BIOEM 2016
5-10 June, Het Pand, Ghent, Belgium

Rational and Summary of Exposure and Dosimetry

Myles Capstick[1] and Niels Kuster[1,2]

[1] IT'IS Foundation, ETH Zurich, Switzerland
[2] D-ITET, ETH Zurich, Switzerland

IT'IS FOUNDATION

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Outline

- NTP Protocol
- Exposure levels
- Communication standards
- Exposure environment
- Chamber characterisation
- Temporal field strength variation
- Numerical and experimental dosimetry
- Posture analysis
- Overall SAR uncertainty

Introduction

- General Project Objectives
  - These studies are designed to characterize the potential toxicity and carcinogenicity of cell phone radio frequency radiation (RFR) in Sprague-Dawley rats and B6C3F1 mice exposed unconstrained in reverberation chambers

- Rationale
  - More than 100 million communication devices in the US yet guidelines for cell phone RFR are based largely on protection from acute injury from thermal effects. Little is known about possible health effects of long-term exposure to minimally thermal levels of cell phone RFR

Exposure Groups

- NTP Requirements for this study
  - Three exposure groups plus sham
  - 100 animals per group
- Up to 24 hours exposure per day
  - Perform A determined that 2 hours was not enough
- Animals need to be unconstrained
- NIST proposed reverberation chambers and made the first feasibility studies

NTP Protocol

- Dose selection
  - The selection of the high dose – either the maximum deliverable dose or the maximum tolerable dose where there is no mortality and < 10% weight loss
  - Typically in a 2 year study they would wish to see some evidence of toxicity – close to maximum dose (could be ~5% reduction in weight)
  - To maximise the possibility of seeing toxic or carcinogenetic effects
  - -Whole body exposure to evaluate all tissues

- To determine the doses a thermal pilot study followed by a prechronic study were performed, therefore, the system needed to be able to achieve up to 20 W/kg during these phases

Exposure levels

Rat dose groups

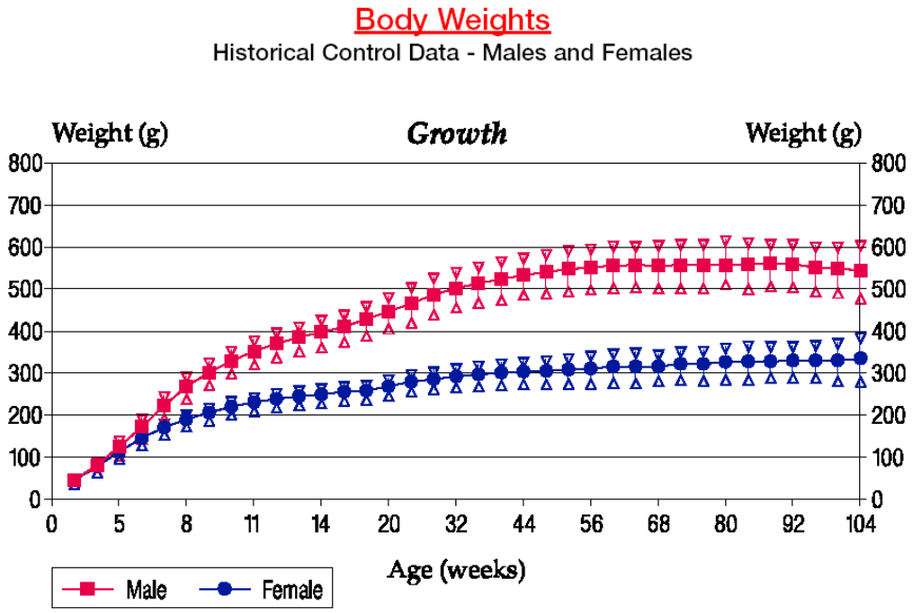
- 6.0 W/kg
- 3.0 W/kg
- 1.5 W/kg
- 0 W/kg

7 chambers for male rats with up to 112 animals

Mouse dose groups:

- 10 W/kg
- 5.0 W/kg
- 2.5 W/kg
- 0 W/kg

7 chambers with 216 mice half male half female



Signal types

- There was the hypothesis that the modulation envelope could be of importance in interaction mechanisms
- Analogue phones were essentially obsolete and 2nd generation phones were prevalent.
- GSM/PCS - chosen due to its wide spread use
- CDMA, namely IS95 - chosen as it was an up and coming access technology in the USA
- ON-OFF cycles were chosen based on the effects that were observed in previous studies (such as the Ross Adey studies)
  - Also allowed the number of amplifiers to be reduced by factor two
  - Interleaved GSM and IS95 in alternate 10 min slots

