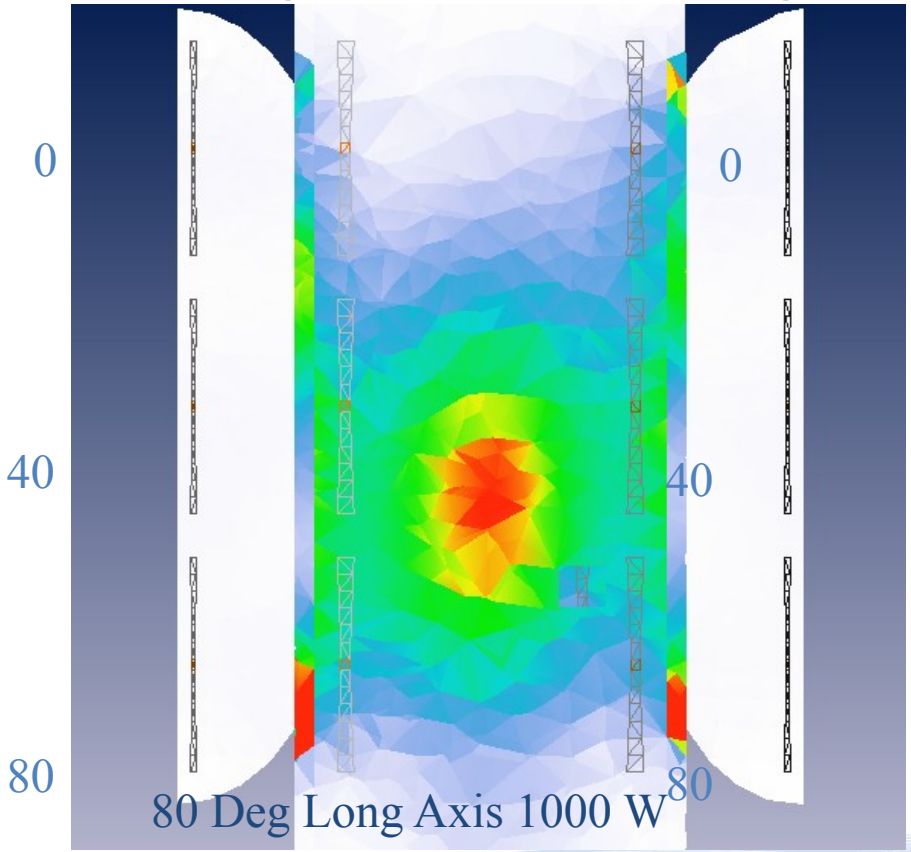


Equal Phase 1000 W

50 Deg Long Axis 1270 W

Hyperplan Simulation of Heating Pattern Steering





Pyrexar MEDICAL

BSD-2000 3D/MR System

1997 - Munich - Siemens 0.2T

2001 - Berlin - Siemens Symphony 1.5T

2007 - Erlangen - Siemens Symphony 1.5T

2008 - Dusseldorf - Siemens Symphony 1.5T

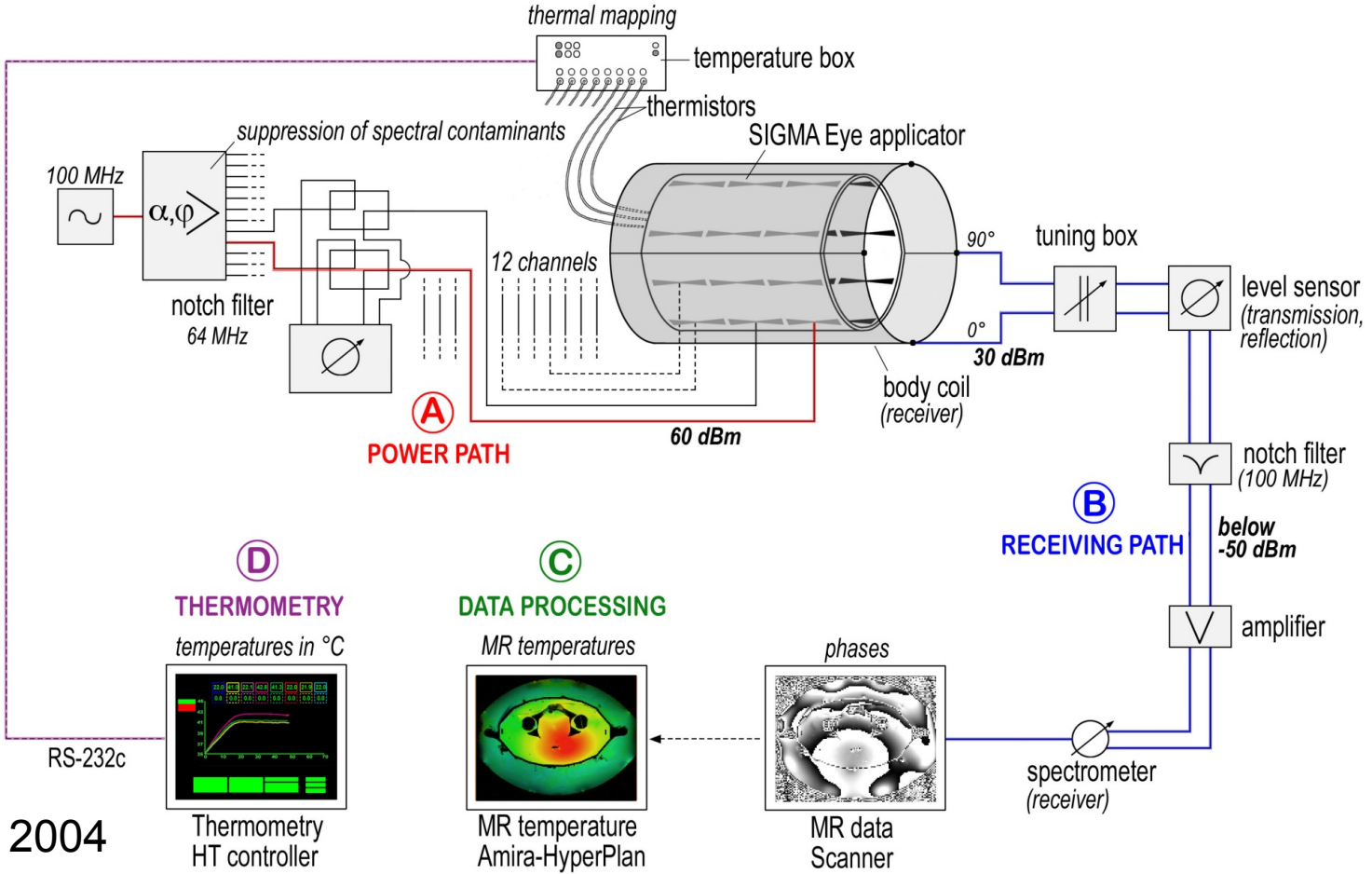
2009 – Duke University - GE Signa HDxt 1.5T

