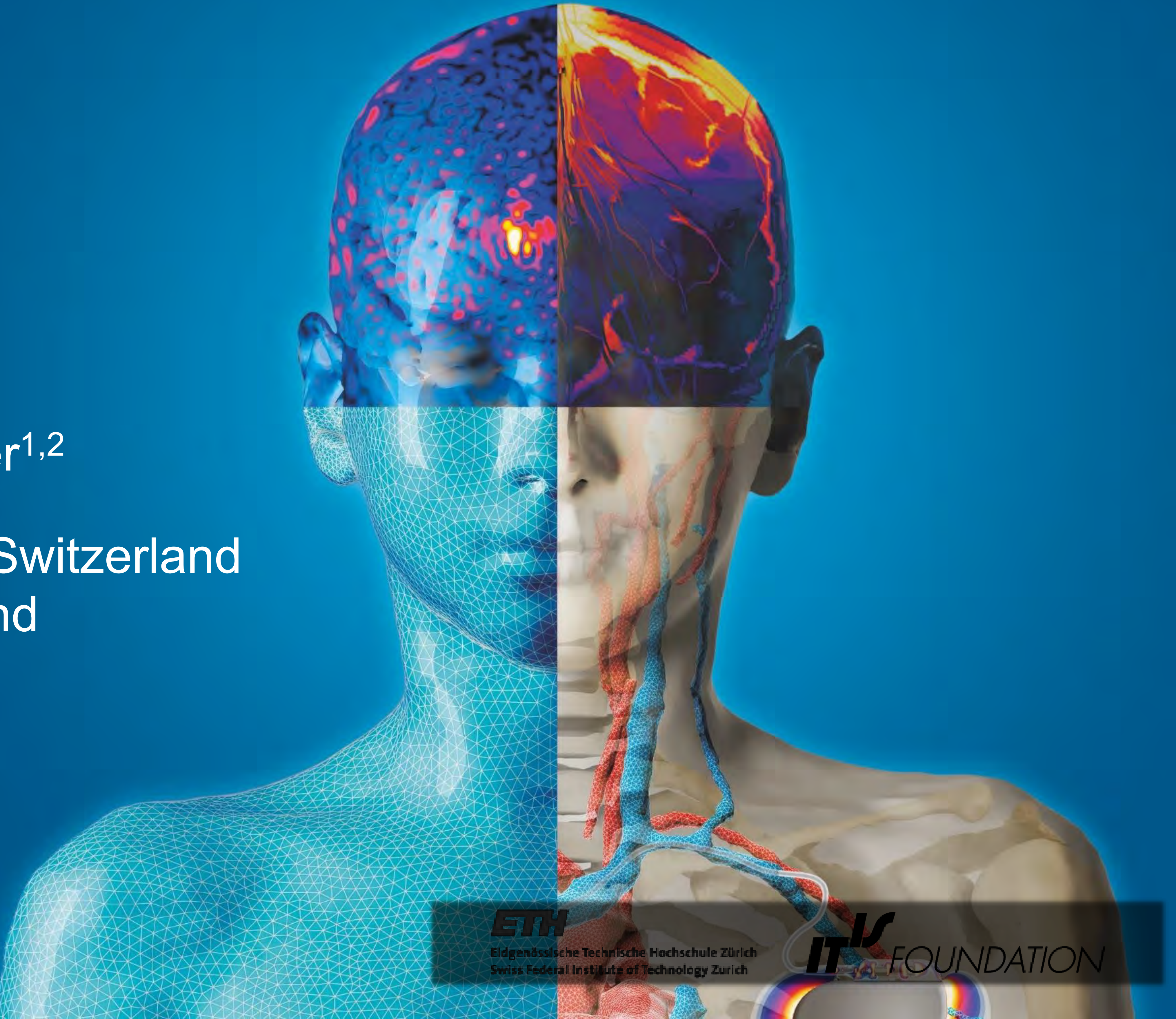
NTP Study: Dosimetry

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

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



Outline

- Introduction
- Dosimetry
- Numerical dosimetry and anatomical animal models
- Exposure environment
- Whole body and organ SAR
- Experimental validation
- Water system dosimetry
- Uncertainty and variational analysis
- Exposure summary
- Conclusions

What is Dosimetry

- dosimetry in the fields of health physics and radiation protection is the measurement, calculation and assessment of the internal exposure to the body
- for non-ionising radiation in the radio frequency range the exposure quantity is Specific Absorption Rate (SAR)
- SAR is expressed in Watts per kilogram (W/kg)
- for humans there are two regulatory limits
  - local peak absorption limit averaged over 1g or 10g of tissue
  - whole body average SAR

- it is not possible to measure SAR directly in a subject (humans or animals)
- measure the EM fields incident on the subject
- perform numerical simulations (dosimetry) using anatomical numerical models
- validate in homogenous experimental phantoms

What Determines the SAR?

relating to the exposure subject

- size of the subject
- weight of the subject
- electrical properties of the tissues
- anatomy
- posture

relating to the exposure field

- strength of the EM field
- proximity of the source (reactive near field versus far field)
- frequency of the EM field
- direction and polarisation of the EM field

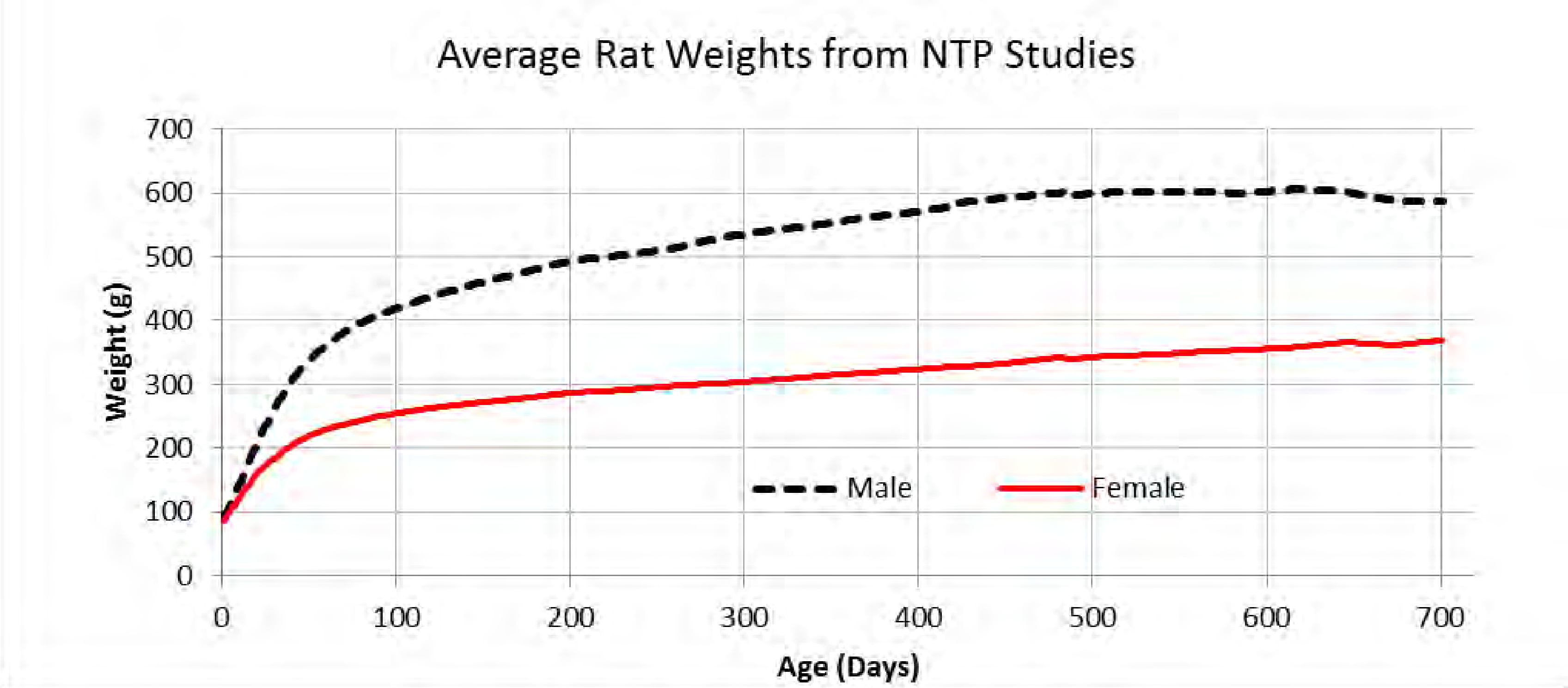
Exposure Groups

exposure quantification

- incident field
- induced fields (SAR)

SAR is a function of

- incident field
- body mass, size and anatomy



Numerical Dosimetry

- high resolution anatomical models (more 100 anatomical structures segmented)

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

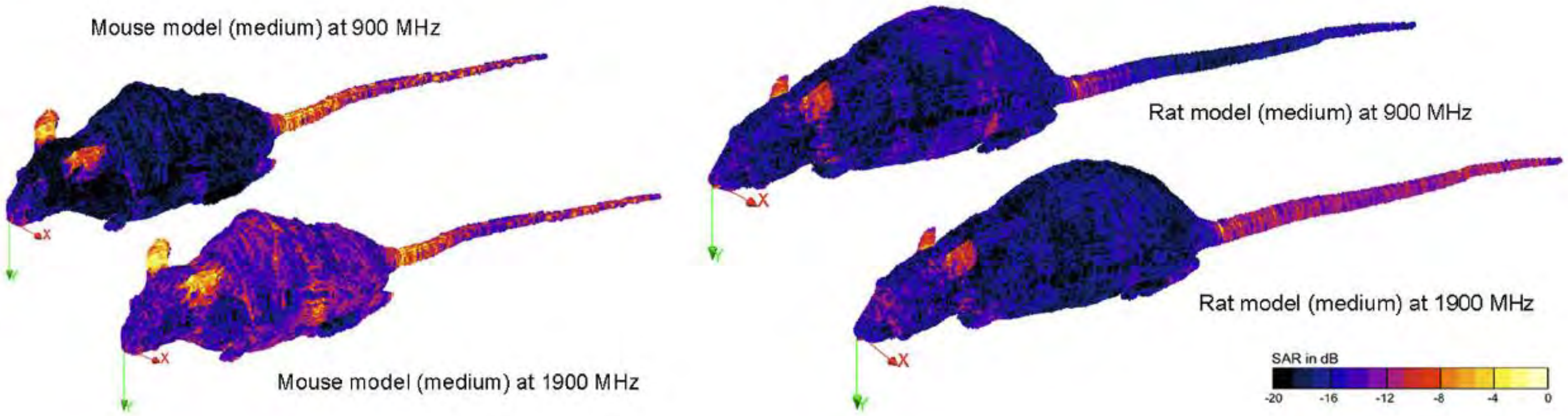
Tissue Parameters

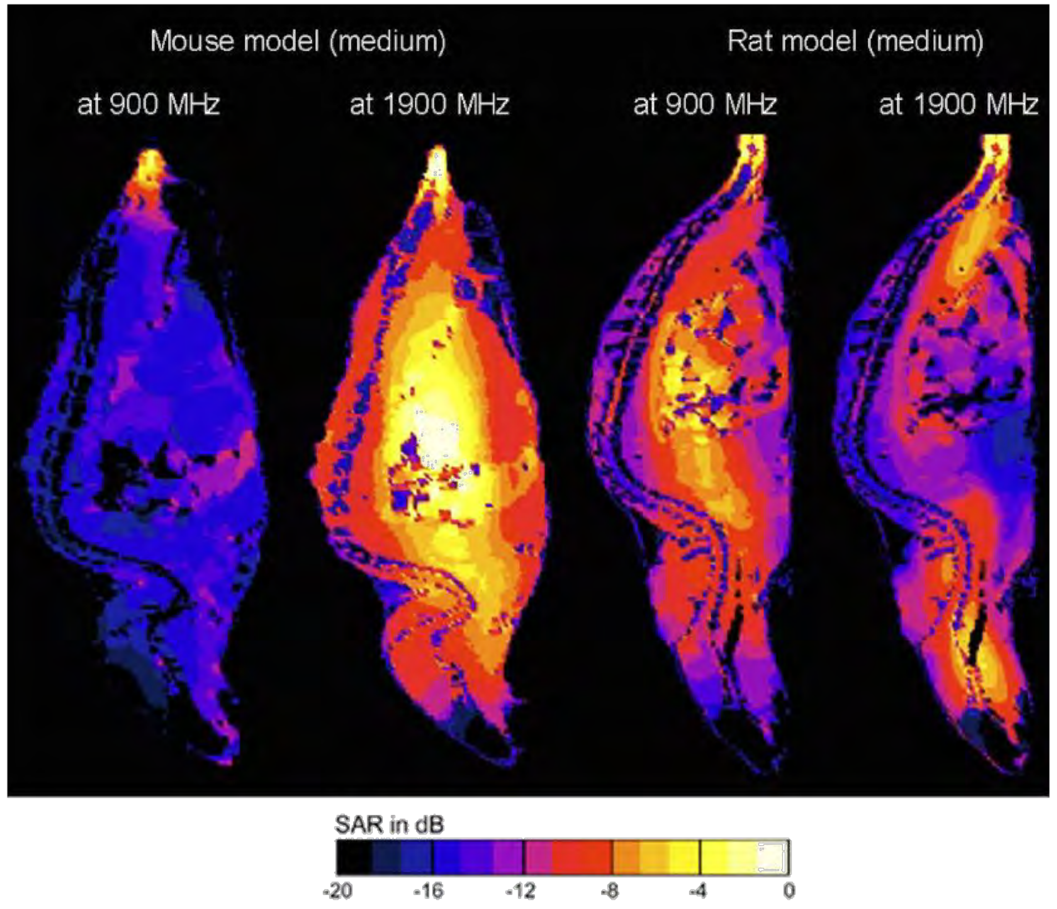
Tissue	Relative Permittivity	Elec. Cond. (S/m)
Blood	61.4	1.54
Blood Vessel Wall	44.8	0.70
Bone	20.8	0.34
Bone Marrow	11.3	0.23
Brain	49.4	1.26
Cerebrospinal Fluid	68.6	2.41
Fat	11.3	0.11
Heart Muscle	59.9	1.23
Kidney	58.7	1.39
Large Intestine	57.9	1.08
Liver	46.8	0.85
Lung	22.0	0.46
Midbrain	49.4	1.26
Muscle	55.0	0.94
Pancreas	59.7	1.04
Skin	41.4	0.87
Small Intestine	59.5	2.17
Spleen	57.2	1.27
Stomach	65.1	1.19
Tongue	55.3	0.94
Tooth	12.5	0.14

- databases of tissue electrical parameters are available based on the published literature
- each tissue in the anatomical model is assigned the correct electrical properties
- examples for 900 MHz

Exposure Frequency

- numerical dosimetry for the 2 main cellular bands (800-1000 &1800 – 1950 MHz)
- evaluation of SAR distribution
- consideration of SAR sensitivity



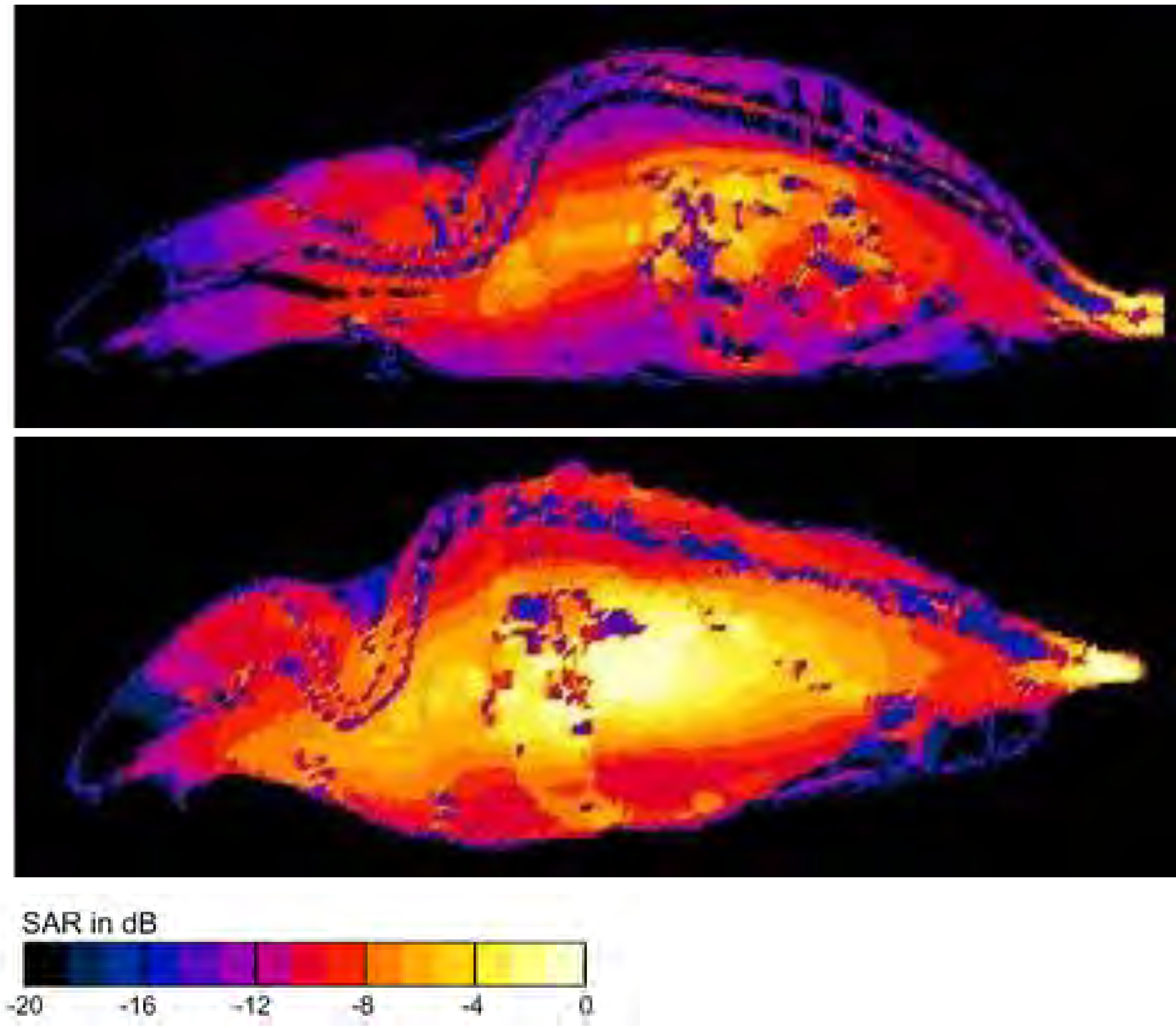


Numerical Dosimetry

two outcomes

- whole body SAR
- organ / tissue specific SARs

- conclusions for the NTP study
  - rat exposed at 900 MHz
  - mouse exposed at 1900 MHz