Communications standards and signals

- 2nd Generation mobile phone signals
- GSM uplink
- CDMA – IS95 uplink

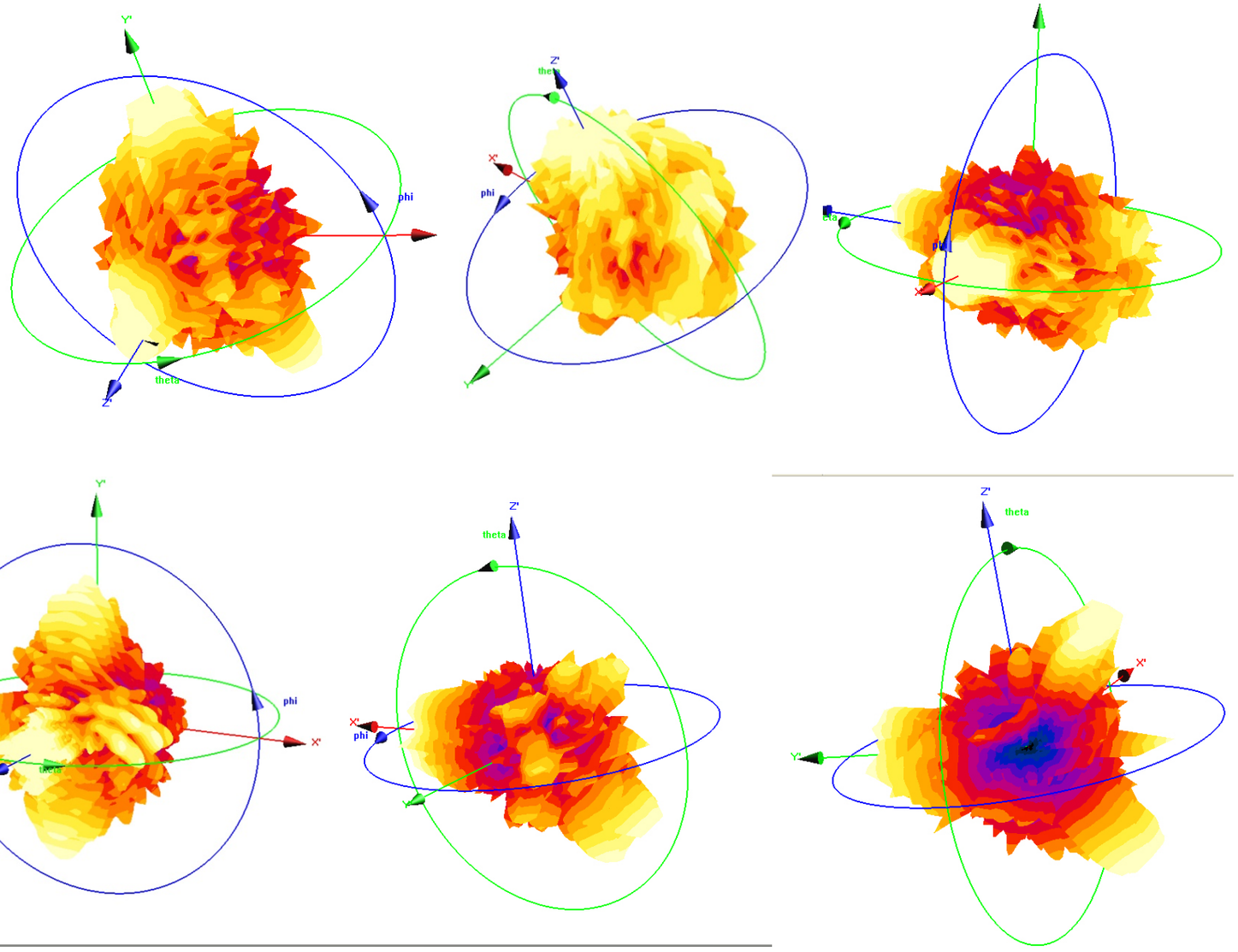
Quantity	IS95	GSM
Modulation:	QPSK	GMSK
Chip rate:	1.22880 Mcps	n/a
Rev link filter	IS95	Gaussian
Roll-off factor	0.2	0.5
Uplink channel type	traffic	traffic
Channel rate	9600 bps	270,833 symbols/s
Frame quality indicator	on	n/a
Convolutional encoder	on	n/a
Block interleaver	on	n/a
Peak-to-average ratio	5.39 dB	9.1 dB