2011 - Tübingen - Siemens Symphony 1.5T

2014 - Rotterdam – GE 450W 1.5T

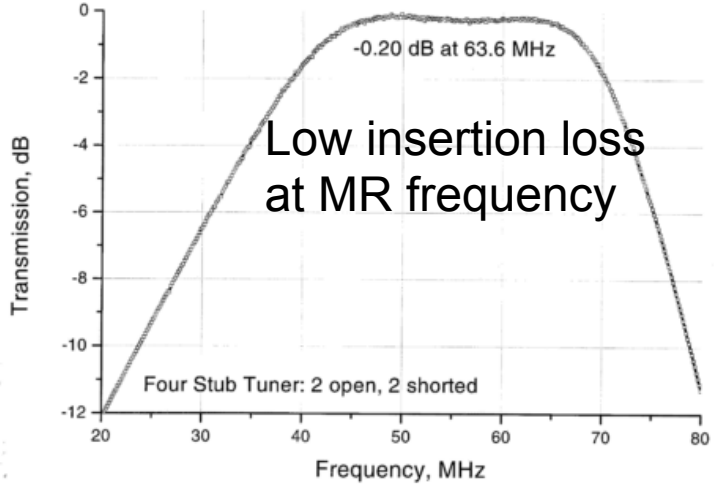
2017 – Munich – Philips Ingenia 1.5T

BSD-2000 MRI Integration

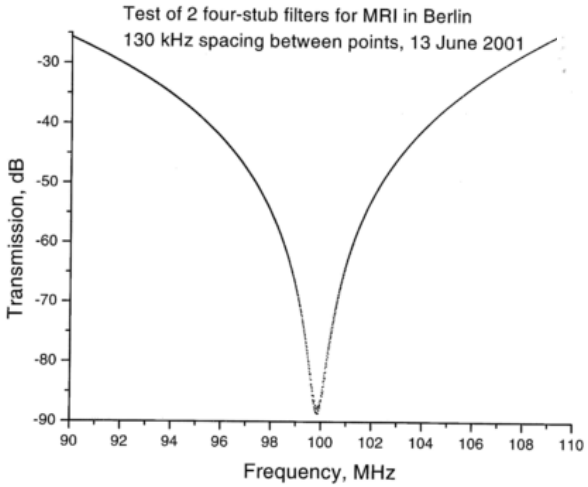


Gellermann et al 2004

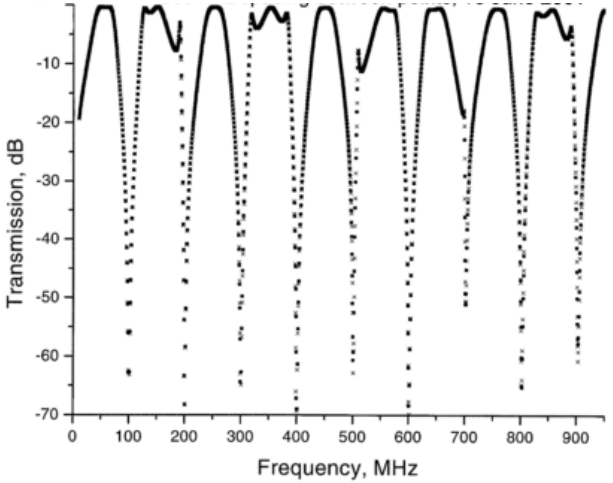
MR Receive Path Coaxial Stub Filter



Low insertion loss at MR frequency

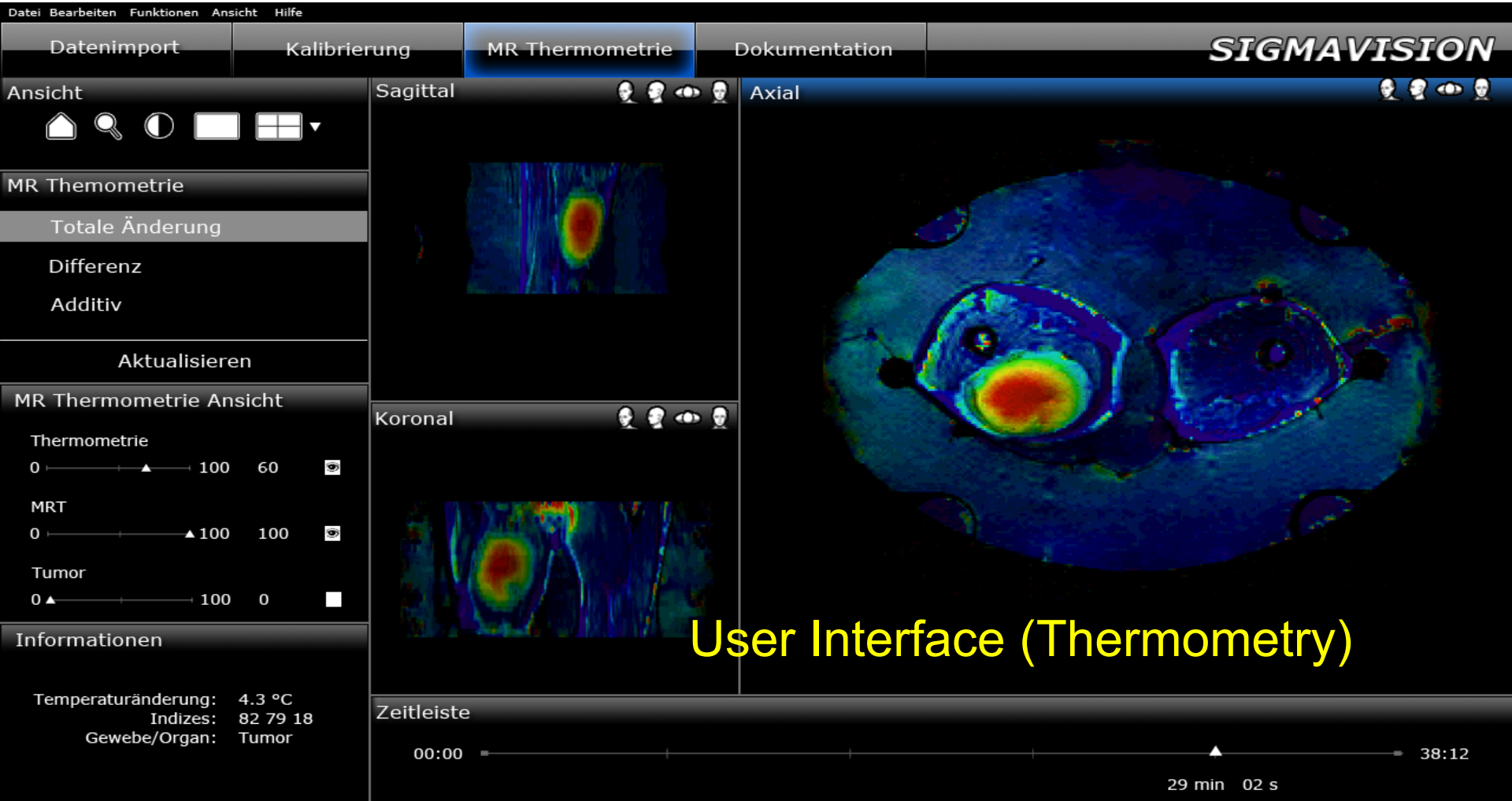