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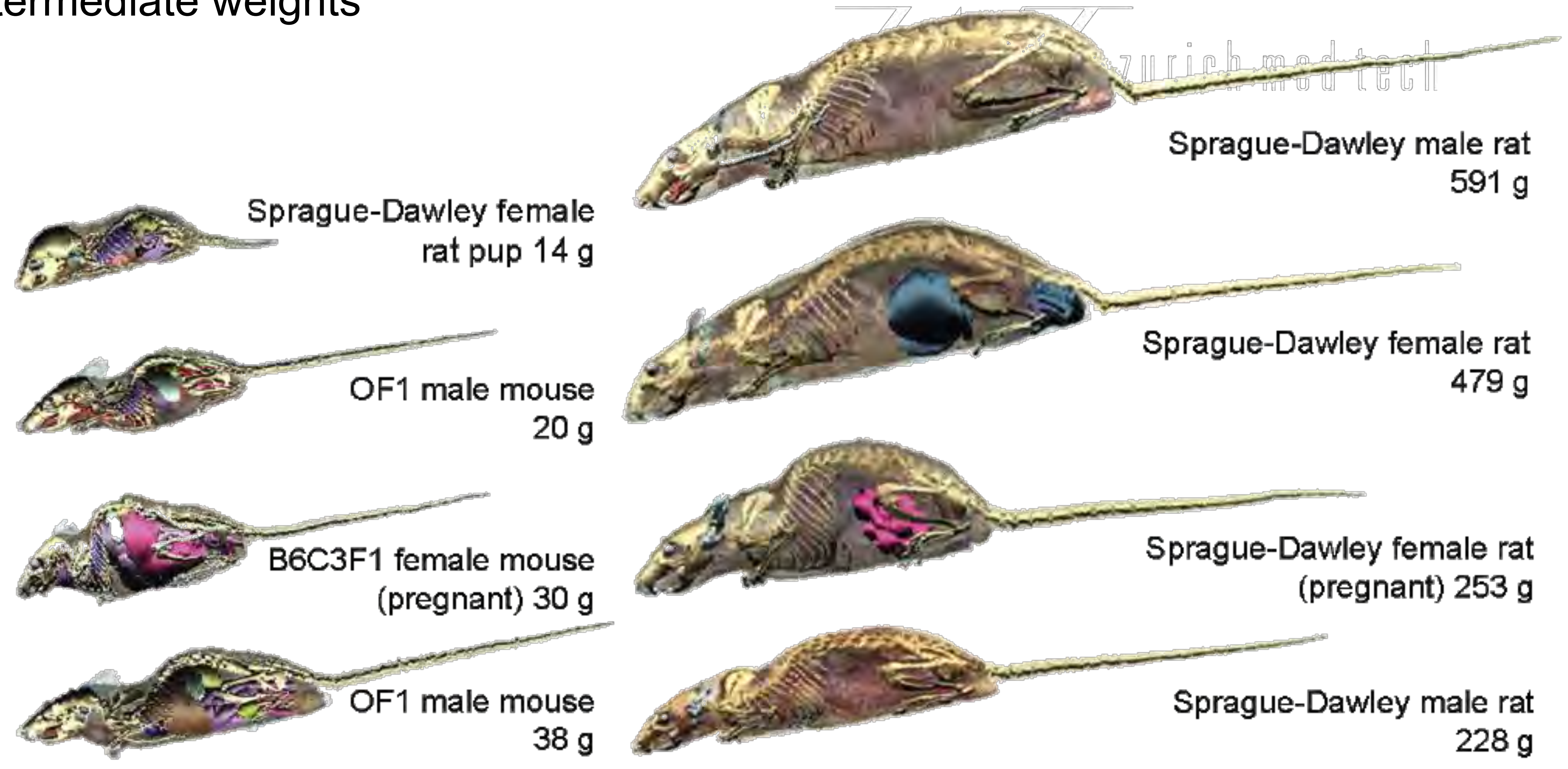
Anatomical Models Used for Dosimetry

- all available mouse and rat models
- models scaled to intermediate weights



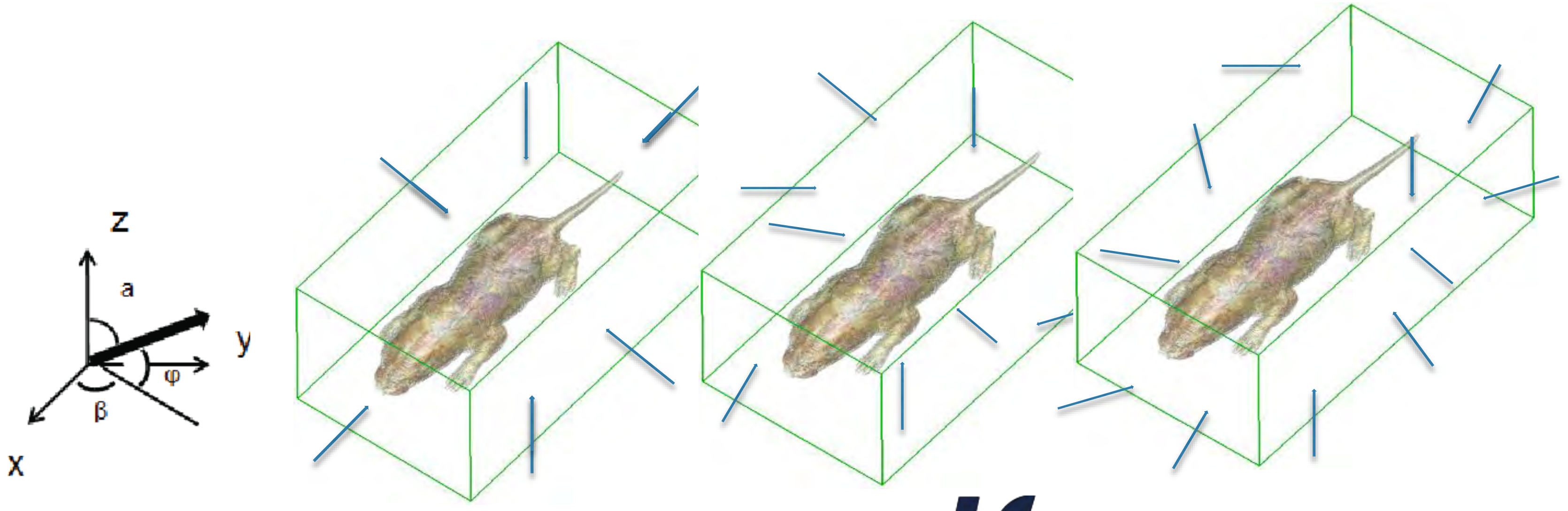
Reverberation Chamber Exposure Environment

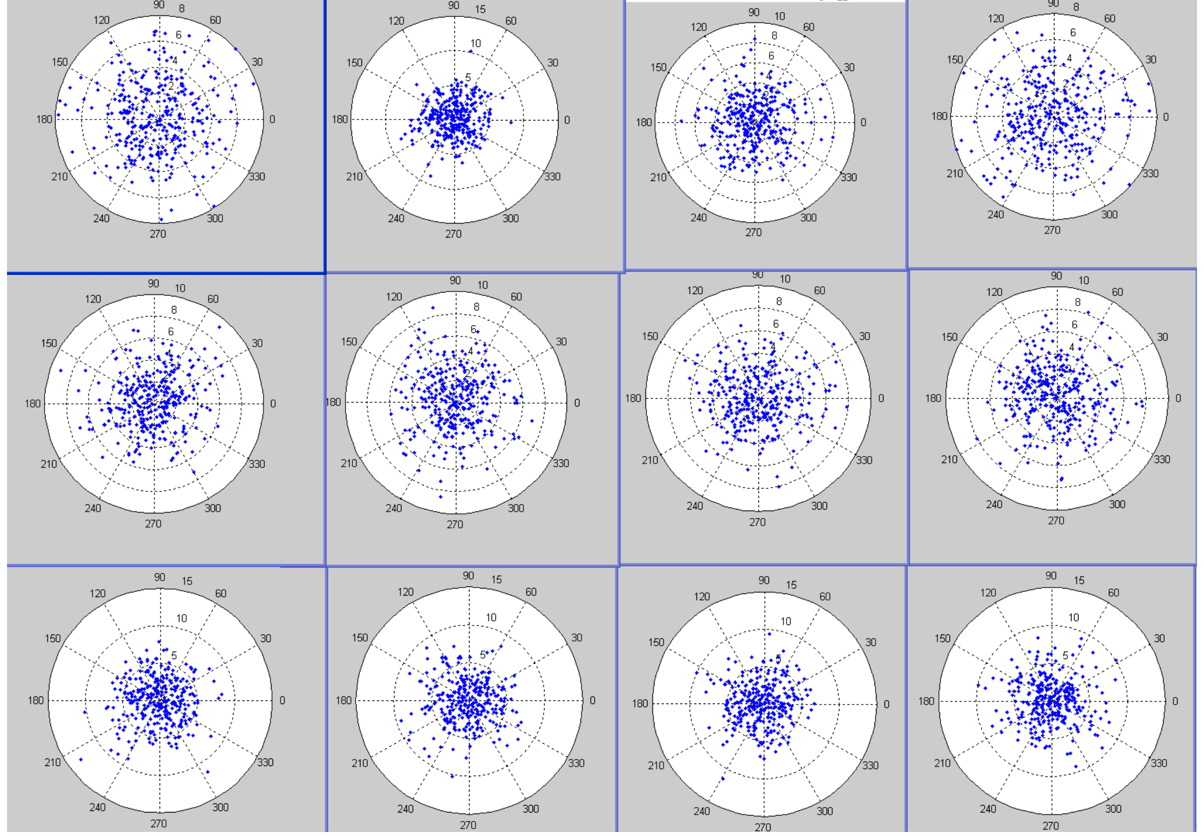
reverberation chambers

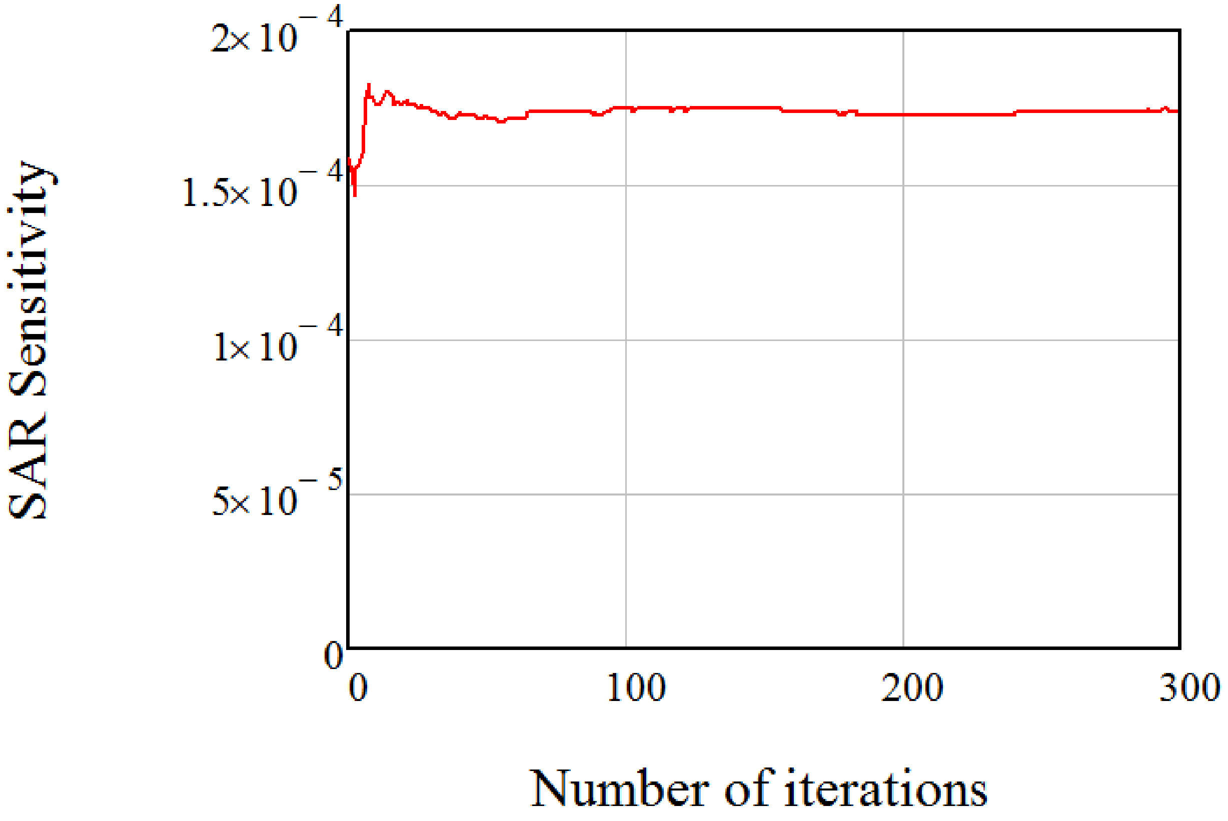
- isotropic field
- homogeneous
- Rayleigh distributed temporal variations

exposure environment representations

- random plane-wave method
- 12 plane-wave method







Random Planewaves

- each input plane wave has
  - random amplitude (with a Rayleigh distribution)
  - random phase
  - random polarization
- this E field will be incident on the cage, where the mouse/rat is located, with:
  - random angles of arrival described in terms of angles θ, φ
- each exposure condition consists of > 200 random planewaves

Normalization

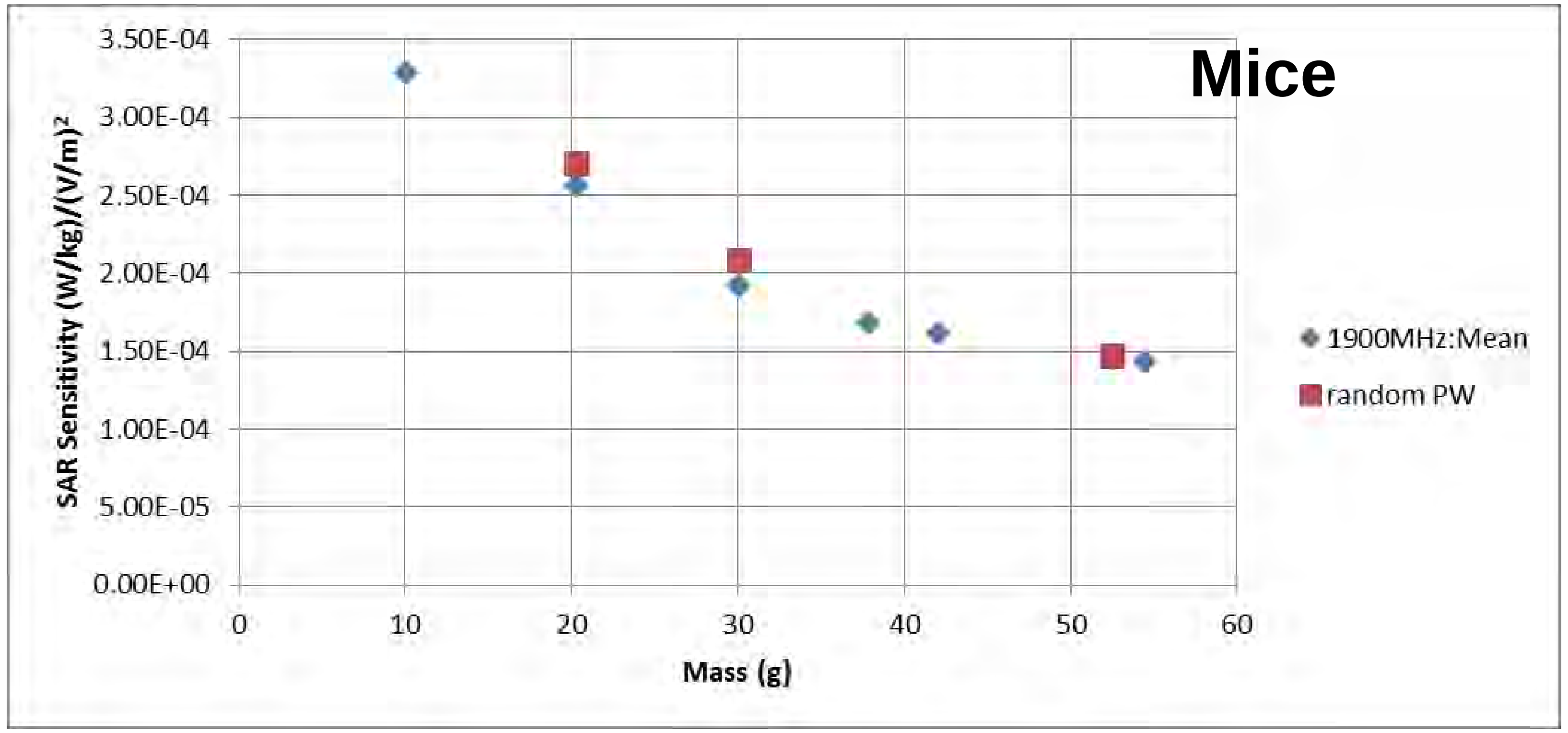
- SAR normalized to 1 V/m E-field strength ((W/kg)/(V/m)2) was calculated by one of two methods:

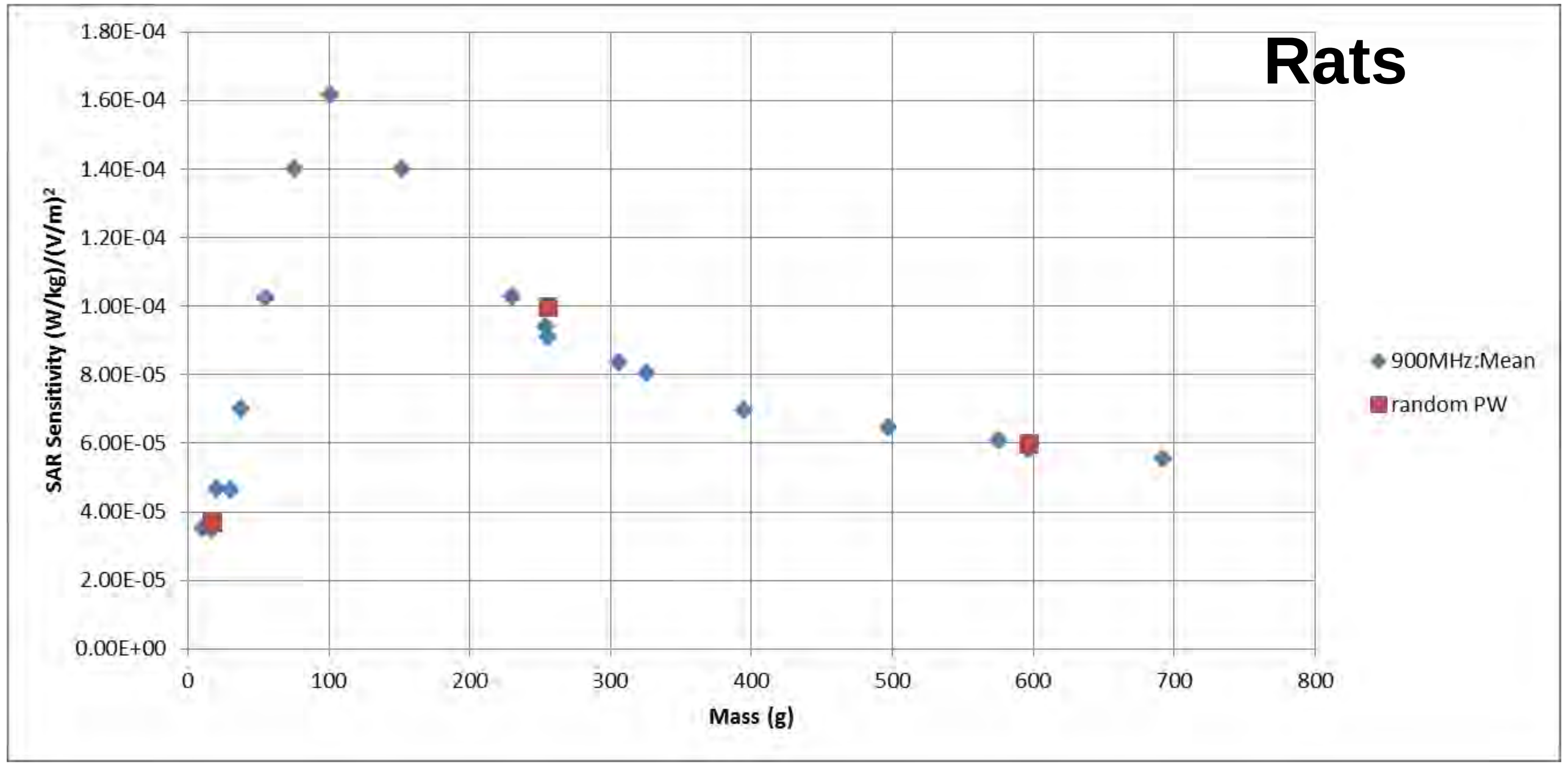
$$\text{normalized } SAR = \sum_{1}^{m}(SAR_m/|E_m|^2)/m$$

$$\text{normalized } SAR = \sum_{1}^{m} SAR_m/\sum_{1}^{m}|E_m|^2/m$$

- where m is the number of stirrer rotations.
- the first method averages the instantaneous SAR divided by the instantaneous field squared, equivalent to a simulation by simulation normalization;
- the second is more akin to the situation in the real exposure setup, where the average SAR is divided by the mean square E-field
- these two normalization procedures for a random n-plane wave method converge when n = 500 and m = 300, and both averaging regimes give similar results.

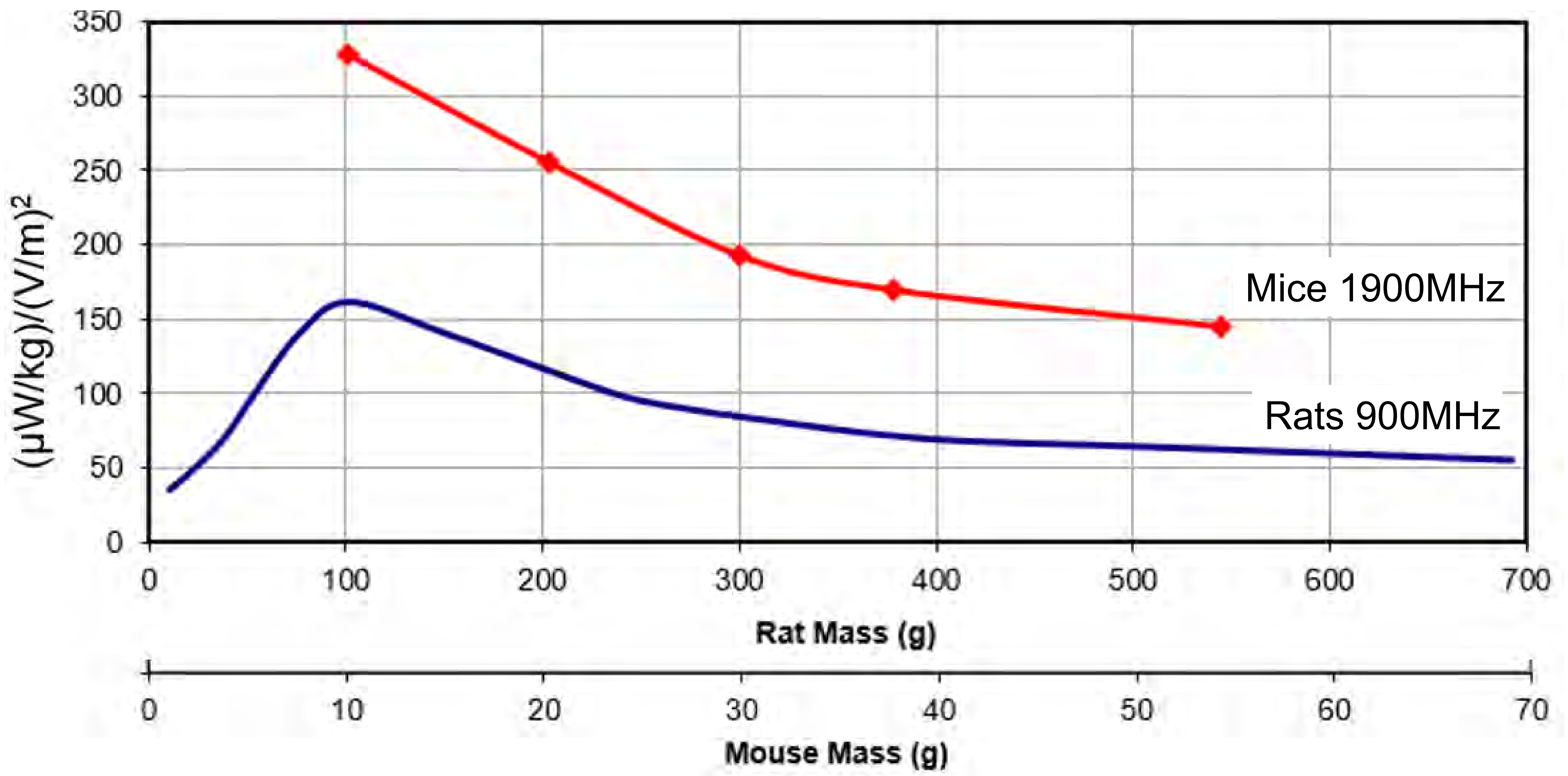
SAR Sensitivity





- determined by random plane-waves method and simplified model

Whole Body SAR Sensitivity of Rats (900 MHz) and Mice (1900 MHz)



Numerical Dosimetry (Organ Specific SAR and Uncertainty)

Rats exposed at 900 MHz

Organs	oSAR/wbSAR (dB)		Uncertainty (k=1)		Uncertainty (k=2)	
	male	female	male	female	male	female
Blood Vessels	3.7	4.6	25%	37%	49%	74%
Bones	-8.8	-7.8	26%	34%	51%	67%
Cerebral Hemisphere	0.3	-0.7	53%	44%	106%	88%
Connective Tissue	-3	-1.9	24%	35%	48%	69%
Fat	-8.8	-6.6	24%	34%	48%	68%
Glands	1.6	1.6	38%	49%	75%	98%
Heart	2.7	4.7	25%	42%	50%	83%
Intestine, Large	1.6	1.7	25%	34%	50%	68%
Intestine, Small	3.3	4.4	26%	35%	51%	69%
Kidneys	0.5	0.2	25%	42%	49%	84%
Liver	0.7	2	25%	35%	49%	69%
Lung	3.2	4.2	26%	36%	52%	71%
Muscles	0.3	1.3	24%	34%	48%	67%
Skin	-1.3	-0.3	25%	34%	49%	67%
Stomach	2	1.4	28%	35%	56%	70%

Mice exposed at 1900 MHz

Organs	oSAR/wbSAR (dB)		Uncertainty (k=1)		Uncertainty (k=2)	
	male	female	male	female	male	female
Blood Vessels	4.1	3.2	24%	35%	48%	69%
Bones	-6.9	-7.7	22%	35%	43%	70%
Cerebral Hemisphere	-0.2	0.3	43%	47%	85%	93%
Connective Tissue	-2.4	-2.7	21%	35%	42%	69%
Fat	-6.8	-8	28%	36%	56%	72%
Glands	2.7	2.1	36%	38%	71%	76%
Heart	0.7	1.7	23%	38%	46%	75%
Intestine, Large	2.1	0.8	21%	37%	42%	74%
Intestine, Small	3.6	2.7	26%	35%	51%	70%
Kidneys	1.4	0.2	35%	38%	70%	76%
Liver	1.6	0.4	32%	40%	64%	79%
Lung	3.3	3	35%	41%	69%	81%
Muscles	0.6	-0.2	21%	35%	42%	69%
Skin	-0.9	-1.5	26%	35%	51%	69%
Stomach	1.9	0.6	38%	36%	75%	72%

- high-water-content tissues (muscle, liver, skin, and brain) was ± 2.6 dB of the wbSAR
- low-loss tissues (bone and fat) were less exposed by a factor of ~8 dB compared to the wbSAR

Brain and Heart SAR

- the heart and brain have average SARs that differ from the whole body average
- the ratio between heart and brain and whole body SAR changes with age and sex (body shape)

For mice

- heart – average 1.72 x wbSAR, standard deviation 8%
- brain – average 1.00 x wbSAR, standard deviation 27%

For rats

- heart – average 2.27 x wbSAR, standard deviation 72%
- brain – average 1.05 x wbSAR, standard deviation 51%

Dosimetry of Dam and Pups

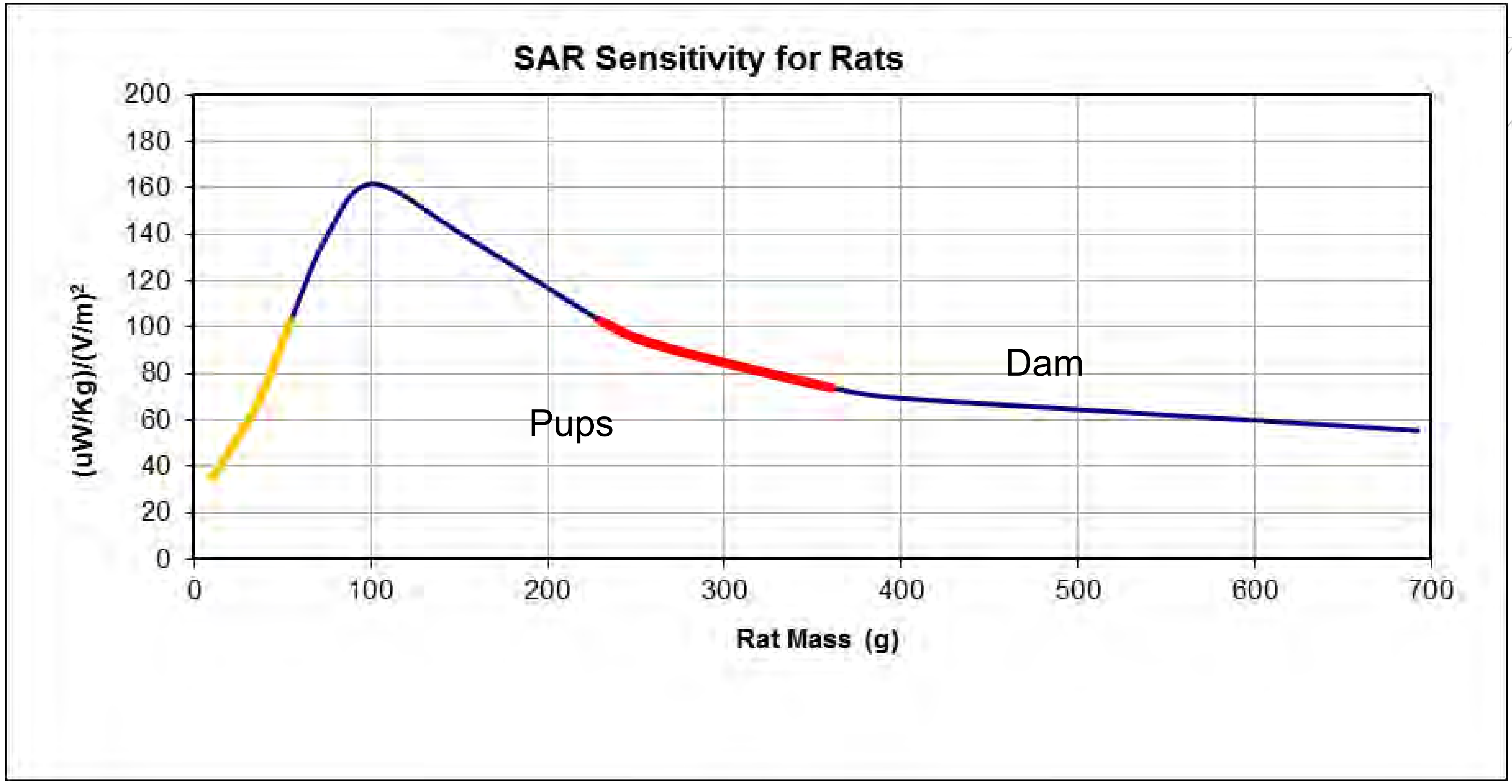
- for the rats the pups were exposed with their mother until weaning

12 rat pups in in clump

12 rat pups in a clump with the mother on the top

- clumping together significantly increases the SAR of the pups compared to a single pup
- enhanced SAR in the tails of the pups is a possible concern
- the dam exposure is moderately enhanced when in close proximity to the pups
- pups on their own have similar exposure as the dam for the same field conditions

SAR Sensitivity of Dams and Pups



SAR sensitivities overlap between the pups and the dam

SAR Distributions

For Rats at 900 MHz

Weight	Whole Body avg. SAR	wb std. Deviation	SP-5mg	SP-50mg
(g)	(μW/Kg)/(V/m)^2	(μW/Kg)/(V/m)^2	(μW/Kg)/(V/m)^2	(μW/Kg)/(V/m)^2
230	100	71	618	497
486	67	57	648	397
597	59	44	532	393

For Mice at 1900 MHz

Weight	Whole Body avg. SAR	wb std. Deviation	SP-0.5mg	SP-5mg
(g)	(μW/Kg)/(V/m)^2	(μW/Kg)/(V/m)^2	(μW/Kg)/(V/m)^2	(μW/Kg)/(V/m)^2
20	239	193	1643	1084
38	168	127	1127	1015
52	146	121	1350	973

Dosimetry Validation

- it is not possible to validate the dosimetry in real animals or complex inhomogeneous geometries

validate with simplified homogeneous phantoms

- perform numerical dosimetry on the homogeneous phantom
- perform experimental dosimetry on the physical phantom(s)