Other requirements

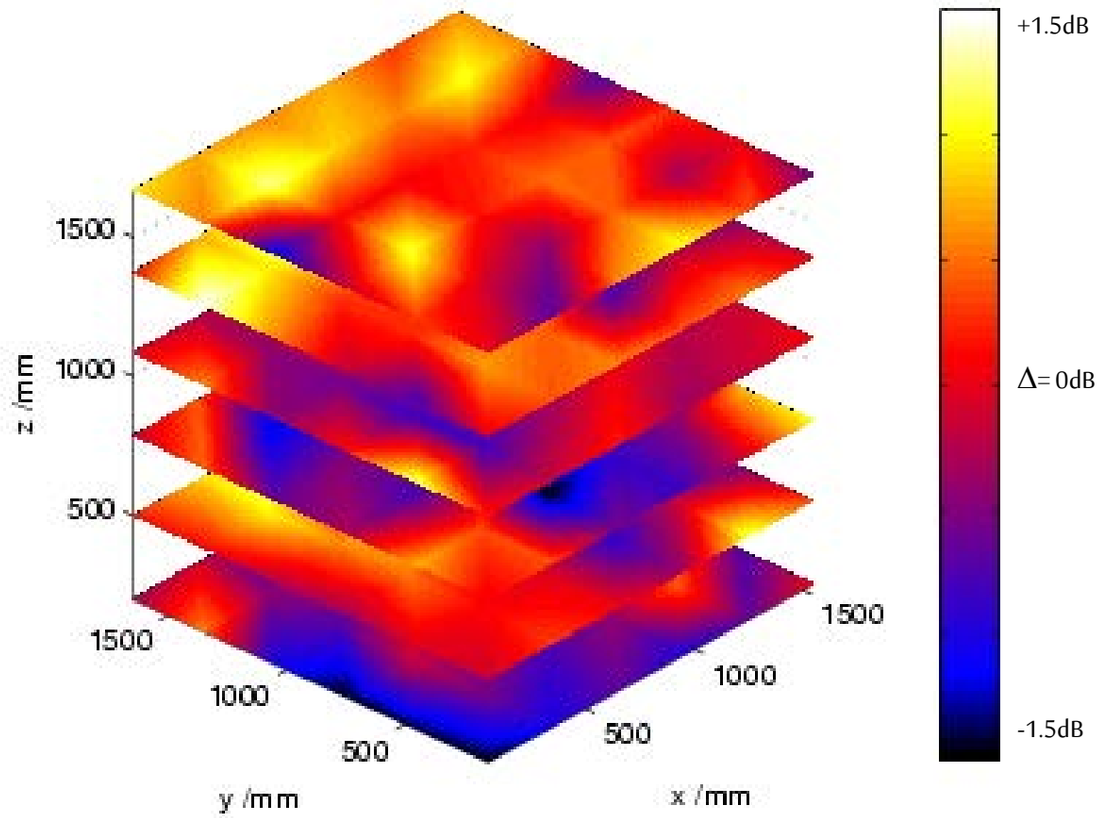
- Tight exposure control
- Inert materials compatible with animal husbandry
  - Stainless steel
  - Polycarbonate, fibreglass.
  - Gold
- 12 air exchanges per hour
- Light levels as per standard laboratories
- Excellent field and SAR homogeneity
- Detailed dosimetry (numerical and experimental)
- Equal noise level in all chambers
- All environmental and exposure parameters to be recorded

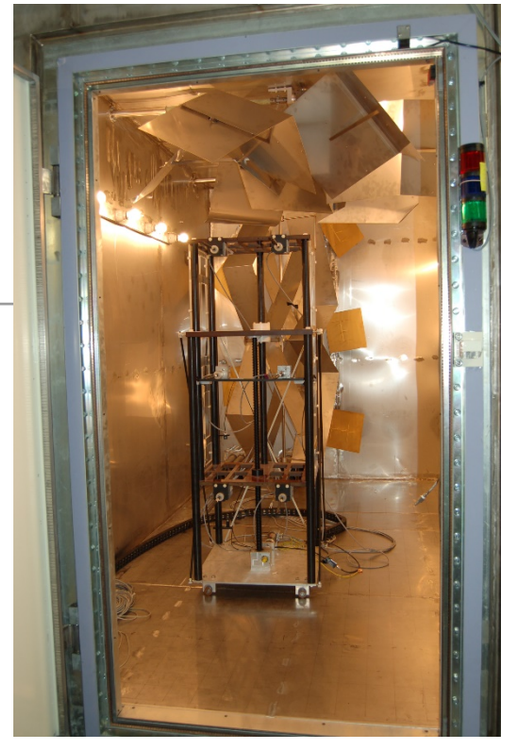
Reverberation Chamber : Two stirrers

Two mode stirrers to achieve high field homogeneity and isotropy



900MHz uniformity – empty chamber

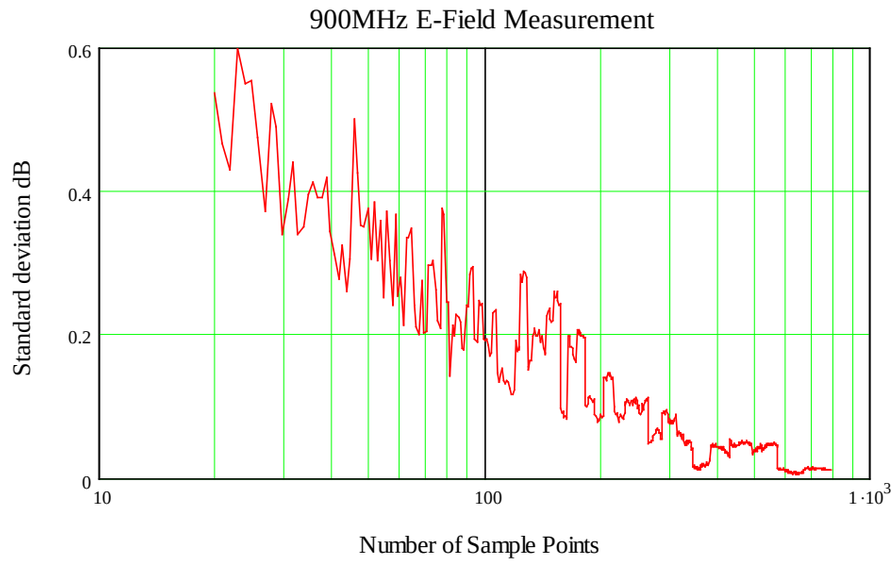




- Field Uniformity
- **900MHz Empty Chamber**
- Total field standard deviation
  0.6dB
- Component Fields SD (Isotropy)
  0.9dB
- Total population range (components)
  ±2.4dB
- Probe effective volume 5 x 5 x 5 mm
- Measured by step and measure method