High insertion loss at HT frequency of 100MHz and harmonics

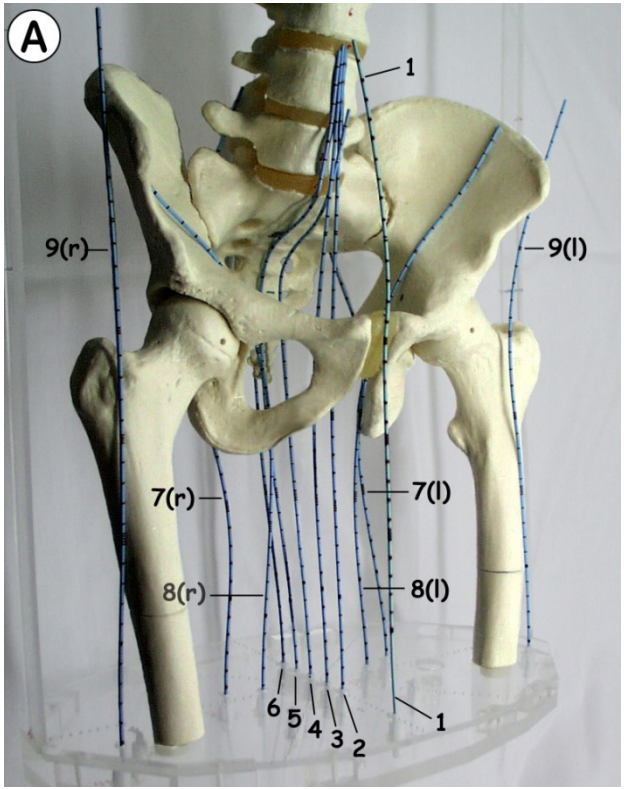


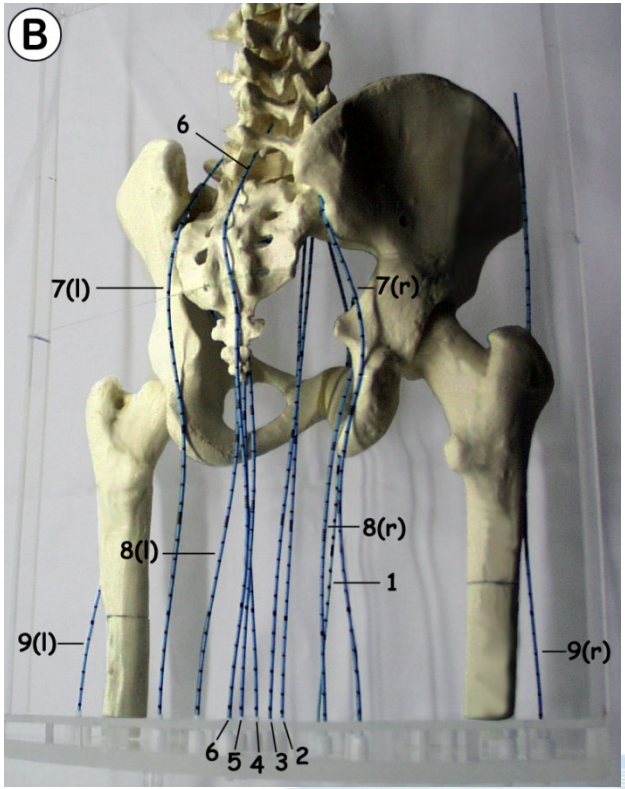
2017 Munich Installation

- Universal System approved for clinical use


Datei Bearbeiten Funktionen Ansicht Hilfe
Datenimport
Kalibrierung
MR Thermometrie
Dokumentation
SIGMAVISION
Ansicht
MR Themometrie
Totale Änderung
Differenz
Additiv
Aktualisieren
MR Thermometrie Ansicht
Thermometrie