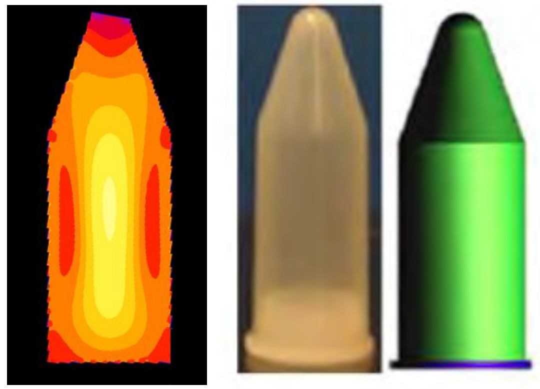
validates

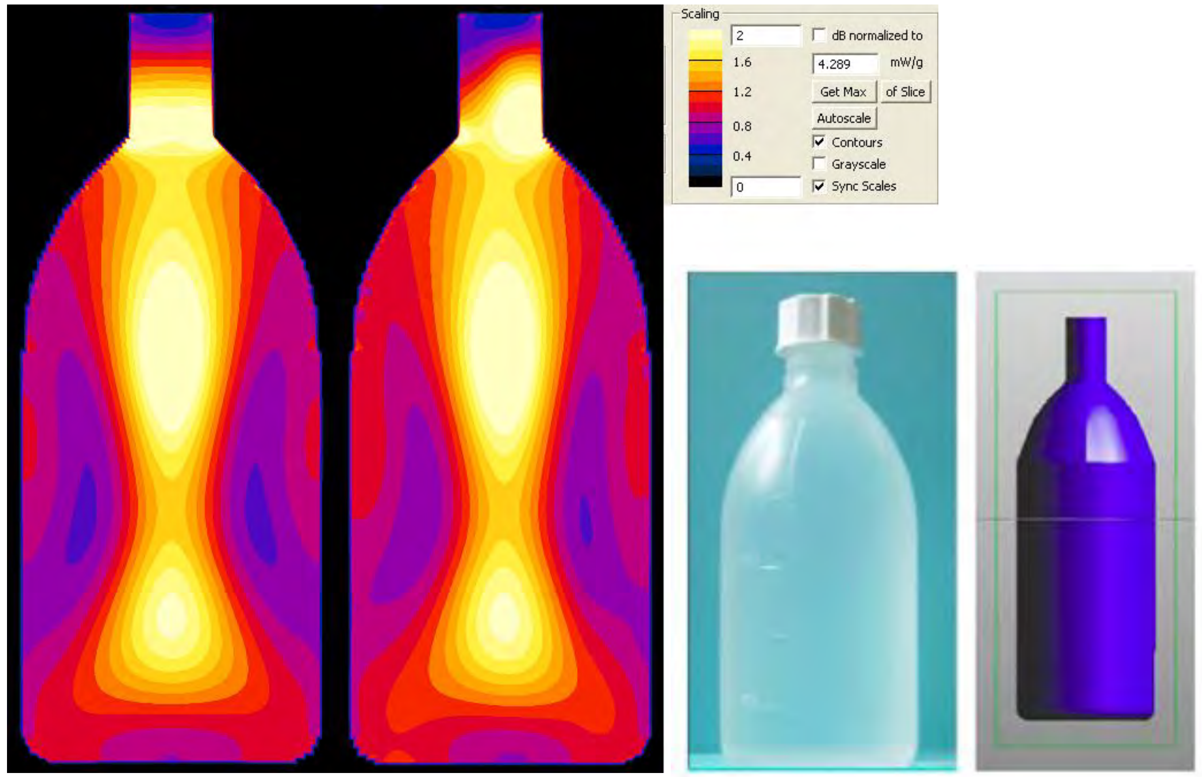
- numerical dosimetry
- model of the exposure environment

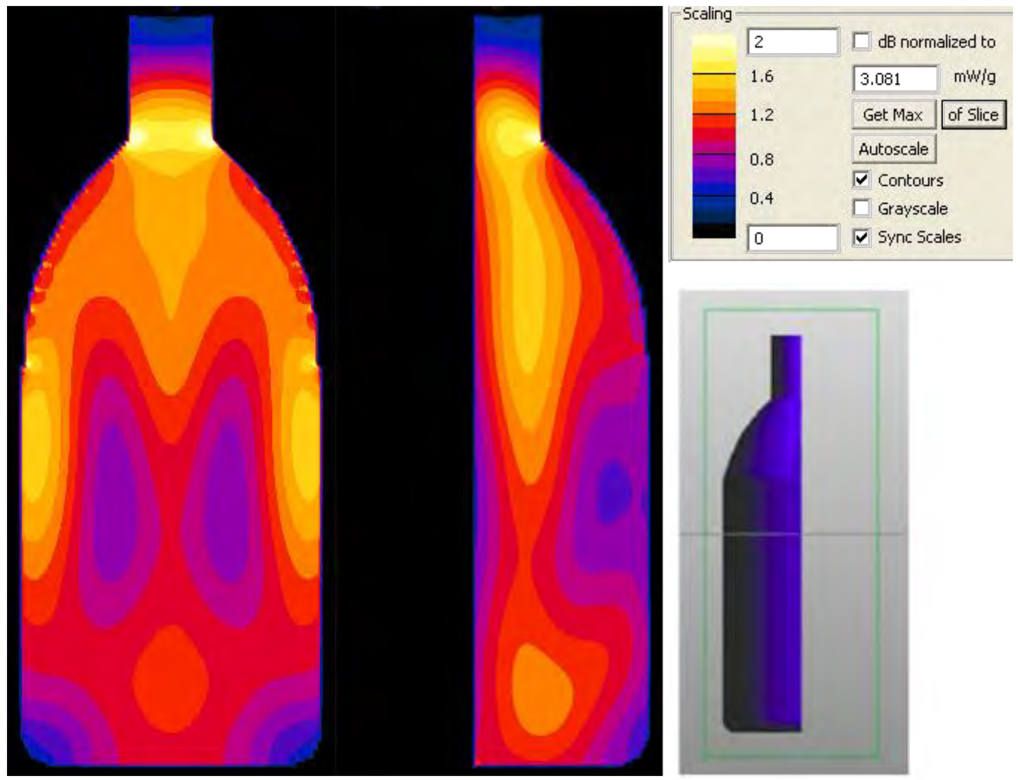
Experimental Dosimetry

- phantoms tailored to have the same whole body SAR as a rat or mouse of the same weight by selecting an appropriate tissue simulating media

zurich med tech





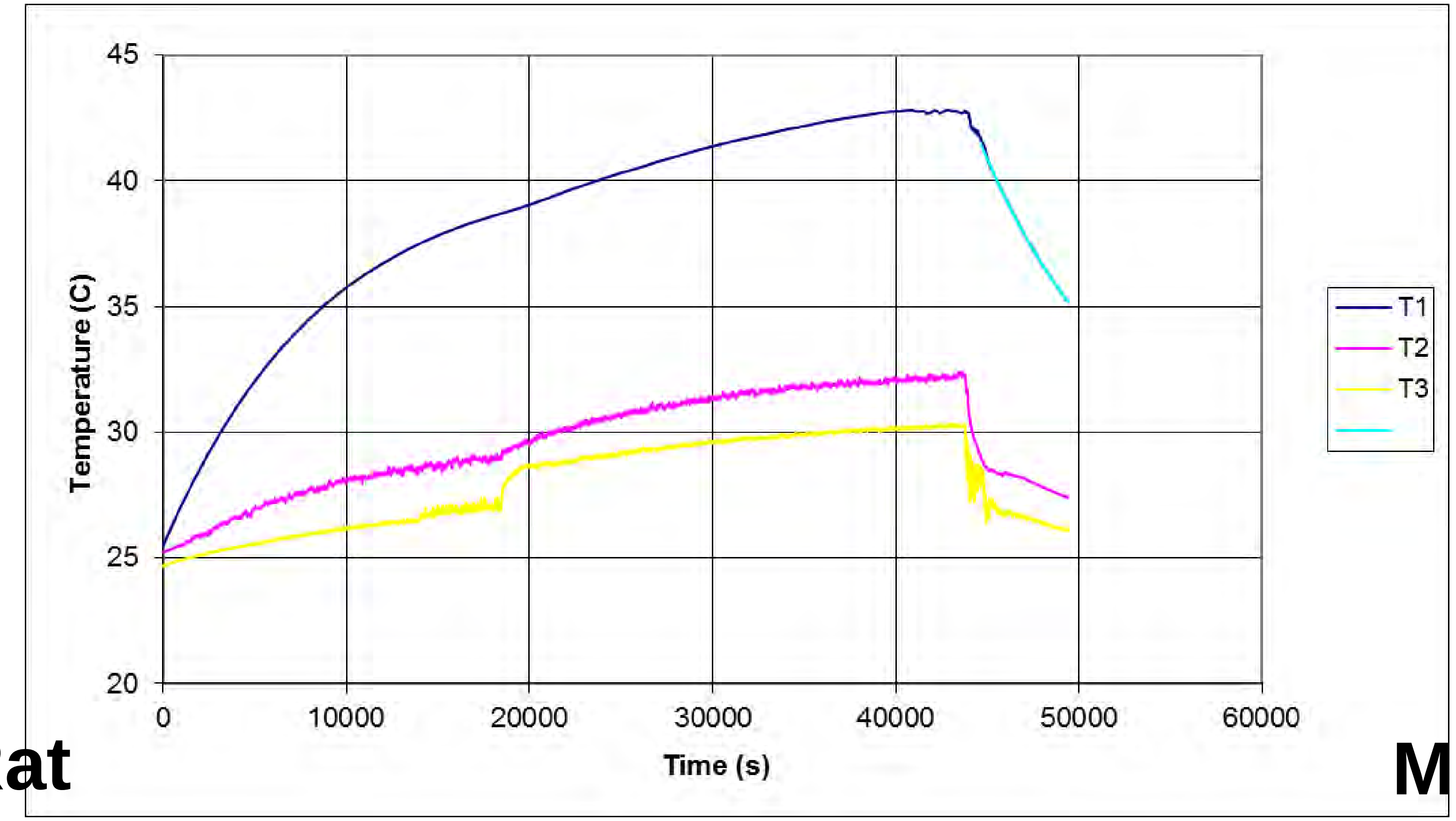


Experimental Dosimetry

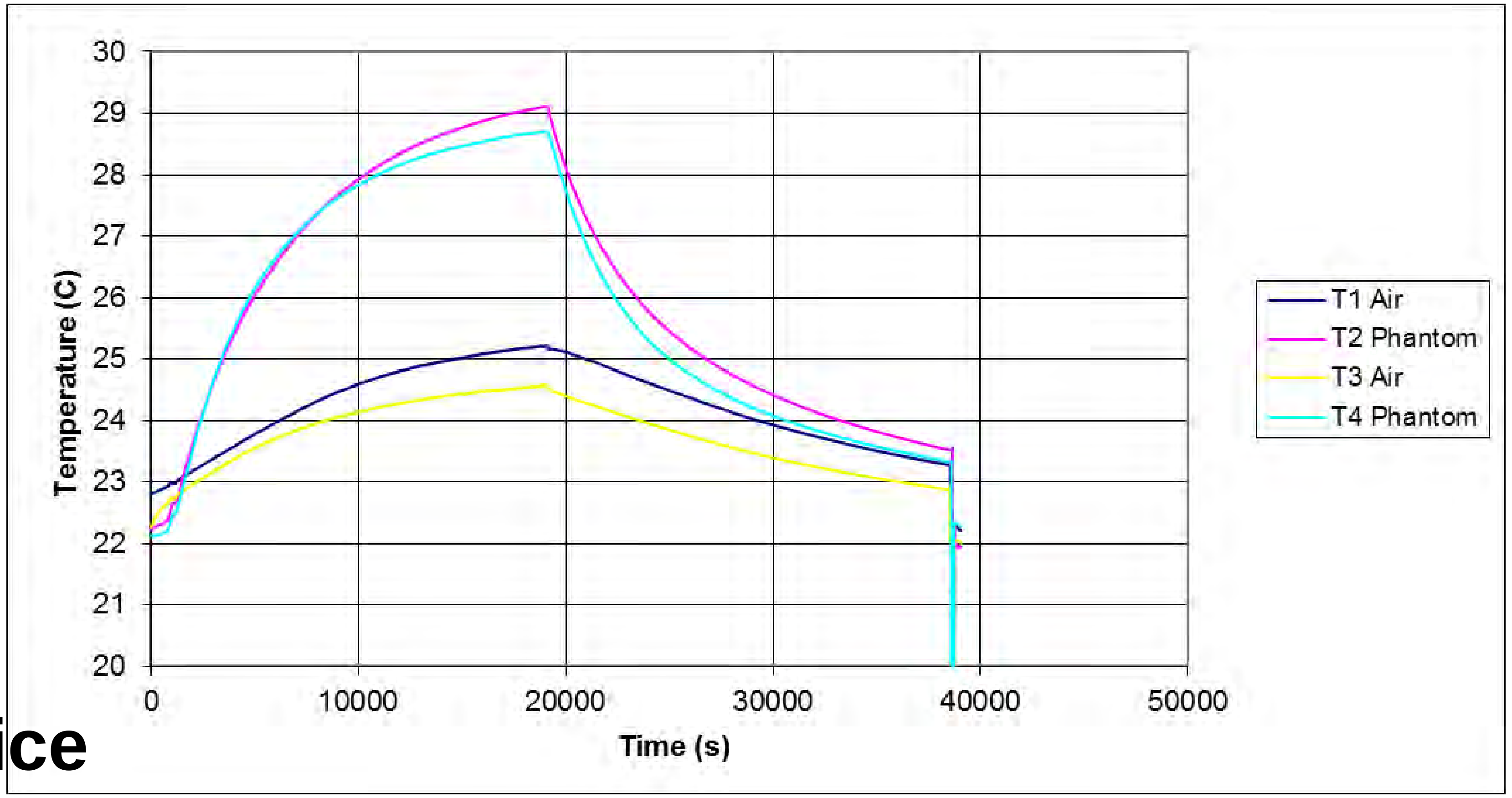
- problems
  - temperature was not stable
  - temperature gradient bottom to top of chamber

EXPERIMENTAL RESULTS OBTAINED IN CHICAGO AND ZURICH IN MALE AND FEMALE RAT PHONTOMS AND MICE PHANTOMS.

Phantom	f MHz	Cal. SAR $\mu W/kg/(V/m)^2$	Meas. SAR $\mu W/kg/(V/m)^2$	StDev %	dev %
Rat(m)	900	55.9	54.9	18.6	-0.2
Rat(f)	900	75.7	73.4	19.7	-3.0
Mouse	1900	164	144	14.0	-12.4



Rat



Mice

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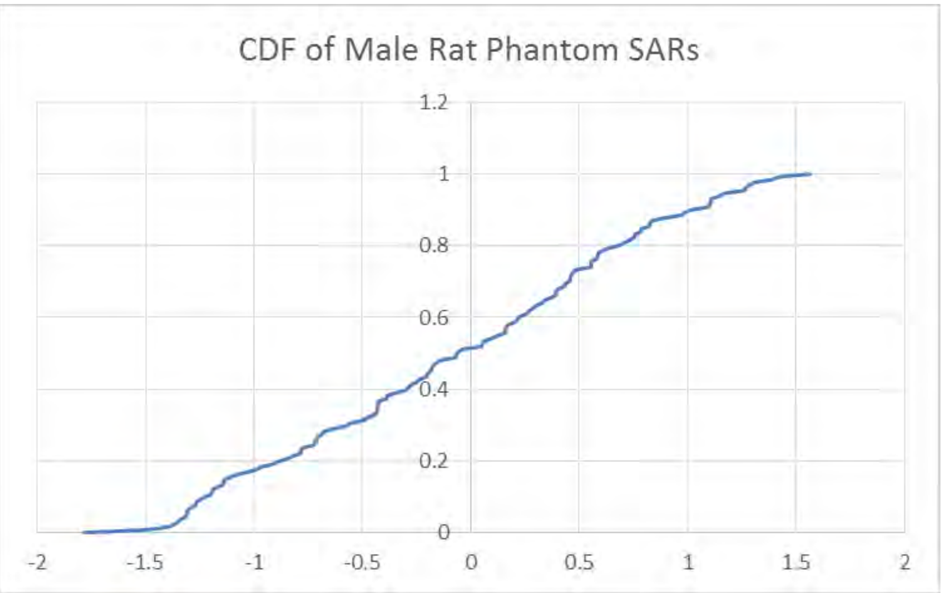
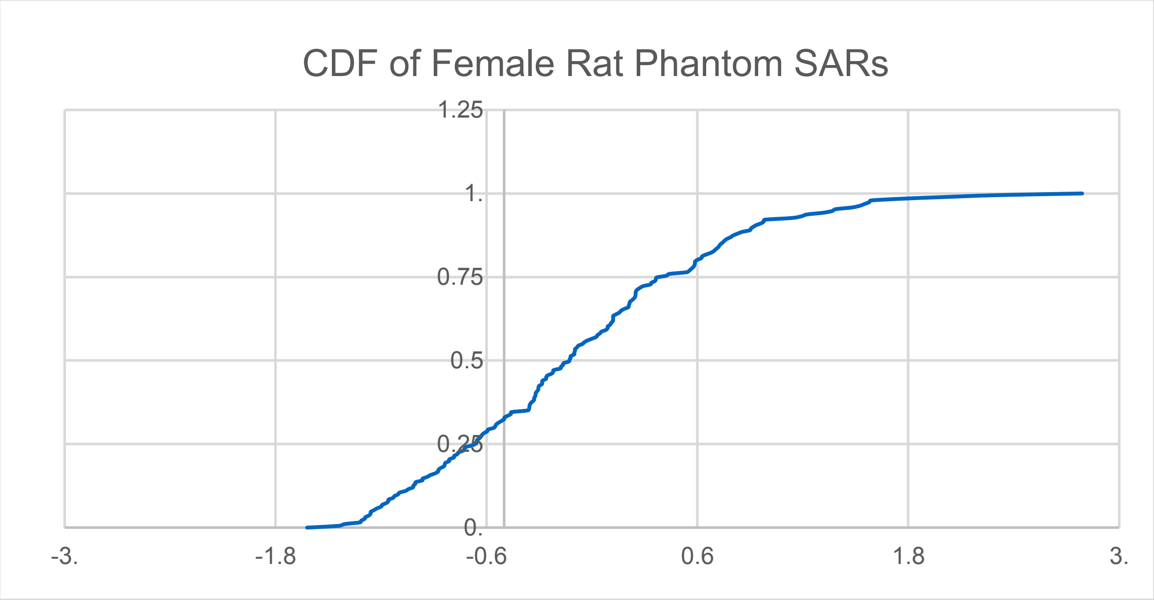
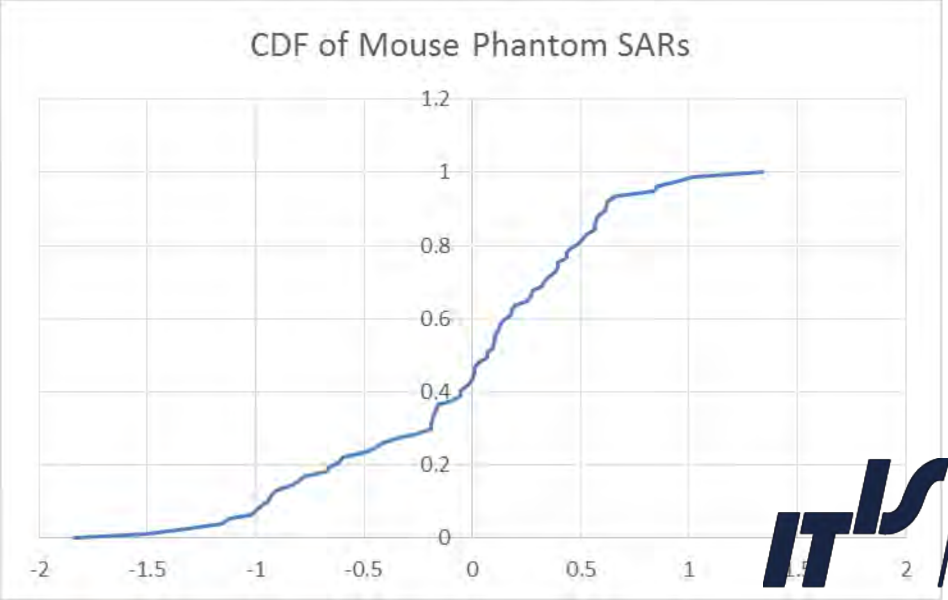
Distribution of Experimental SARs