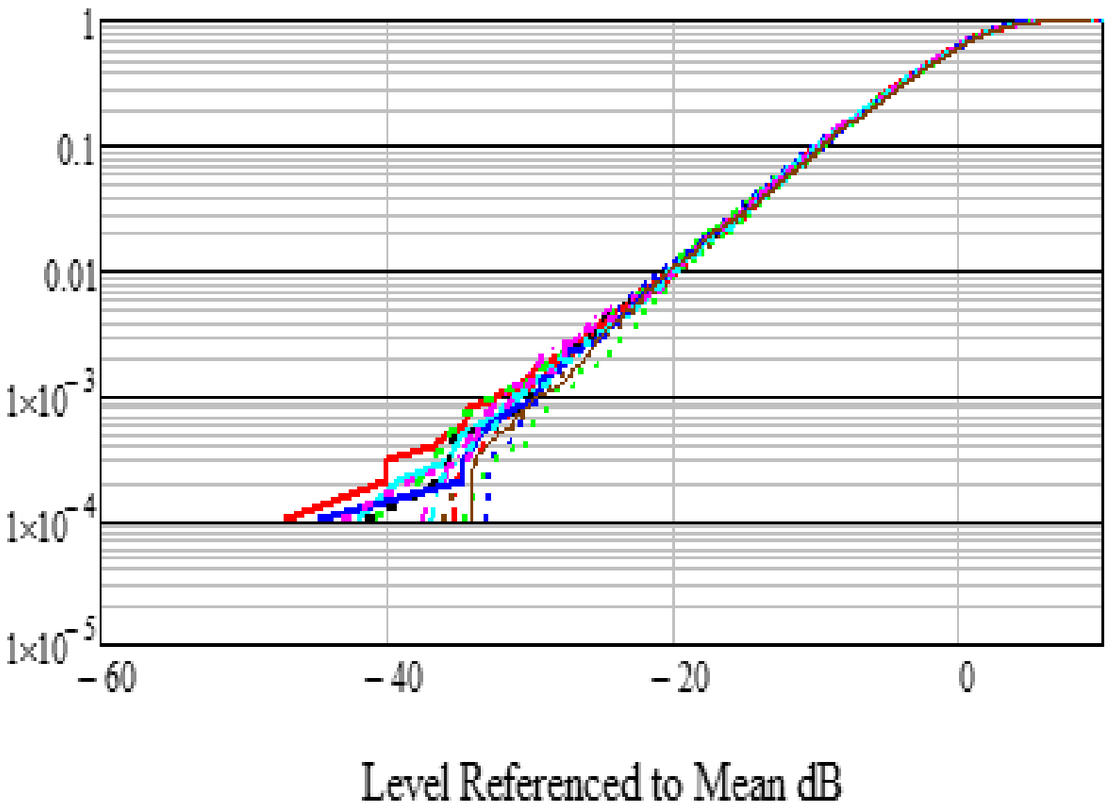
Uncertainty for field homogeneity measurements

Equipment	Uncertainty	Distribution	Divisor x coverage	Standard Uncertainty ±dB
E & H – field probe absolute accuracy	±0.26dB	Normal	1	0.26
Frequency linearity	±0.2dB	rectangular	Ö3	0.12
Dynamic range linearity	±0.2dB	rectangular	Ö3	0.12
Isotropy	±0.4dB	rectangular	Ö3	0.12
Stirrer modulation	±0.6dB	normal	1	0.6
Combined Standard Uncertainty				0.67