0 100 60
MRT
0 100 100
Tumor
0 100 0
Informationen
Temperaturänderung: 4.3 °C
Indizes: 82 79 18
Gewebe/Organ: Tumor
Sagittal
Koronal
Axial
Zeitleiste
00:00
38:12
29 min 02 s
User Interface (Thermometry)

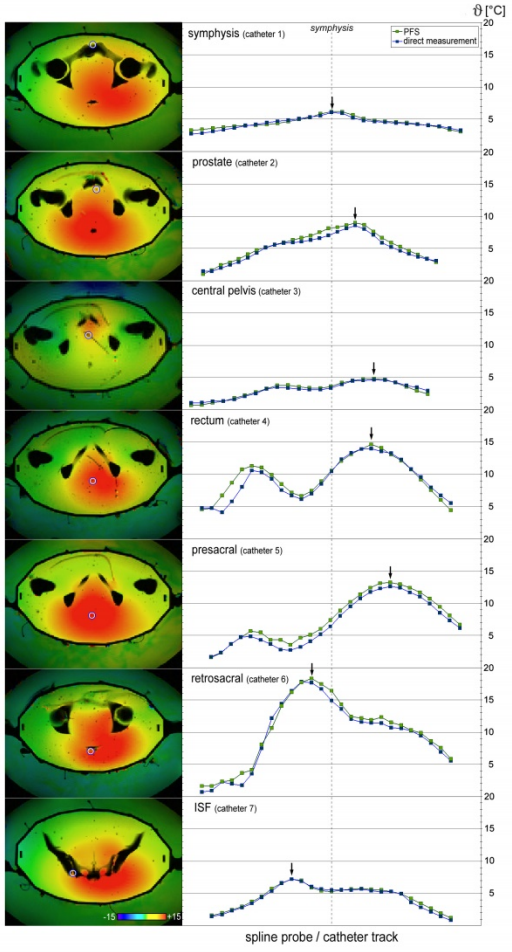
3D-Phantoms With Skeleton And Temperature Sensors





Gellermann et al 2004

Comparison of MR Proton Resonance Shift vs. Direct Temperature Measurement in Phantom