- distributions of all the measured SARs (dB) from the experimental dosimetry in Zurich and Chicago
- 132 male rat phantoms
- 192 female rat phantoms
- 77 mouse phantoms



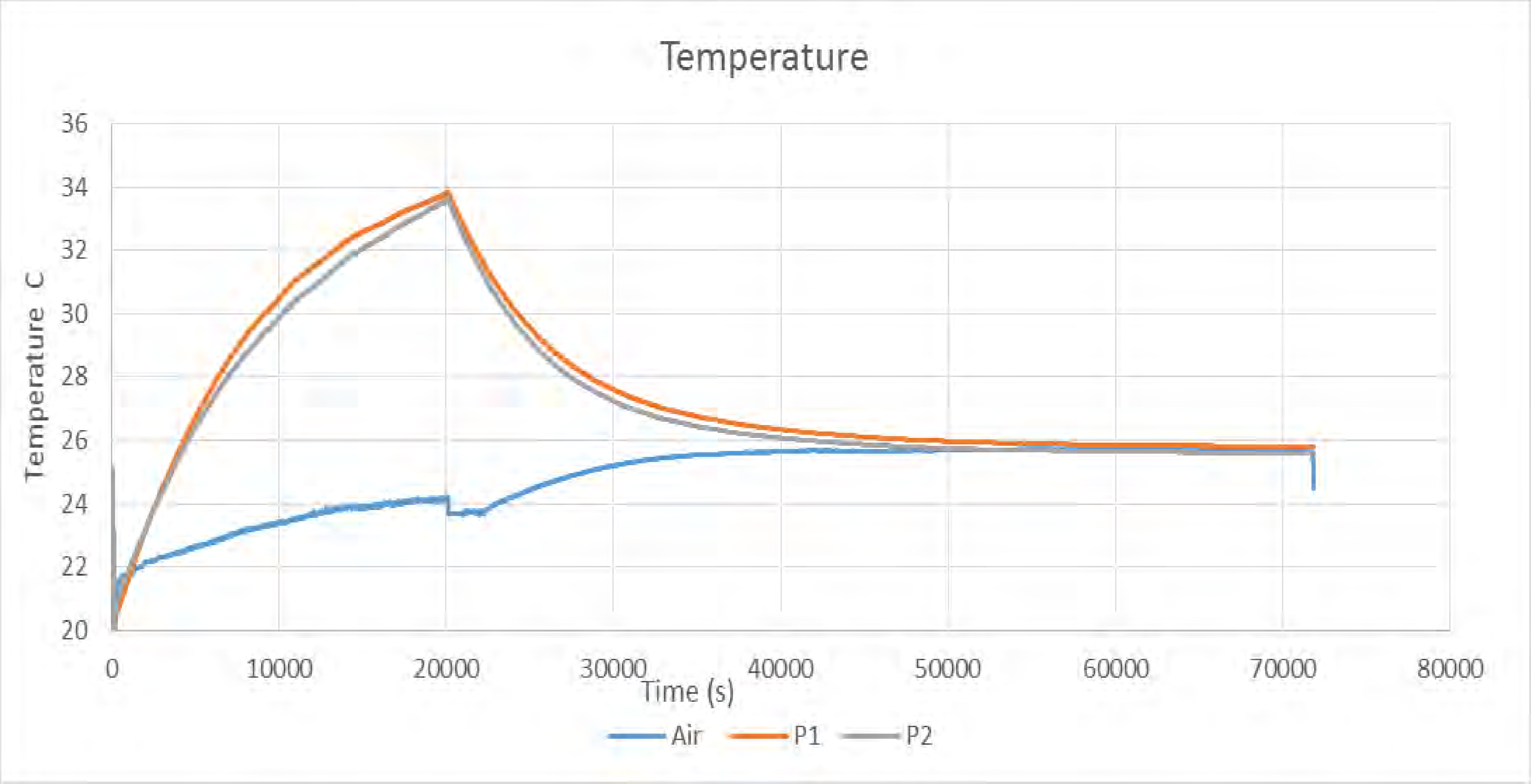




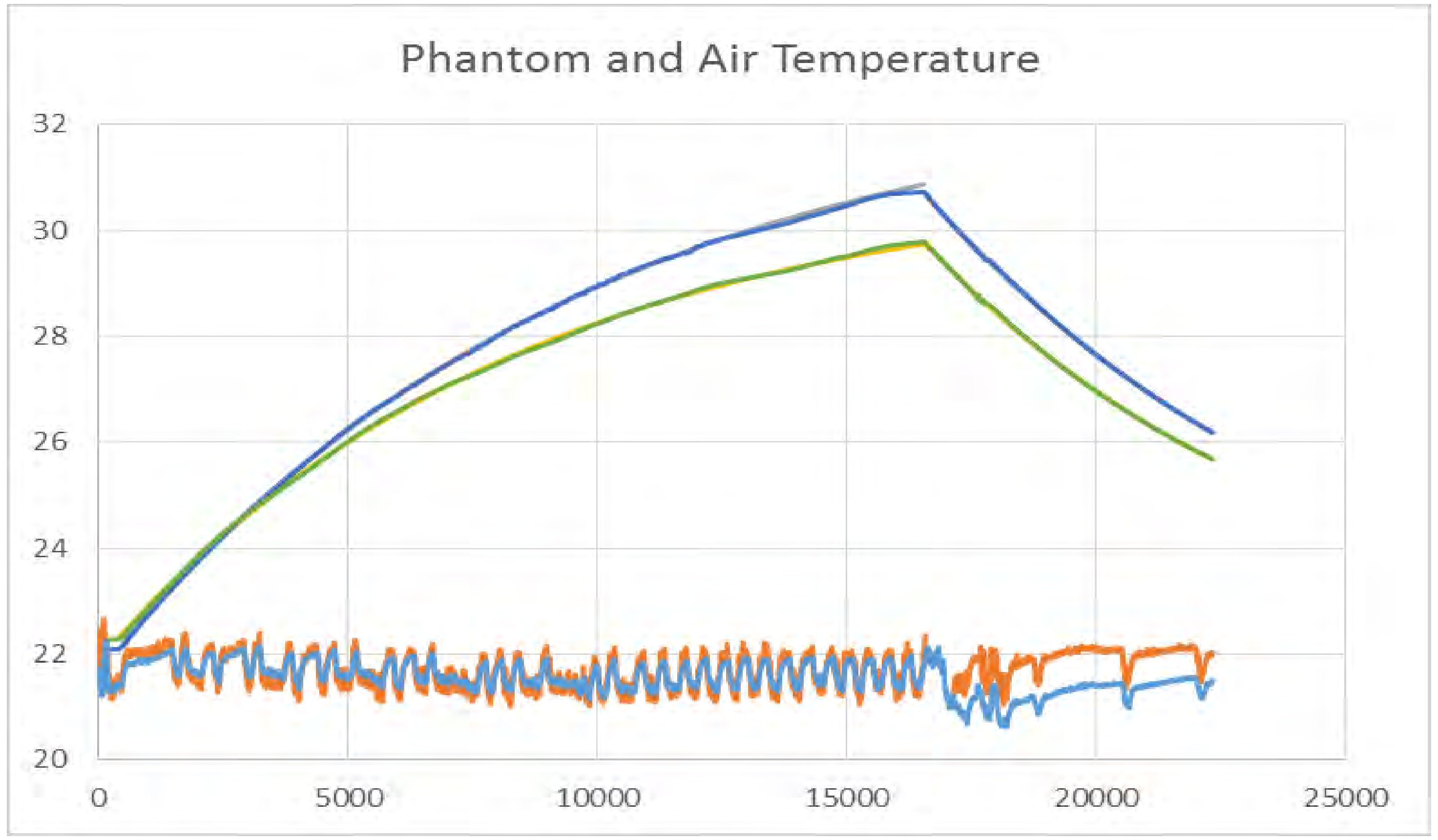
Contributions	Distr.	Std. Unc. Rat	Std. Unc. Mouse
E/H field measurement	N	12.8%	11.3%
Field control	N	4.7%	4.7%
Chamber temperature fluctuations	N	9.6%	9.6%
Temperature probe accuracy	N	1.2%	1.2%
Combined standard uncertainty k=1		16.7%	15.6%
Expanded uncertainty k=2		33.5%	31.2%

Comparison of Results in Similar Chambers with T-Control

difference between numerical and experimental dosimetry 9.5 % or 0.39 dB



difference between numerical and experimental dosimetry 0.2 % or 0.01 dB



Comparison of Results in Similar Chambers with T-Control

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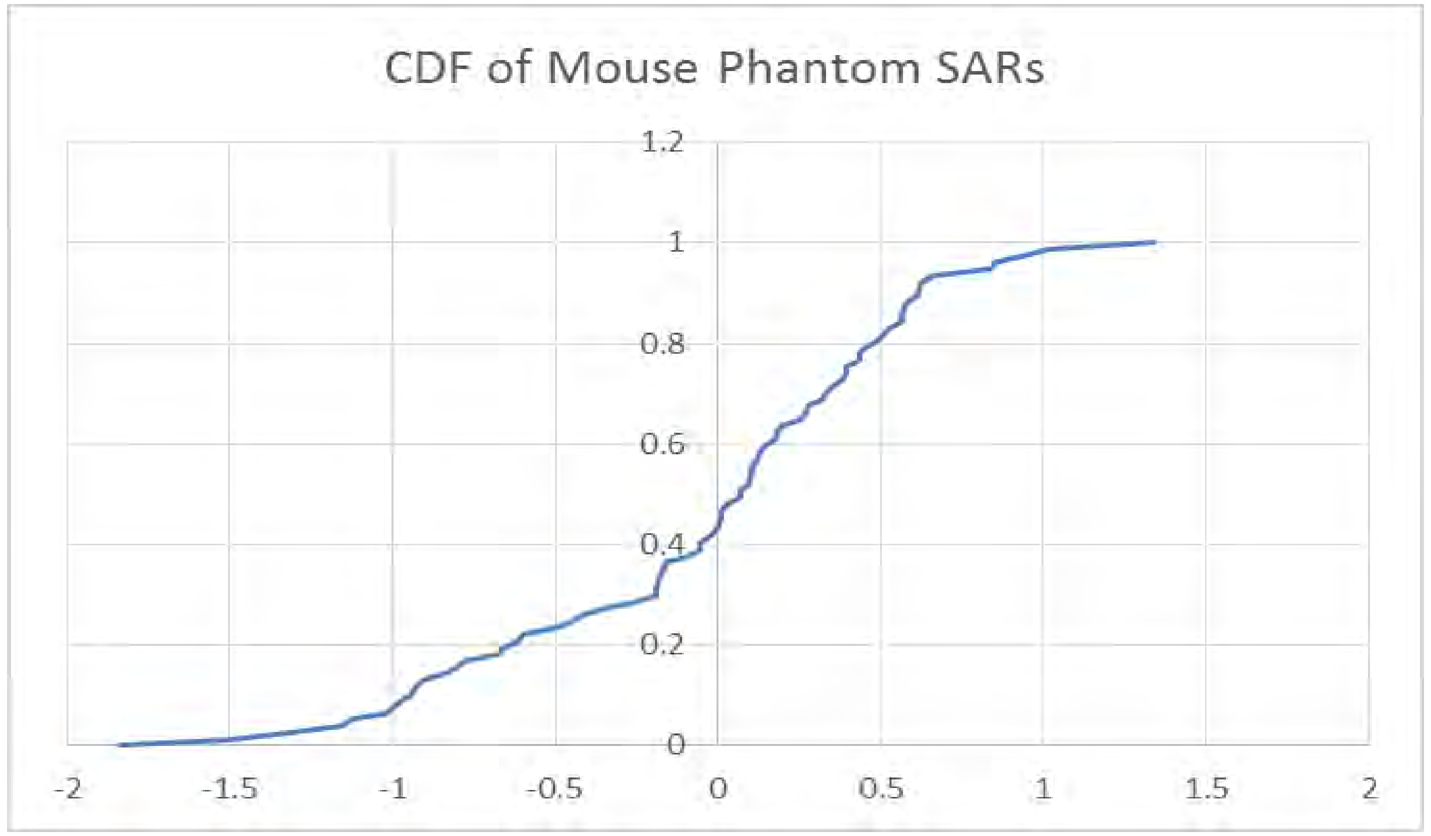
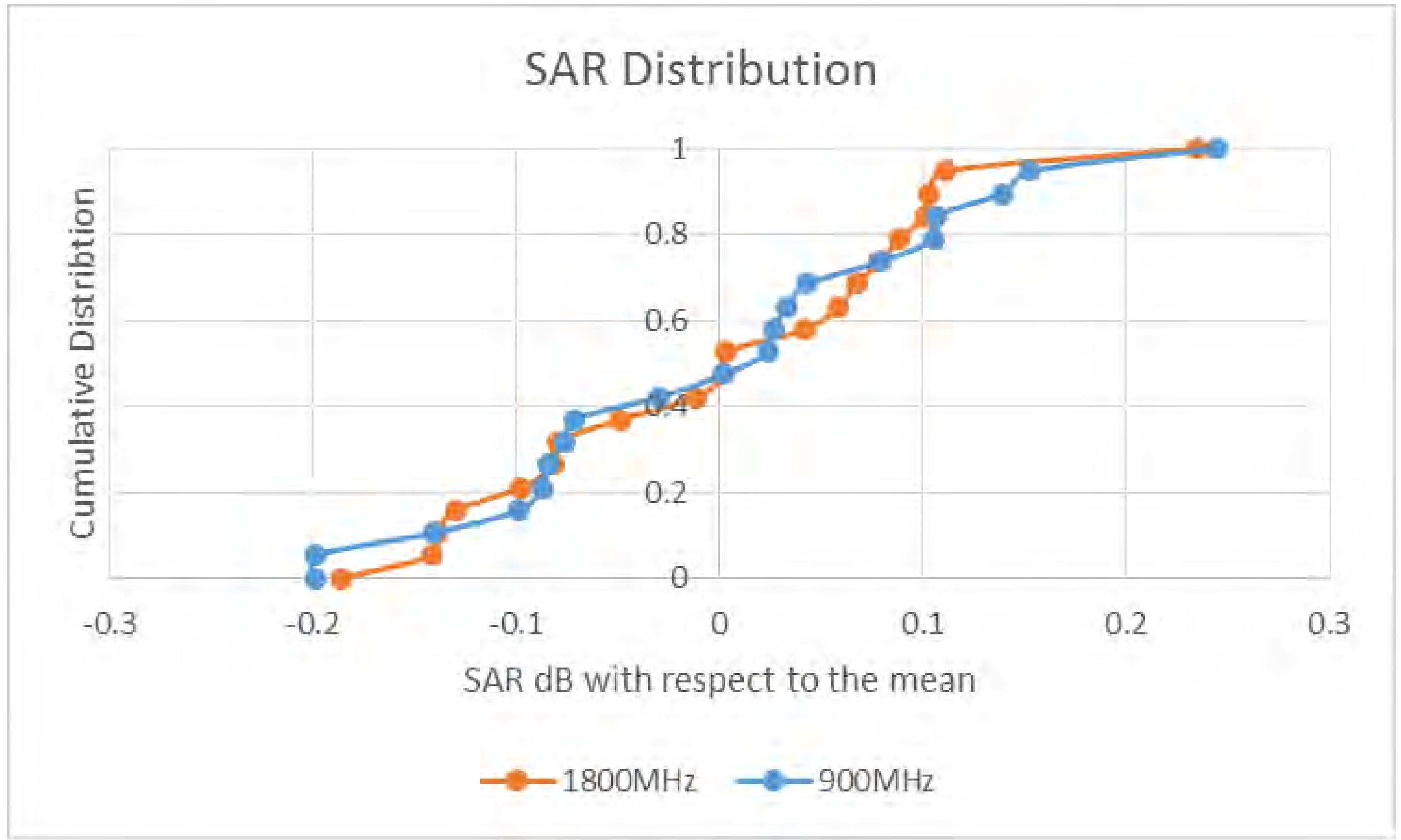