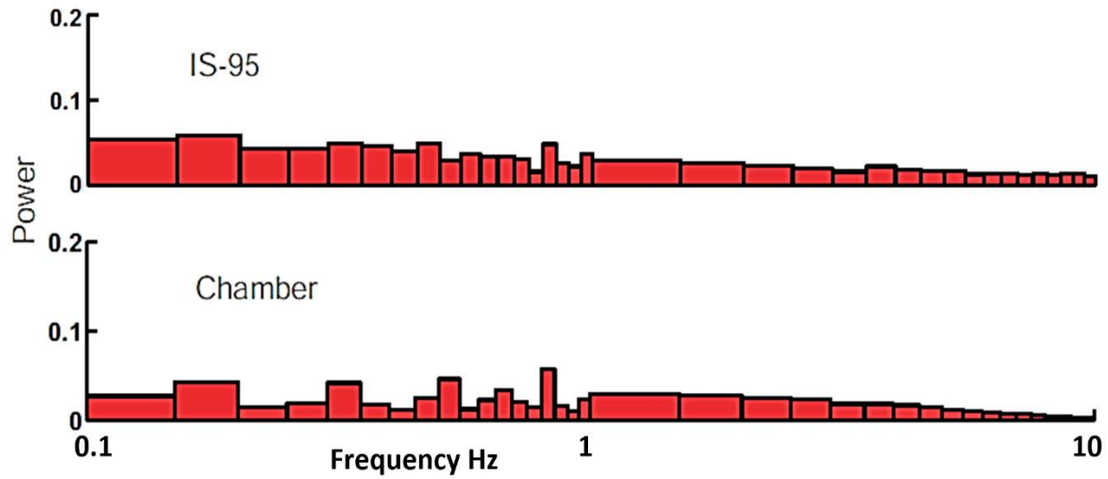
Field variation statistics

- CDF for Qs from 257 to 3071 at 900MHz

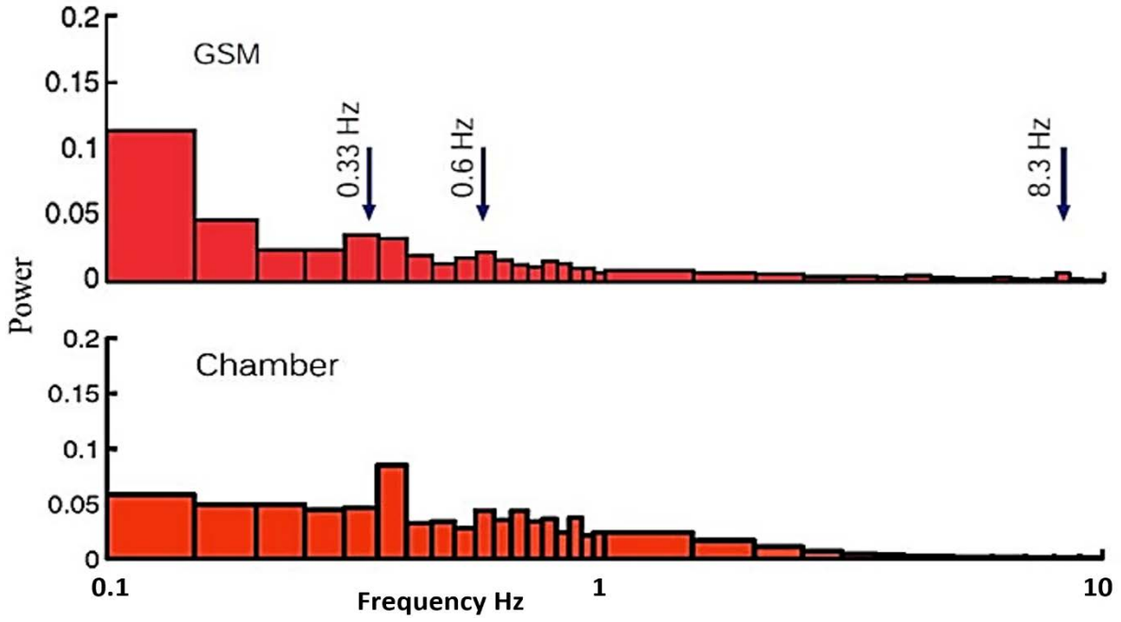


Stirrer speeds and modulation characteristics

- The relative stirrer speeds were for:
  - IS95, 4 : 5
  - GSM, 1 : 2
- the absolute speed depended on the mode density



In IS-95 power control feedback is provided **~800 times/second**, but only alters the power by ±1dB each time
In GSM the power control is handles by the Slow Associated Control Channel SACCH at a rate of **2.08 times/sec**, or Fast Associated Control Channel FACCH at **50 times/sec** the power is stepped in 2dB increments.



Exposure field uncertainty

Equipment	Uncertainty	Distribution	Divisor x coverage	Standard Uncertainty
E & H – field probe absolute accuracy	±0.26dB	Normal	1	±0.26dB
Frequency linearity	±0.2dB	Rectangular	√3	±0.12dB
Dynamic range linearity	±0.2dB	Rectangular	√3	±0.12dB
Isotropy	±0.4dB	Rectangular	√3	±0.12dB
Homogeneity / 2 probes	±0.43dB	Normal	1	±0.43dB
Field control	±0.2dB	Normal	1	±0.2dB
Combined Standard Uncertainty				±0.59dB

Numerical dosimetry

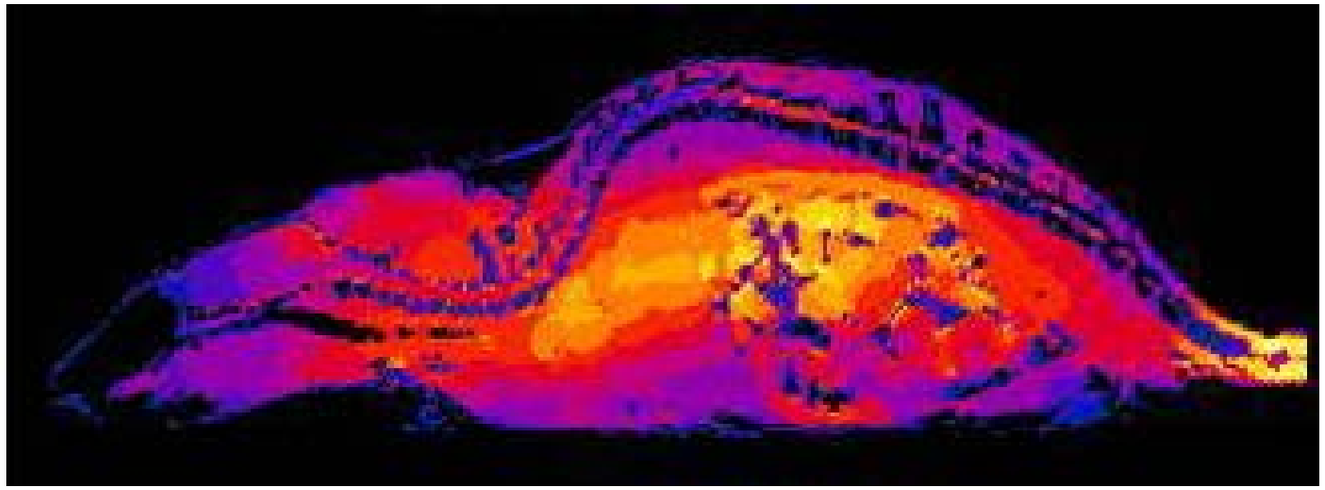
- High resolution anatomical models with more than 100 body parts discriminated.