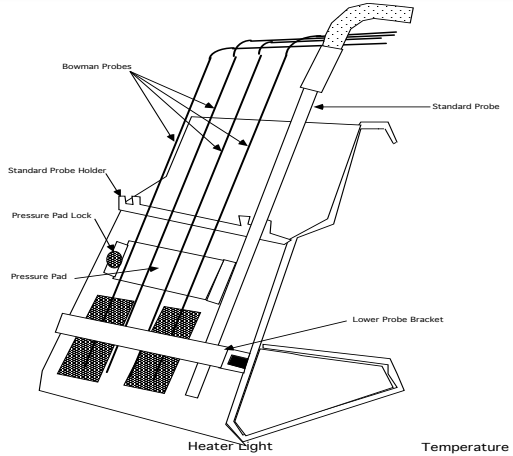


Gellermann et al 2004

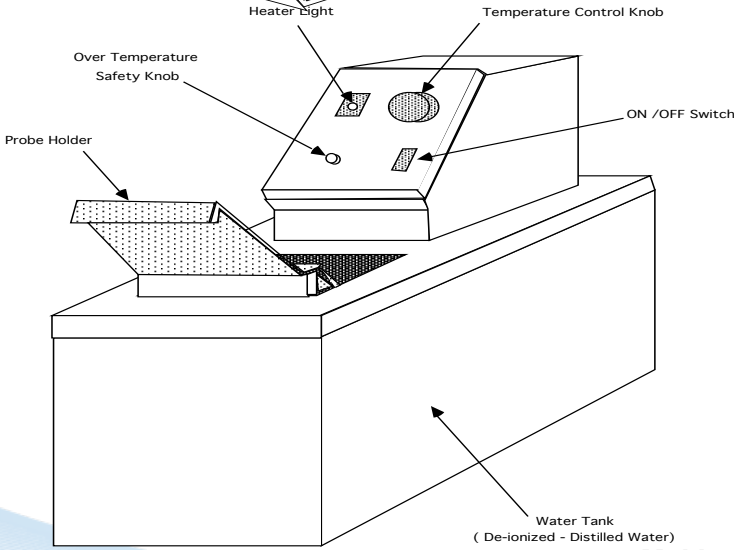
Pyrexar MEDICAL

Recent System Improvements

- MR thermal well vs temperature bath
- Semi-transparent shield treatment room
- Universal MR configuration
- Simplified user interface



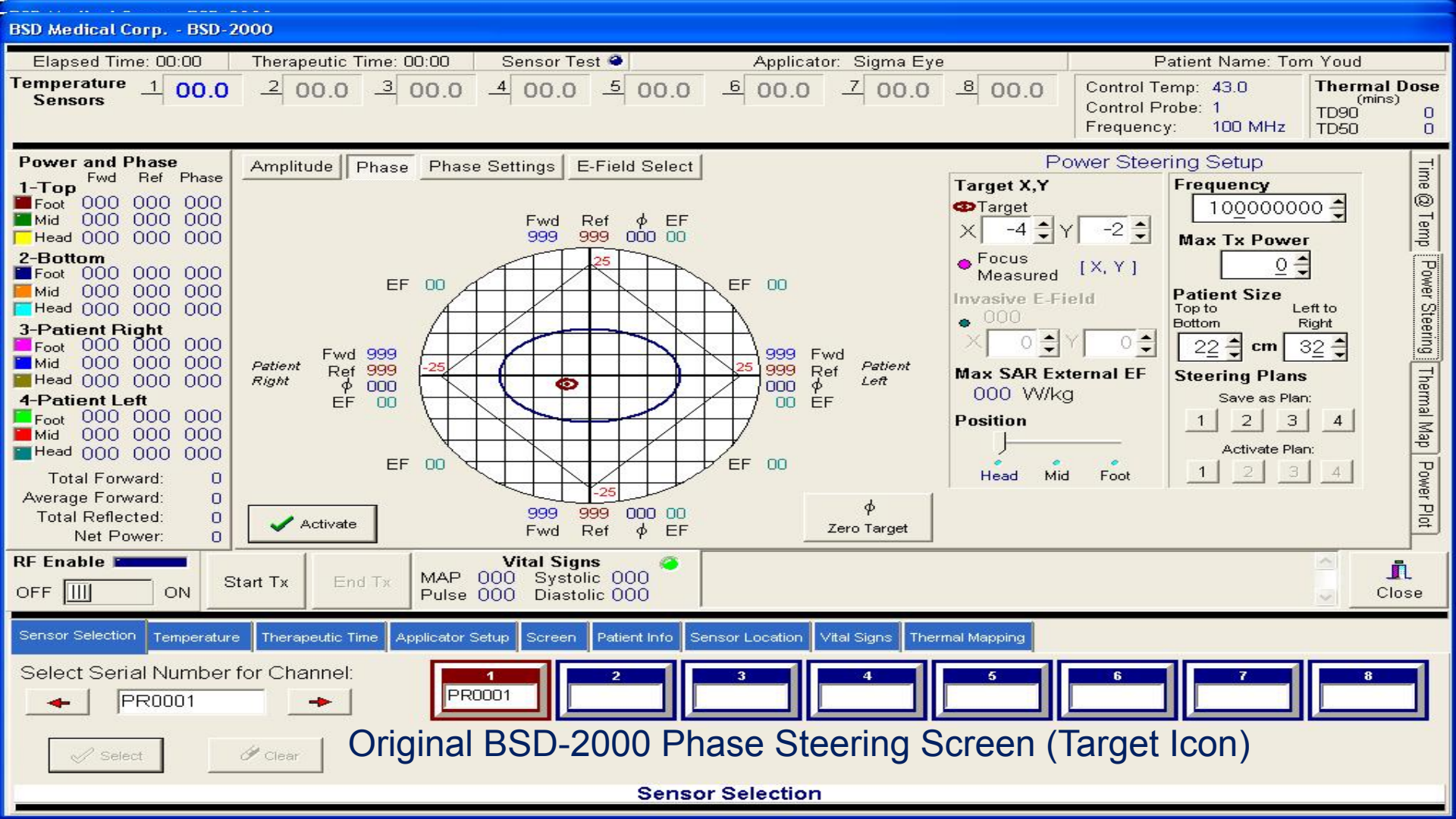
Old Temperature Calibration change from 3 temperature water bath to Thermal Well for MR systems