difference between numerical and experimental dosimetry 0.2 % or 0.01 dB



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**

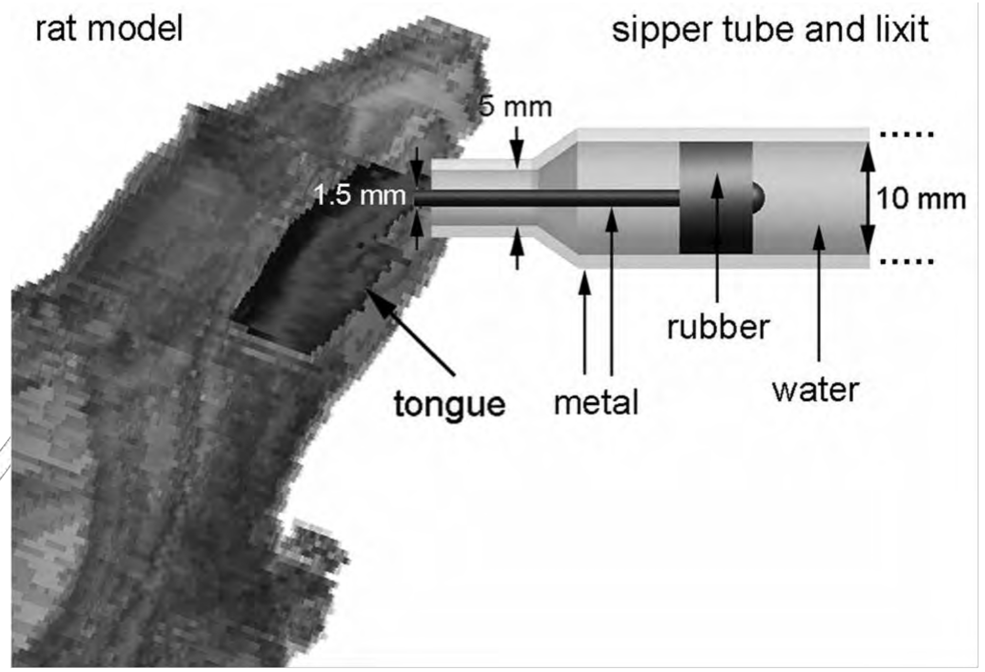
Automatic Watering System

the system to supply drinking water should

- ensure that no energy is absorbed by the water thereby causing dose-dependent elevation in drinking water temperature
- not cause increased SAR or RF burns to the animal, which could deter the animals from drinking

the designed water system can be used in a reverberation chamber environment, because it avoids or minimizes

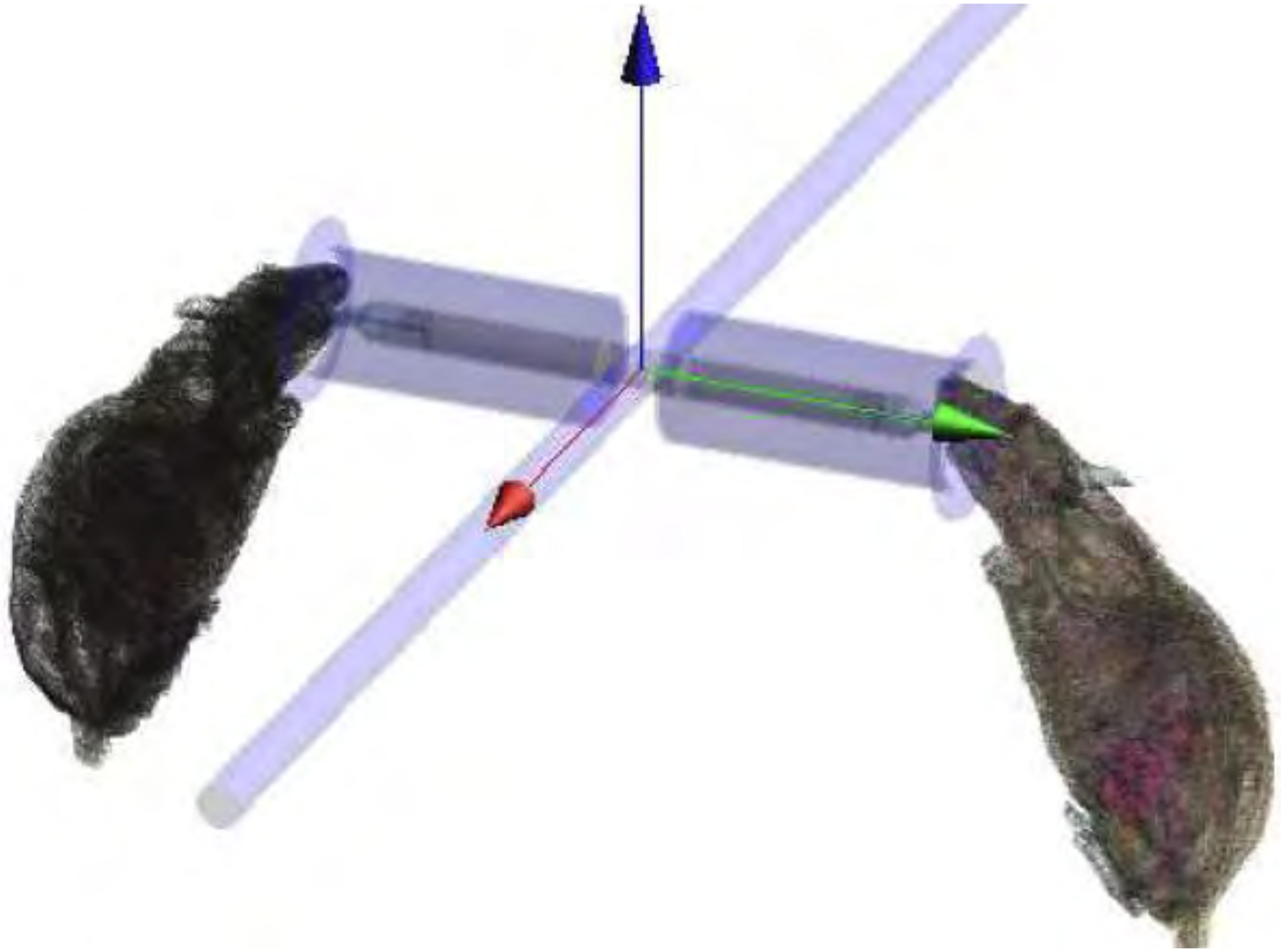
- high local SAR peaks in the animal while drinking
- variations in whole-body average SAR with respect to the animal not drinking
- significant distortions in the fields



Watering System Models

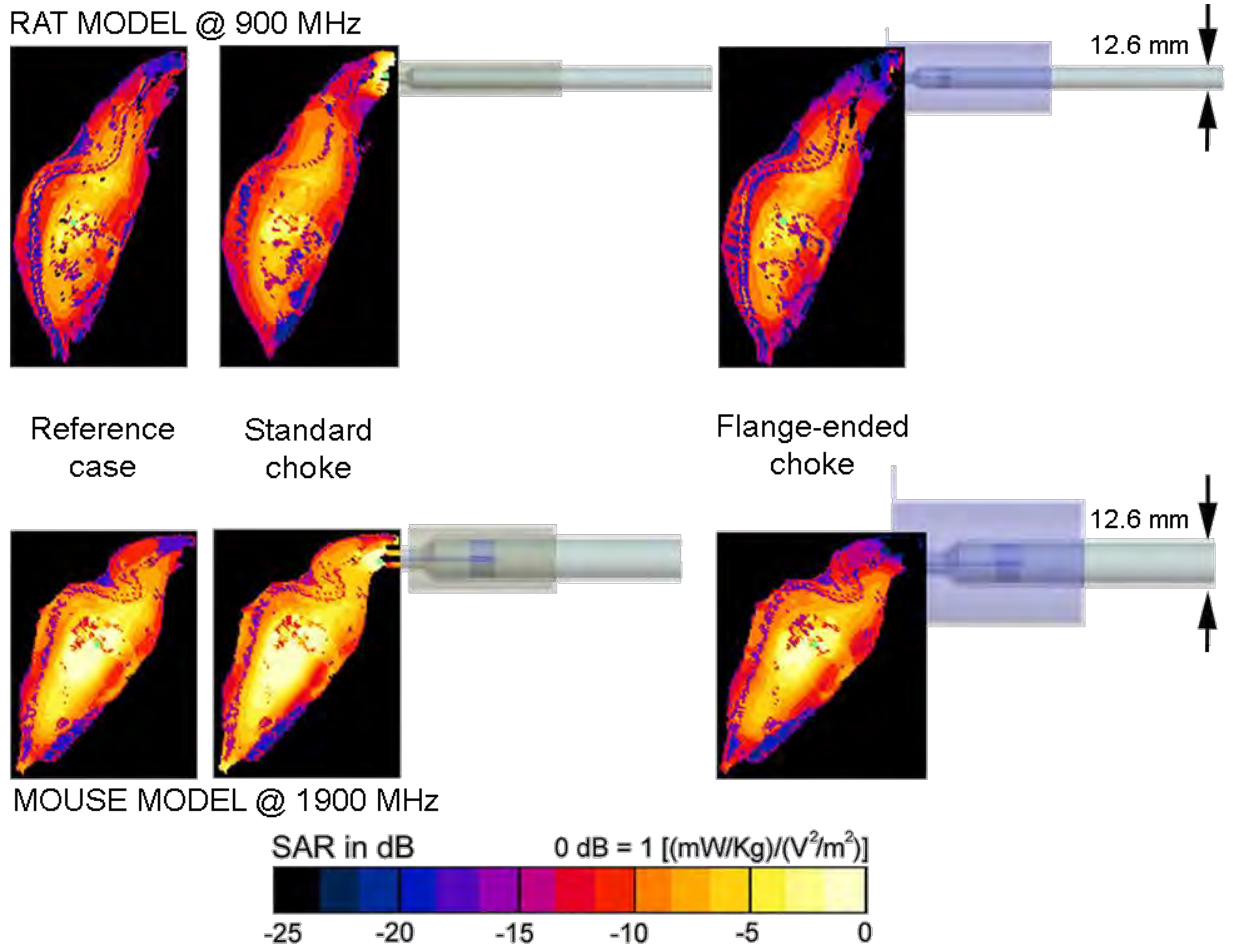
Mice

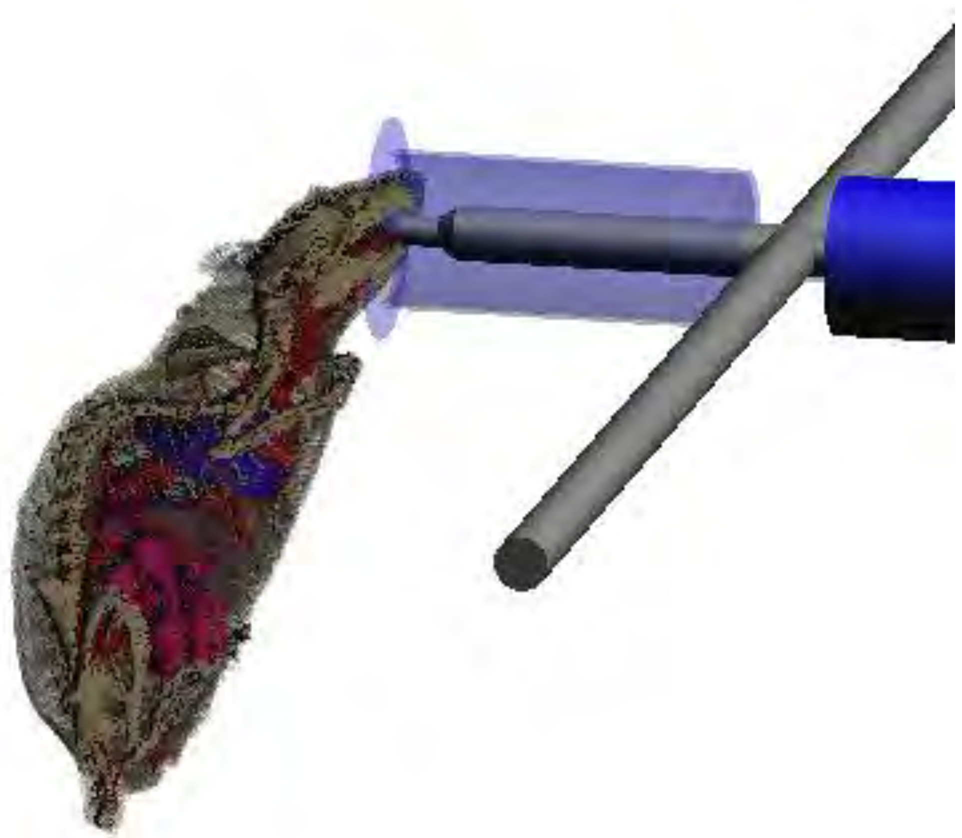
Rats



Numerical Dosimetry Results

- the provision of drinking water in high EM field environments is another significant challenge that has been solved.
- a solution using flanged quarter wave chokes on an automatic watering system ensures no overexposure during drinking.





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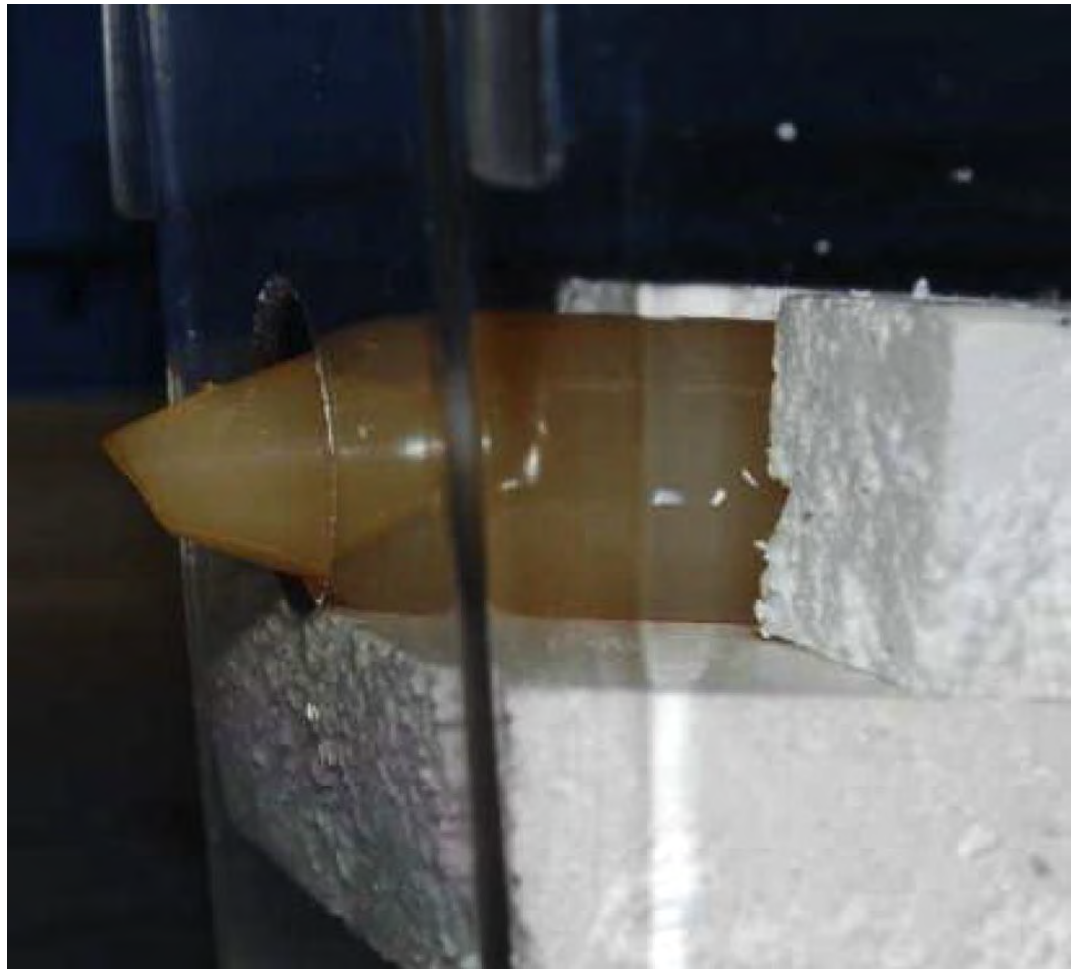
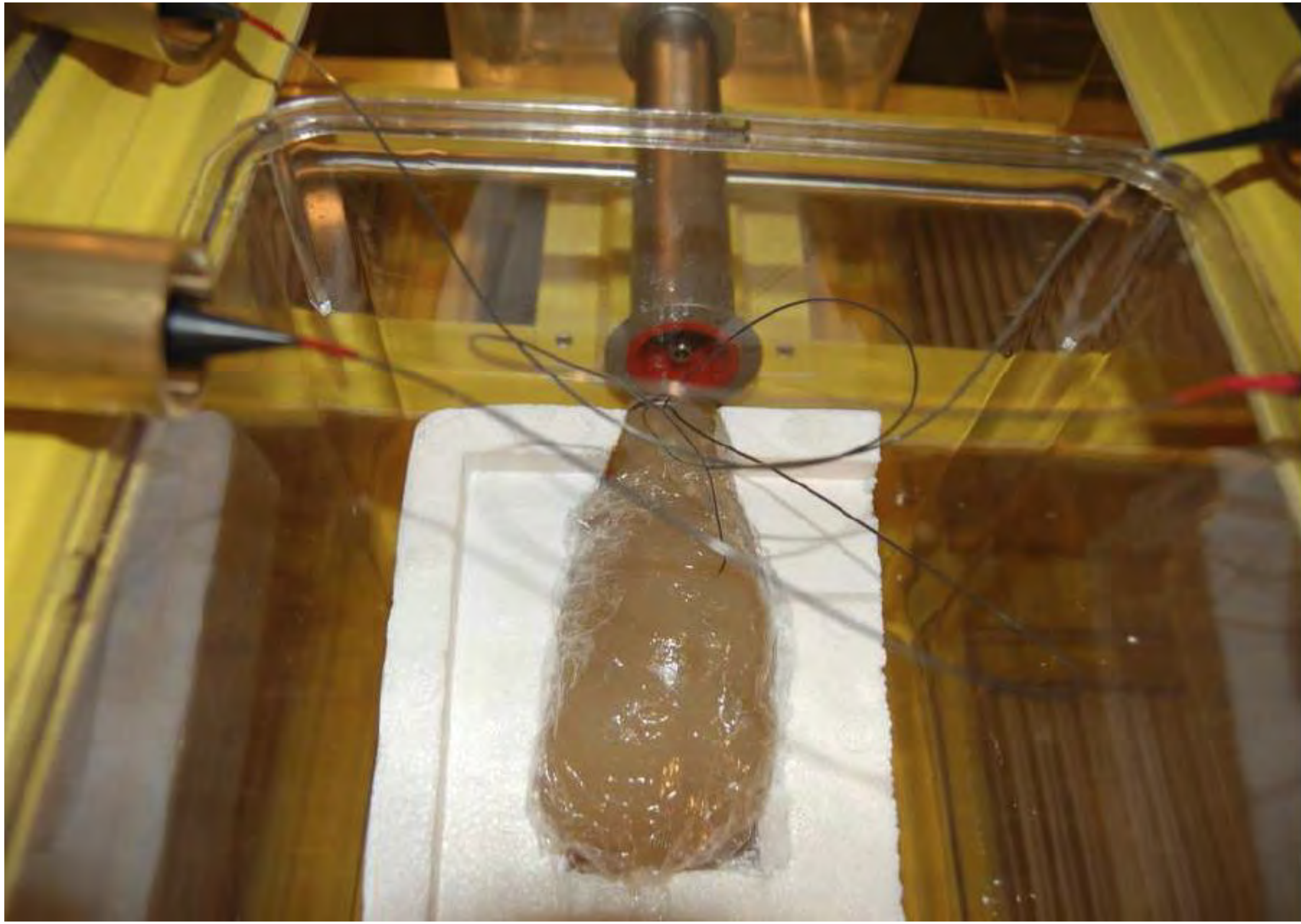
Gel Phantoms