Sprague-Dawley female pregnant rat model
- weight: 253 g
- lenght: 327 mm
- slice distance: 0.595 mm

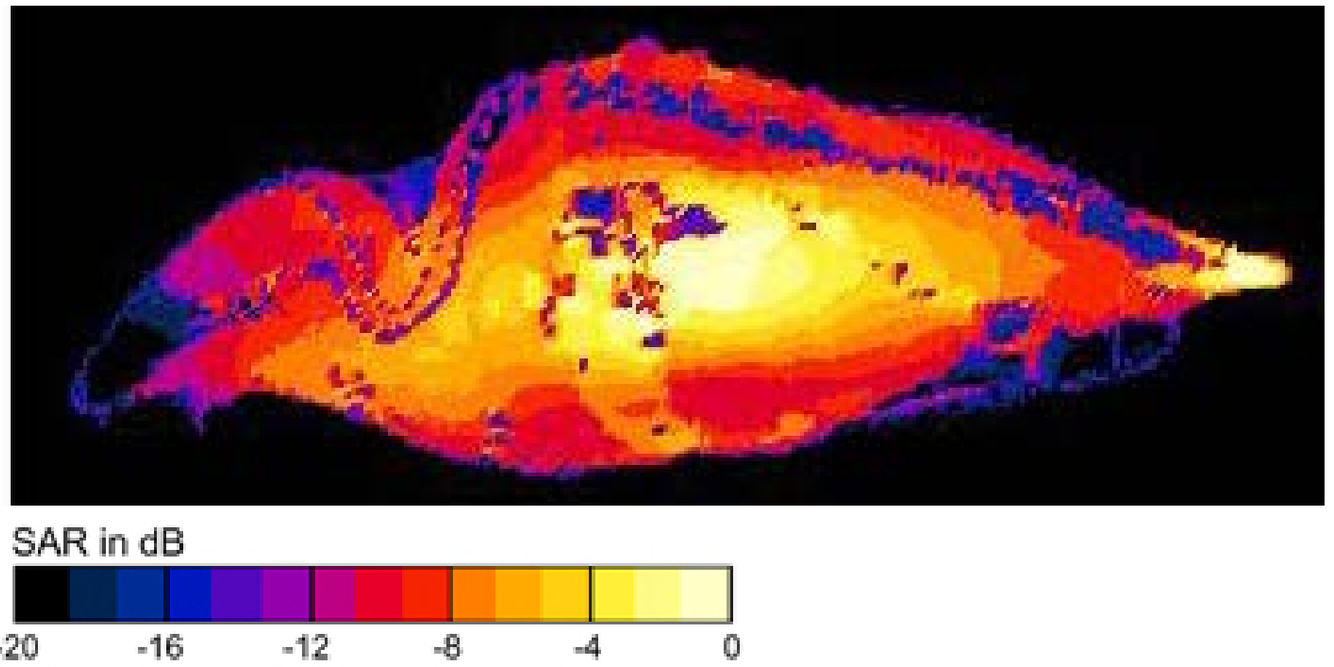
B6C3F1 female pregnant mouse model
- weight: 30 g
- lenght: 147 mm
- slice distance: 0.36 mm