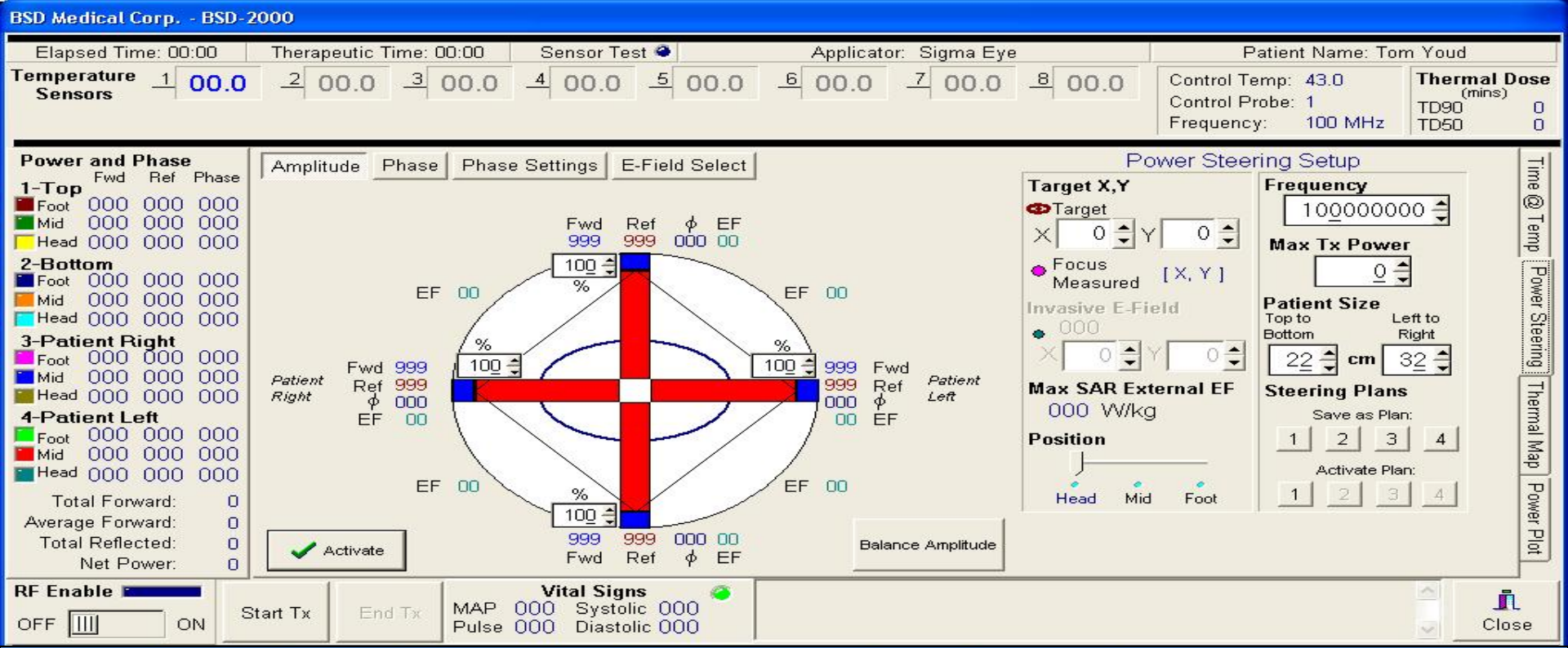


Features:
Temperature display 18 to 60°C
Control Range 29 to 60°C
42°C Thermal Well calibration

Non-MR systems use new semi-transparent perforated metal panels

- No construction required
- Lower Cost
- Validated 90 dB Attenuation
- Use existing HVAC/lighting, if desired
- 2 Days to assemble – 2 people