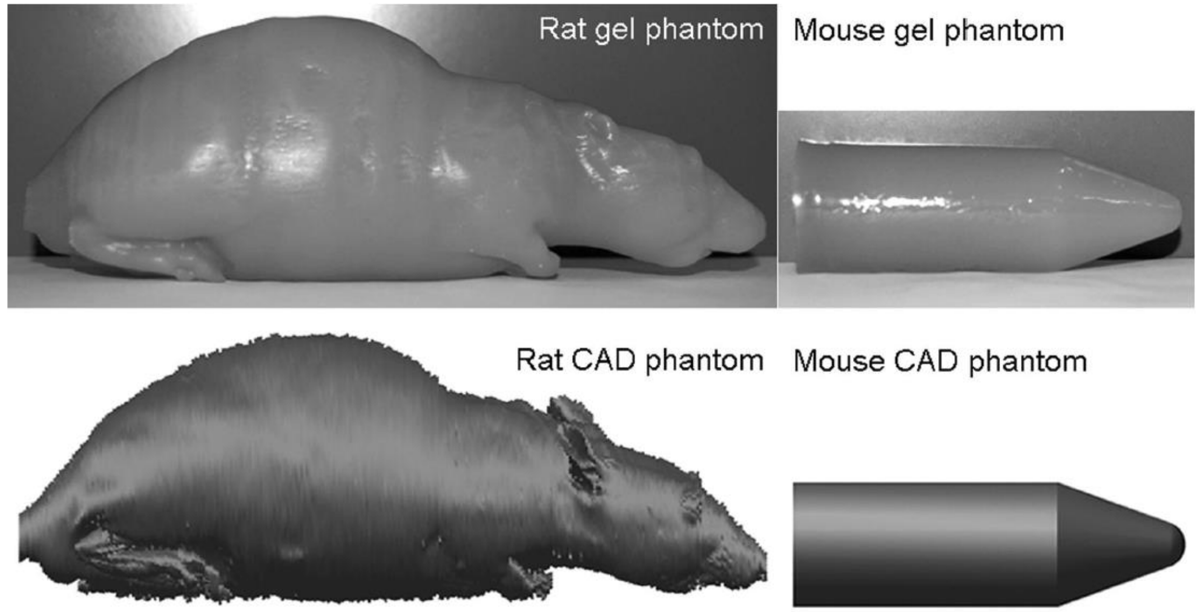
- rat and mouse gel phantoms
- rat phantom shown with the temperature sensors embedded





Experimental Verification

- a relative SAR measurement using fibre based temperature probes inside wideband tissue simulating gel based phantoms



Distance from Lixit	Mouth and Nose			Body	Rate of T-Rise
100mm	9.6	9.3	5.8	17.0	mK/s
10mm	10.7	11.0	8.1	17.2	mK/s
Touching	8.0	7.3	4.3	17.9	mK/s

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Variation Analysis (within the Exposure Groups and Individual Animals)

- posture
- weight variation
- scaling of anatomical models

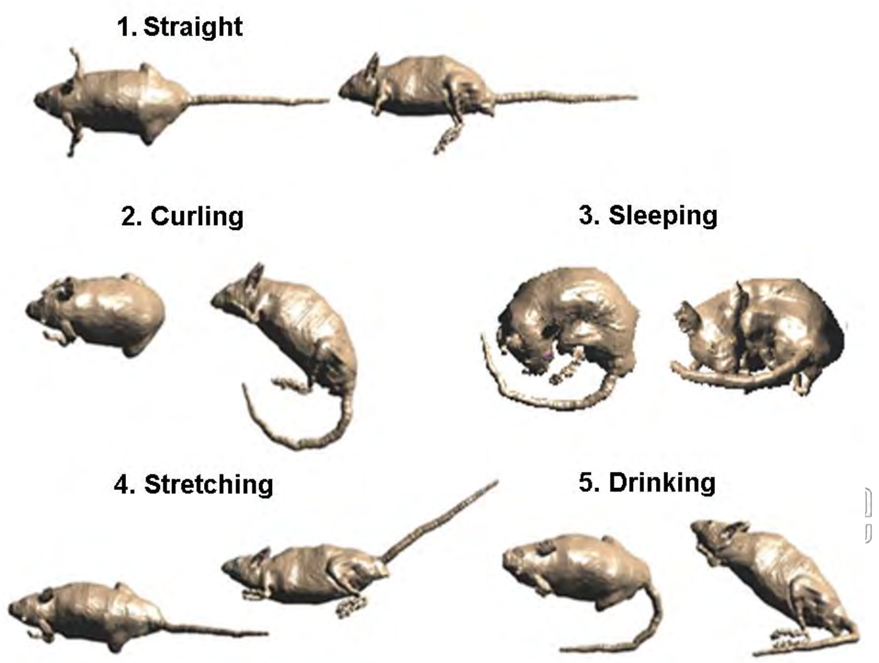
Posture

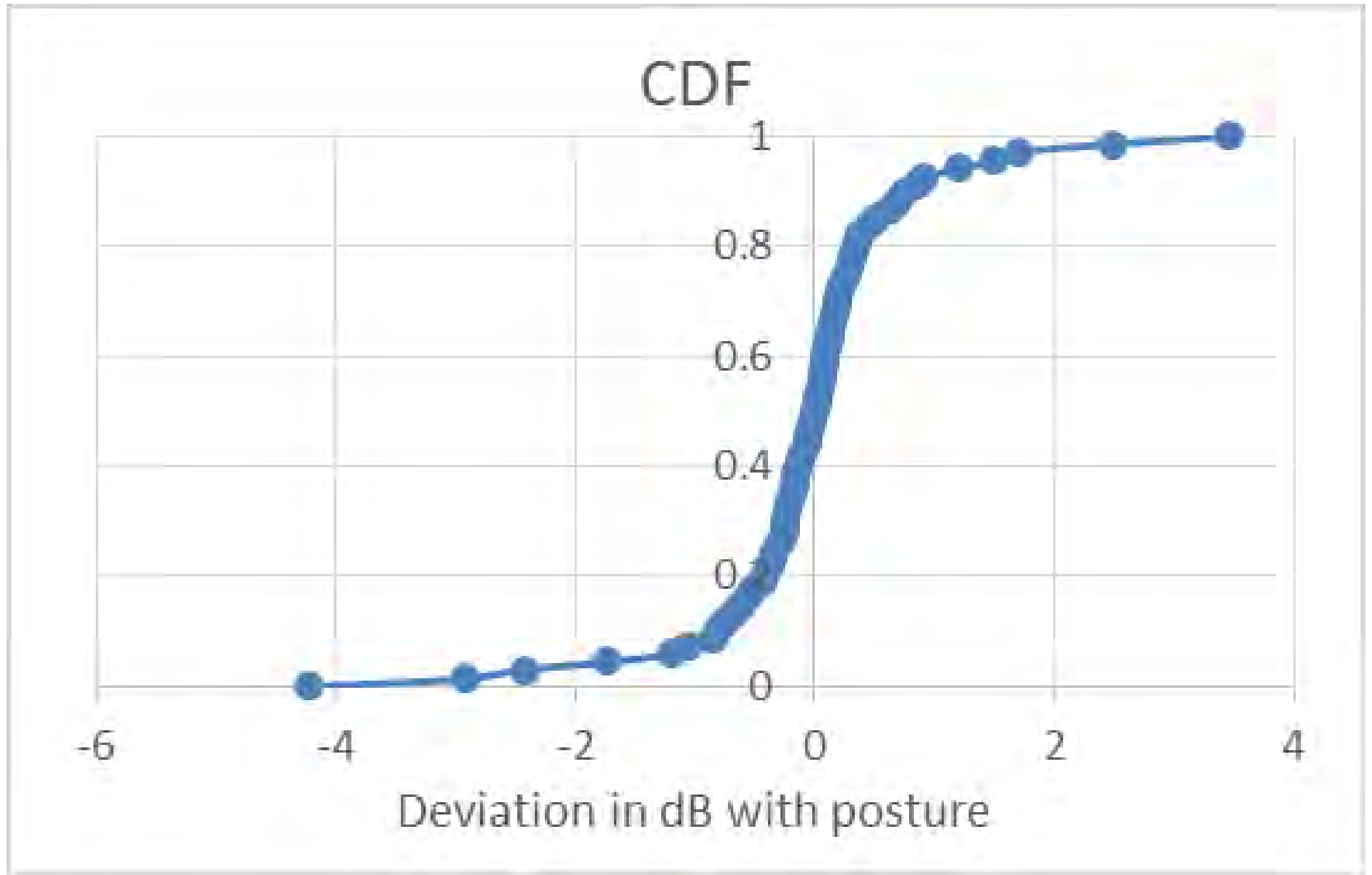
isotropic field ensures minimum variation in whole body SAR with posture

- for mice at 1900 MHz, posture contributes 0.2 dB to the uncertainty

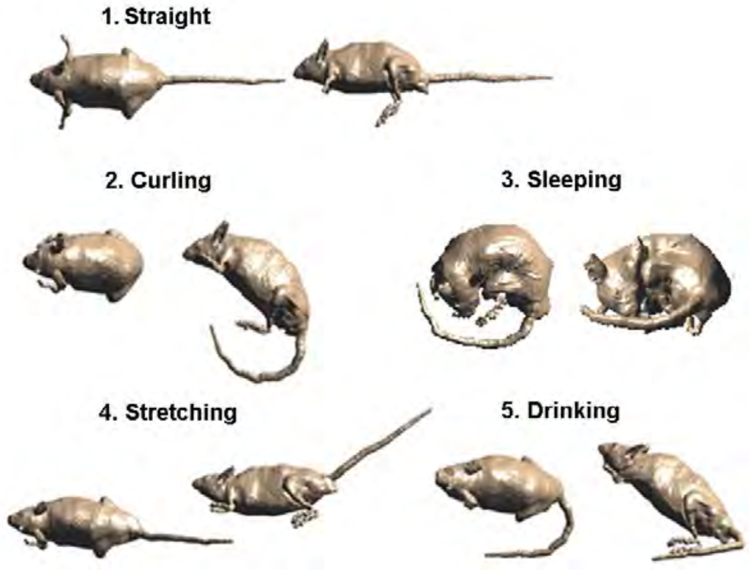
variation in organ specific SAR

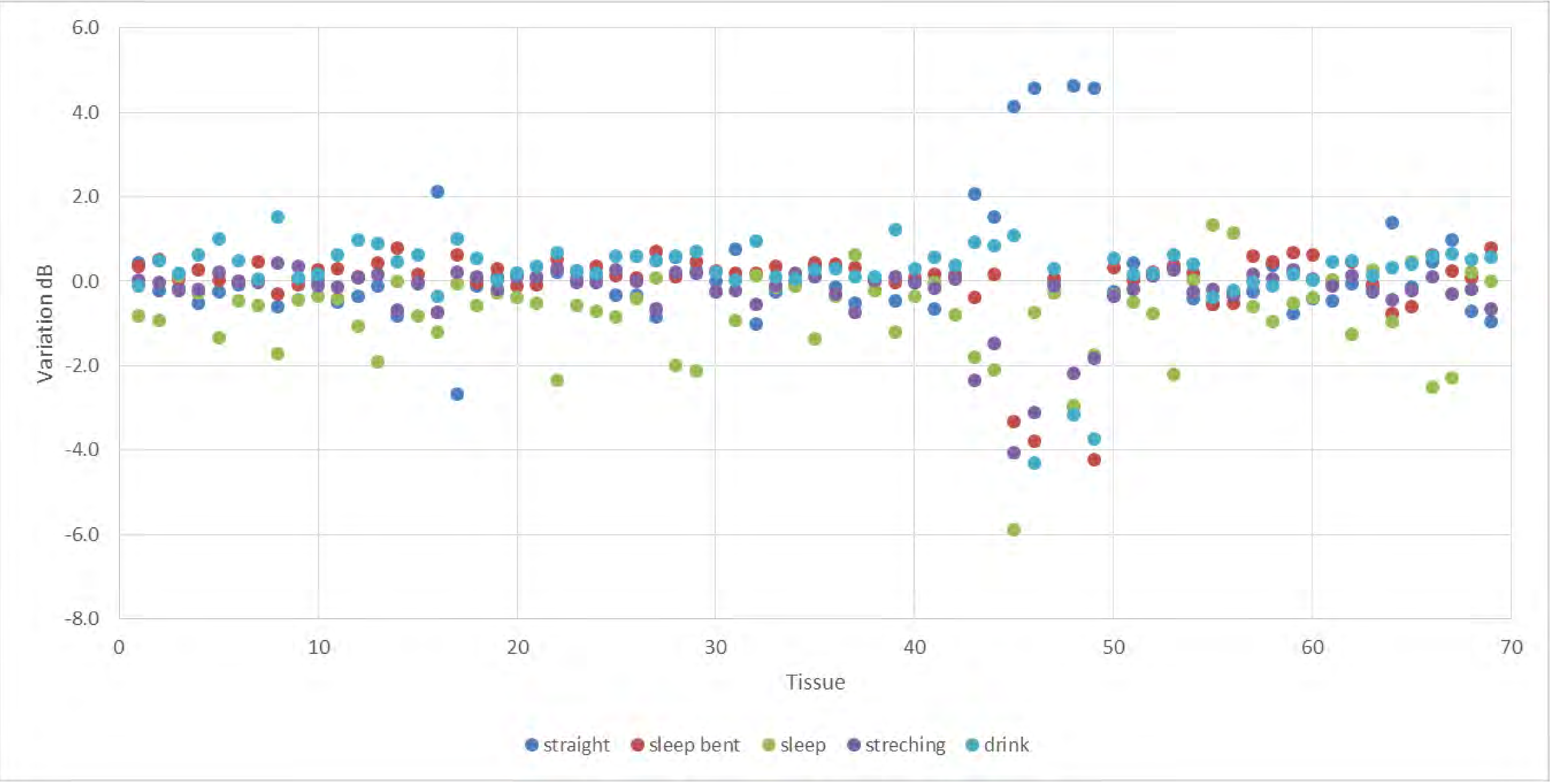
- log normal variation of organs and tissues about the straight posture, 1.2 dB SD