Rat dosimetry

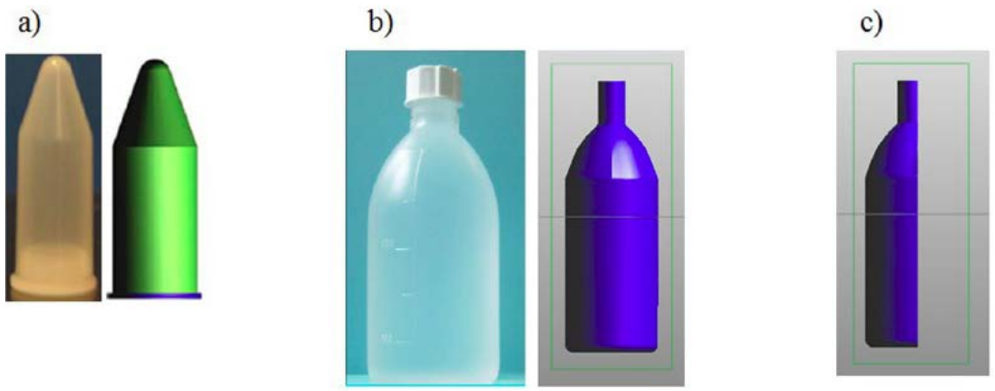
- Rat exposed at 900 MHz



- Mouse exposed at 1900 MHz



Experimental dosimetry

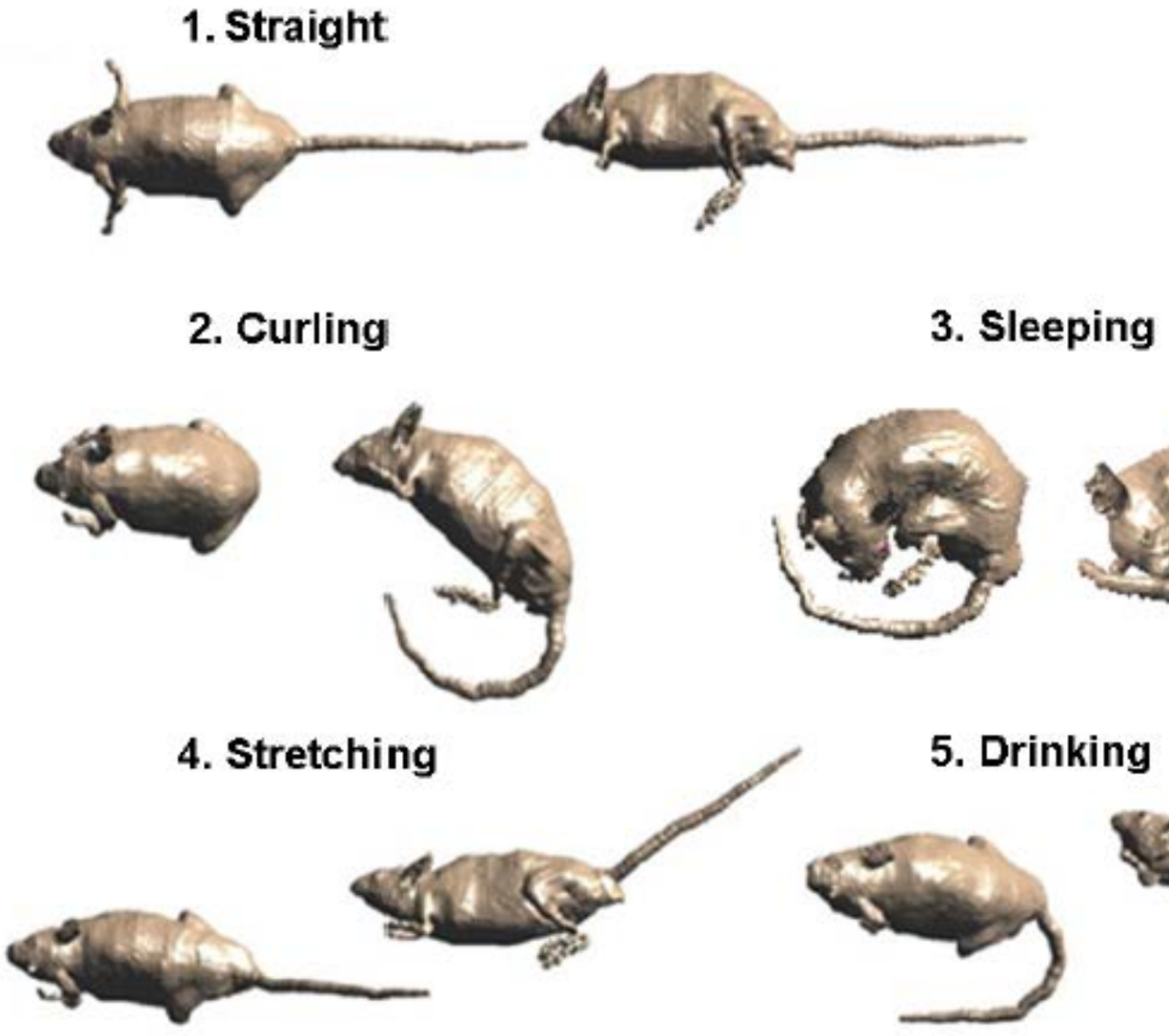


Phantoms tailored to have the same whole body SAR as a rat or mouse of the same weight

	Male Rat	Female Rat	Mice	Unit
Number	132	192	77	
SAR sensitivity				
Experimental	5.49E-05	6.79E-05	1.41E-04	W/kg/(V/m)^2
Numerical	5.59E-05	7.57E-05	1.64E-04	W/kg/(V/m)^2
Difference	-1.79%	-10.29%	-14.26%	
	-0.08	-0.47	-0.67	dB

Contributions	Distr.	Std. Unc. Rat	Mouse
E/H field measurement	N	12.8%	11.3%
Field control	N	4.7%	4.7%
Chamber temperature fluctuations	N	9.6%	9.6%
Temperature probe accuracy	N	1.2%	1.2%
Combined standard uncertainty k=1		16.7%	15.6%
Expanded uncertainty k=2		33.5%	31.2%