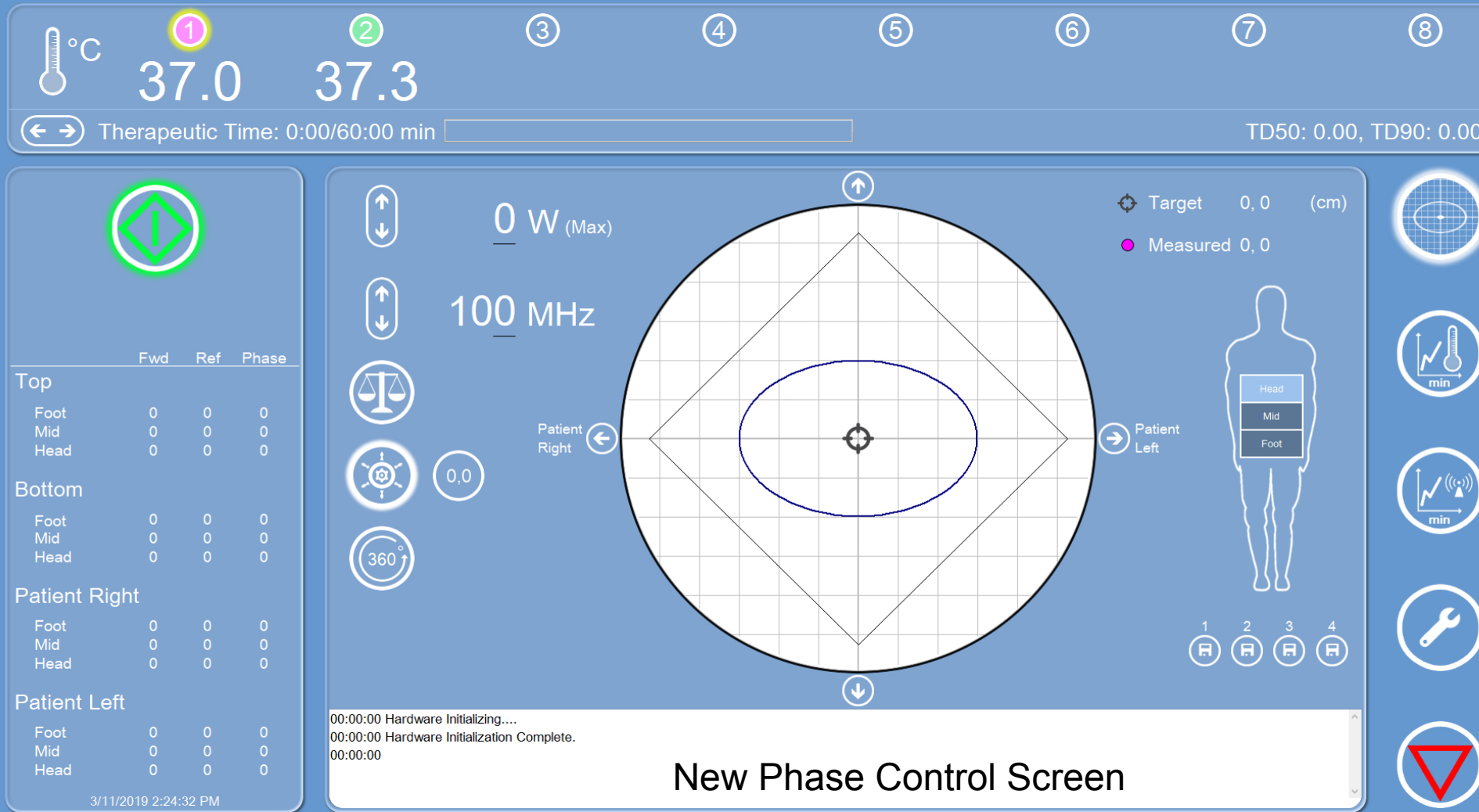

BSD Medical Corp. - BSD-2000
Elapsed Time: 00:00
Therapeutic Time: 00:00
Sensor Test
Applicator: Sigma Eye
Patient Name: Tom Youd
Temperature Sensors
1 00.0
2 00.0
3 00.0
4 00.0
5 00.0
6 00.0
7 00.0
8 00.0
Control Temp: 43.0
Control Probe: 1
Frequency: 100 MHz
Thermal Dose (mins)
TD90 0
TD50 0
Power and Phase
Fwd Ref Phase
1-Top
Foot 000 000 000
Mid 000 000 000
Head 000 000 000
2-Bottom
Foot 000 000 000
Mid 000 000 000
Head 000 000 000
3-Patient Right
Foot 000 000 000
Mid 000 000 000
Head 000 000 000
4-Patient Left
Foot 000 000 000
Mid 000 000 000
Head 000 000 000
Total Forward: 0
Average Forward: 0
Total Reflected: 0
Net Power: 0
Amplitude
Phase
Phase Settings
E-Field Select
Fwd Ref ϕ EF
999 999 000 00
EF 00
Patient Right
Patient Left
25
-25
Activate
ϕ
Zero Target
Power Steering Setup
Target X,Y
Target
X -4 Y -2
Focus
Measured [X, Y]
Invasive E-Field
000
X 0 Y 0
Max SAR External EF
000 W/kg
Position
Head Mid Foot
Frequency
100000000
Max Tx Power
0
Patient Size
Top to Bottom
Left to Right
22 cm 32
Steering Plans
Save as Plan:
1 2 3 4
Activate Plan:
1 2 3 4
Time @ Temp
Power Steering
Thermal Map
Power Plot
RF Enable
OFF ON
Start Tx
End Tx
Vital Signs
MAP 000 Systolic 000
Pulse 000 Diastolic 000
Close
Sensor Selection
Temperature
Therapeutic Time
Applicator Setup
Screen
Patient Info
Sensor Location
Vital Signs
Thermal Mapping
Select Serial Number for Channel:
PR0001
1 PR0001
2
3
4
5
6
7
8
Select
Clear
Original BSD-2000 Phase Steering Screen (Target Icon)
Sensor Selection

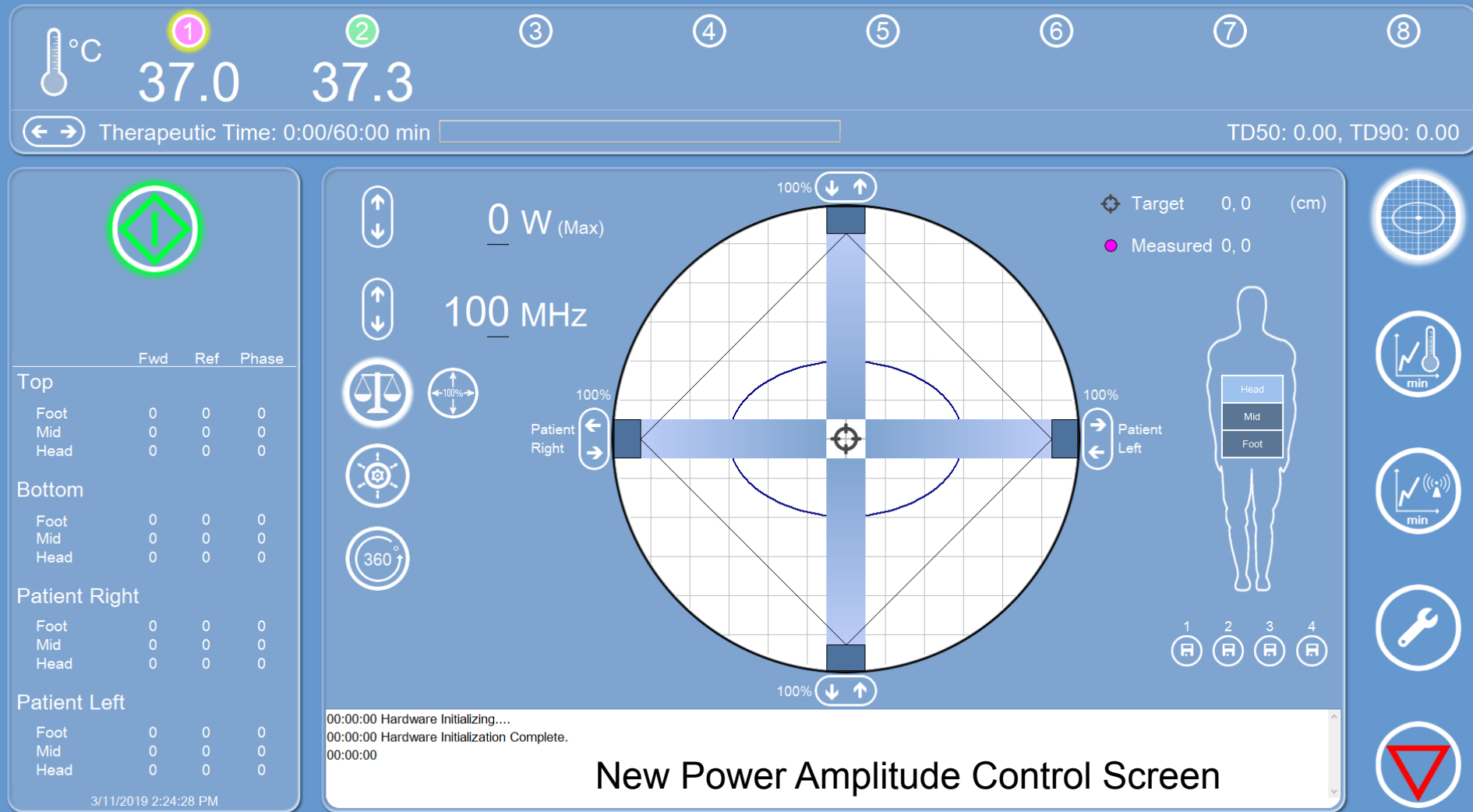


Original RF Power Amplitude Control Screen

New Computer Interface

- Large touch screen monitor
- Modernized user interface
- Simplified & graphical control icons


°C
1
2
3
4
5
6
7
8
37.0
37.3
Therapeutic Time: 0:00/60:00 min
TD50: 0.00, TD90: 0.00
Fwd
Ref
Phase
Top
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
Bottom
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
Patient Right
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
Patient Left
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
3/11/2019 2:24:32 PM
0 W (Max)
100 MHz
0,0
360
Patient Right
Patient Left
Target 0, 0 (cm)
Measured 0, 0
Head
Mid
Foot
1
2
3
4
00:00:00 Hardware Initializing....
00:00:00 Hardware Initialization Complete.
00:00:00
New Phase Control Screen
min
min


°C
1
2
3
4
5
6
7
8
37.0
37.3
Therapeutic Time: 0:00/60:00 min
TD50: 0.00, TD90: 0.00
0 W (Max)
100 MHz
100%
Patient Right
Patient Left
Target 0, 0 (cm)
Measured 0, 0
Head
Mid
Foot
1
2
3
4
360°
min
min
Fwd Ref Phase
Top
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
Bottom
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
Patient Right
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
Patient Left
Foot 0 0 0
Mid 0 0 0
Head 0 0 0
3/11/2019 2:24:28 PM
00:00:00 Hardware Initializing....
00:00:00 Hardware Initialization Complete.
00:00:00
New Power Amplitude Control Screen

RF vs HIFU Phased Array For Hyperthermia

	RF Phased Array	HIFU Phased Array
Focus	Large	Small
Focal Steering	Simple	Complex
Air & Bone	Tolerant	Blockage
Large Tumors	Suitable	Limited
Dose Monitoring	Easy	Difficult
SAR Pattern	Uniform	Non-Uniform

Hal.o Prototype

Patent pending

Conclusion

- 40 years of development has come far
- Current progress have evolved to non-invasive thermometry and pretreatment planning.
- The maturity of current systems has resulted in reliability, durability, uniformity, and clinical utility.