Postures



Little variation in whole body SAR ~ 5%

Larger variations in individual organ SAR

Overall Variability and Uncertainty

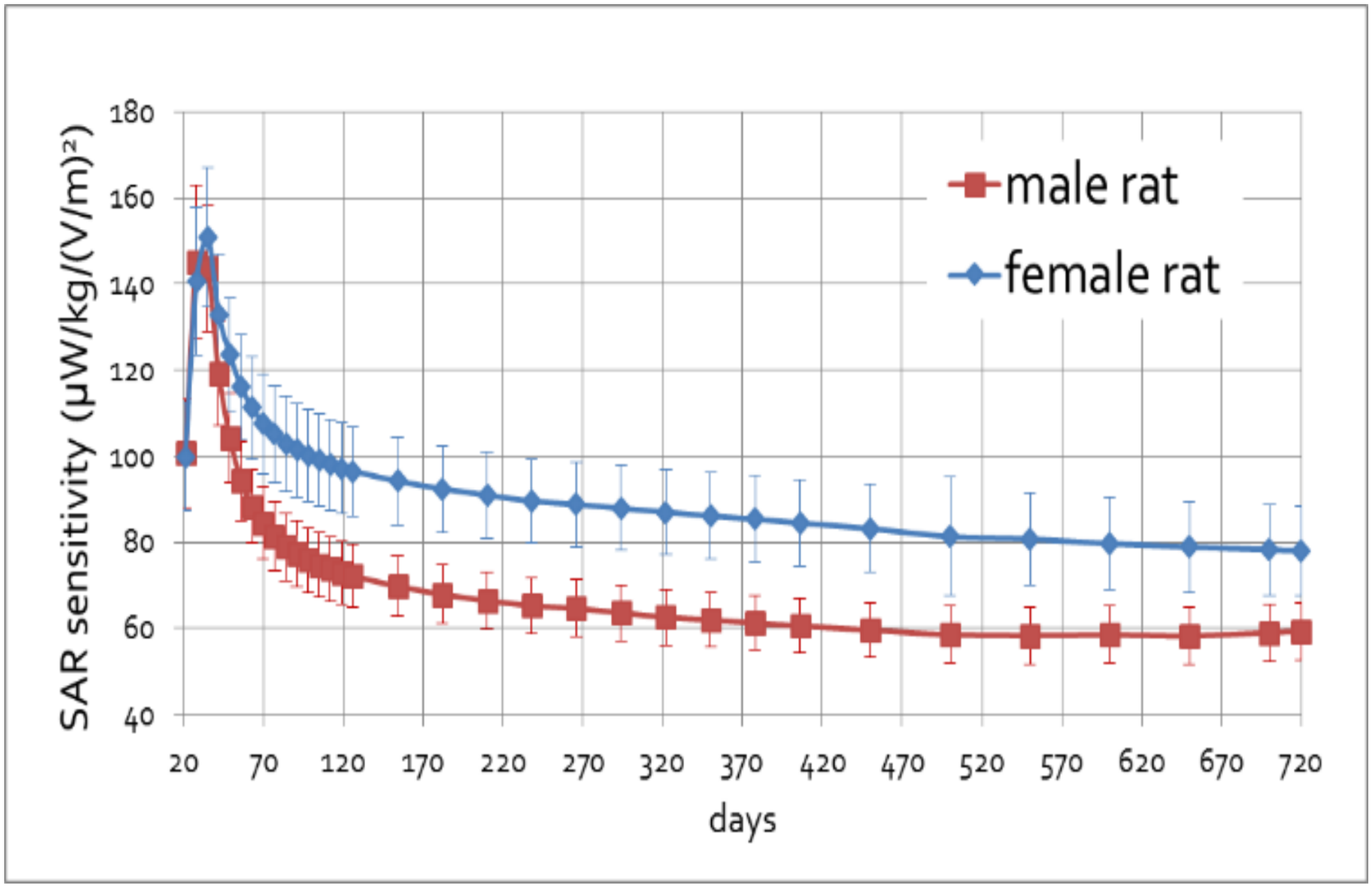
INSTANTANEOUS VARIATION ANALYSIS FOR WBSAR.

Variation sources	Distr.	Var. inst.		
		male rats	female rats	mixed mice
Experimental	R	7.4%	8.4%	7.4%
SAR uniformity				
SAR SD due to weight SD (max.)	N	8.6%	7.6%	8.9%
Postures	N	5.2%	5.2%	5.6%
Overall standard variation k=1		12.5%	12.5%	13%
Expanded variation k=2		25%	25%	26%

- MAXIMUM UNCERTAINTY OVER WHOLE LIFE TIME

Contributions	Distr.	Standard Uncertainty %			
		Rat		Mouse	
		Male	Female	Male	Female
E/H field measurement	N	13%	13%	11%	11%
Field Control	N	4.7%	4.7%	4.7%	4.7%
Planewaves vs. random waves	R	2.4%	2.4%	1.8%	1.8%
SAR sensitivity expression fit	N	7.2%	7.2%	3.0%	3.0%
Scaling	R	1.6%	6.5%	12%	20%
Anatomical model dosimetry	R	3.9%	3.9%	0.8%	0.8%
Rodent growth rate (max.)	R	17%	17%	6.2%	6.2%
Combined standard uncertainty k=1		24%	24%	18%	24%
Expanded uncertainty k=2		47%	48%	36%	49%

Uncertainty as a function of age for Rats



Conclusions

- The exposures were independently validated by NIST
  - Before the start of the study
  - Before the chronic study
  - After the completion of all studies
- System was never down for more than ~12 hours
- Total exposure time > 99% of the planned duration