Posture





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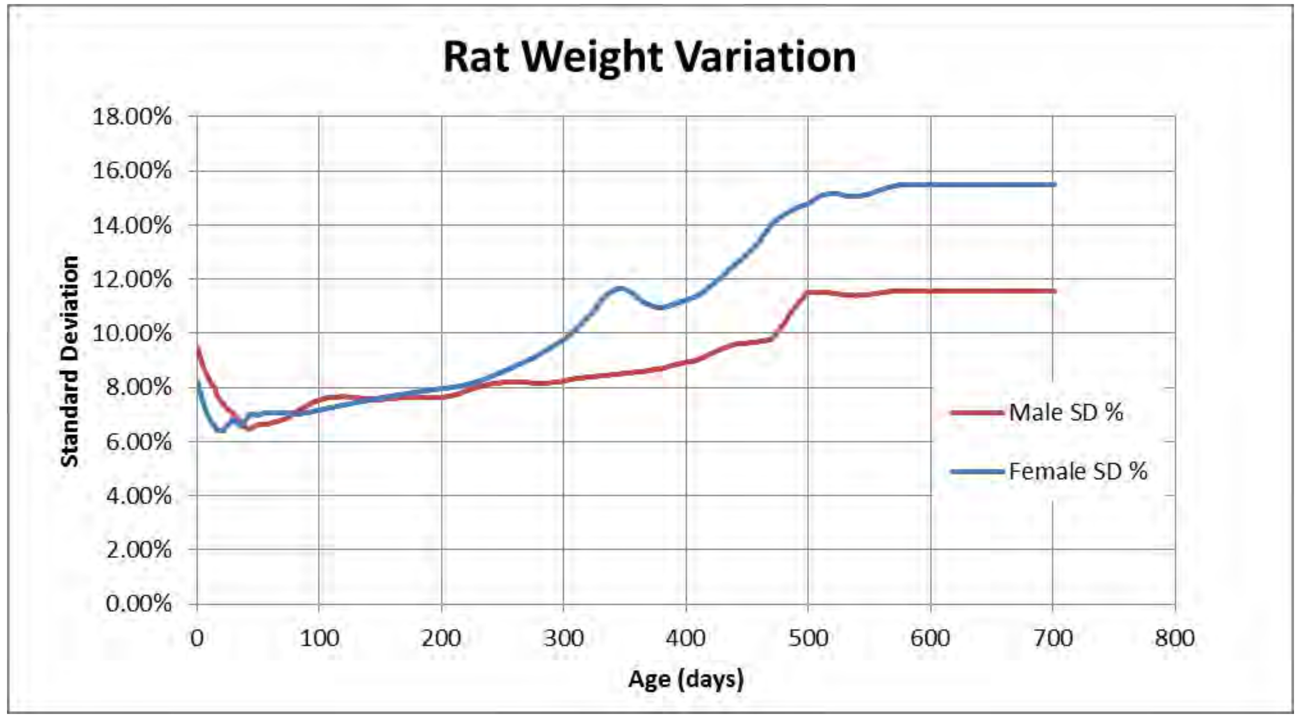
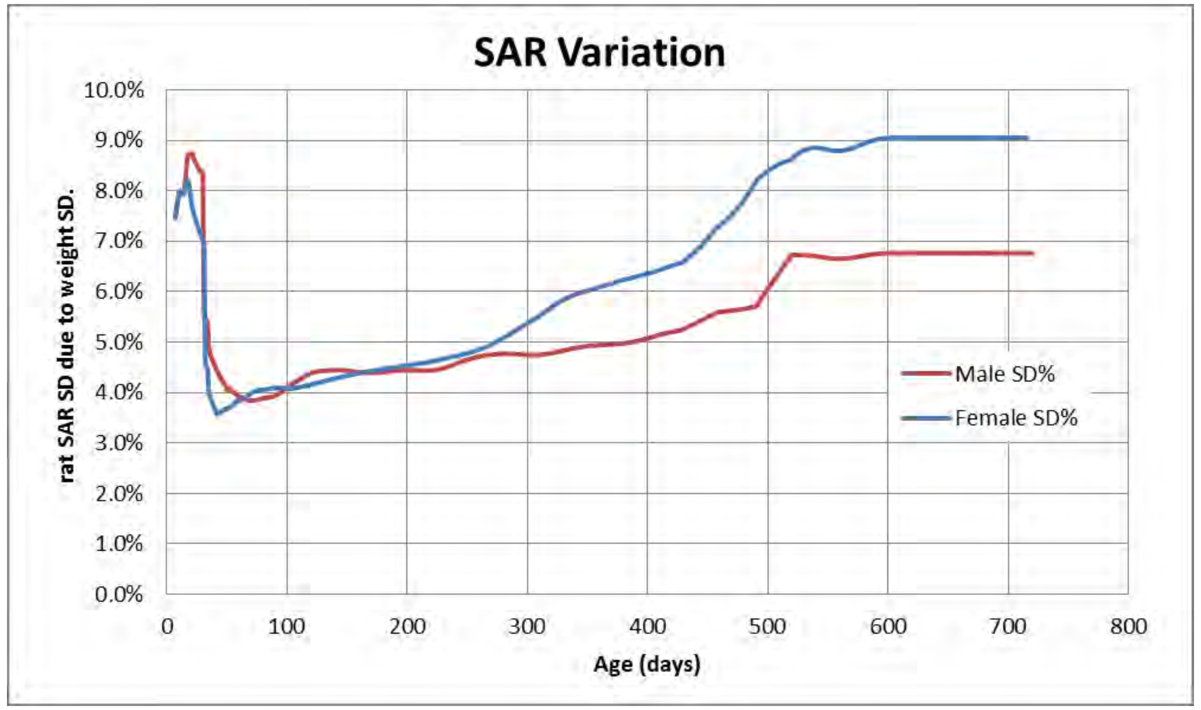
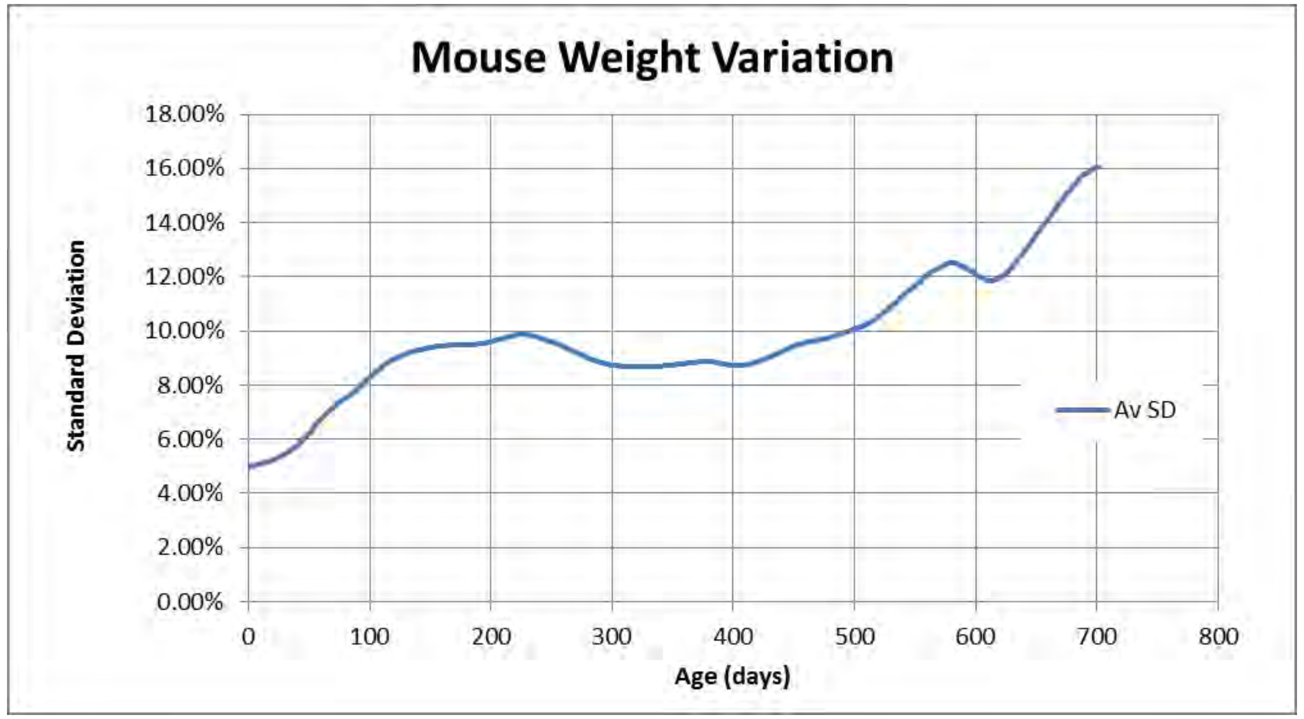
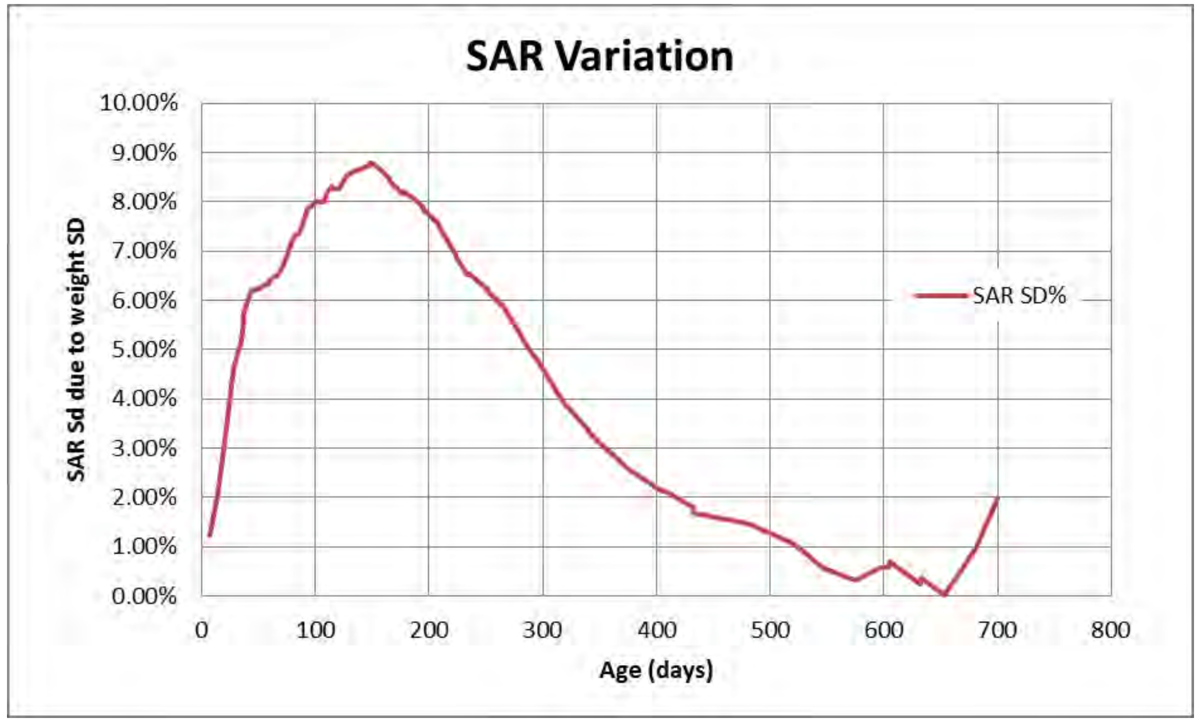
Animal Weights

- weight variation gives rise to SAR variation







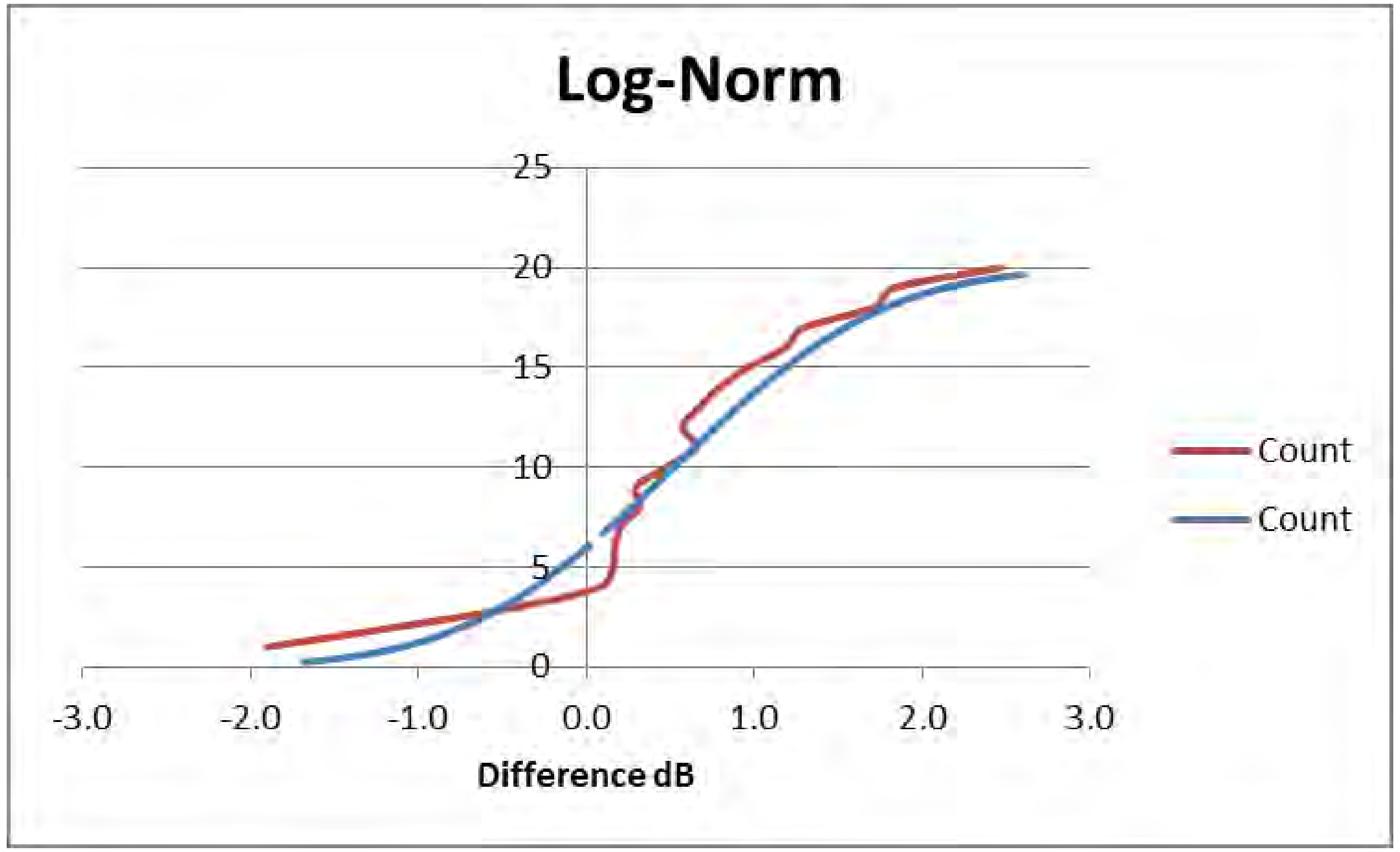


Scaling of Anatomical Models

- models are scaled up or down in weight to close the gaps between models
- this introduces some uncertainty

Uncertainty is assessed by

- scaling models to the same weight as other anatomically correct models
- scaling two models to a weight halfway between both models
- assessing WB SAR
- assessing organ specific SAR



Organ specific SAR differences for a large rat (597g) scaled to 232g

WB SAR difference 0.3 dB

Uncertainty Evaluation (Average Lifetime)

Contribution	Distribution	Standard Uncertainty %		
		Male rat	Female rat	Mouse
E and H-field measurement	normal	16.7	16.7	16.7
Field Control	normal	4.7	4.7	4.7
12 plane Waves vs. Random Planewaves	rect.	2.4	2.4	1.8
Numerical simulation	rect.	3.9	3.9	0.8
SAR sensitivity expression fit	normal	7.2	7.2	3.0
Scaling	rect.	3.9	3.9	1.9
Overall uncertainty		**19.7**	**19.7**	**17.8**
Expanded uncertainty k=2		**39.4**	**39.4**	**35.6**

Uncertainty Evaluation (Average Lifetime)

Contribution	Distribution	Standard Uncertainty %		
		rat	Female rat	Mouse
E and H-field measurement	[illegible]	[illegible]	16.7	16.7
Field Control	[illegible]	[illegible]	4.7	4.7
12 plane Waves vs. Random Planewaves	rect.	2.4	2.4	1.8
Numerical simulation	rect.	3.9	3.9	0.8
SAR sensitivity expression fit	normal	7.2	7.2	3.0
Scaling	rect.	3.9	3.9	1.9
Overall uncertainty		**19.7**	**19.7**	**17.8**
Expanded uncertainty k=2		**39.4**	**39.4**	**35.6**

- mice max offset 9.4%
- rat max offset 8.9%

Uncertainty Evaluation (Average Lifetime)

Contribution	Distribution	Standard Uncertainty %		
		Male rat	Female rat	Mouse
E and H-field measurement		16.7	16.7	16.7
Field Control		4.7	4.7	4.7
12 plane Waves vs. Random		2.4	2.4	1.8
Numerical simulation	rect.	3.9	3.9	0.8
SAR sensitivity expression fit	normal	7.2	7.2	3.0
Scaling	rect.	3.9	3.9	1.9
Overall uncertainty		**19.7**	**19.7**	**17.8**
Expanded uncertainty k=2		**39.4**	**39.4**	**35.6**

- dielectric parameter
- discretization
- simulation convergence

Uncertainty Evaluation (Average Lifetime)

Contribution	Distribution	Standard Uncertainty %		
		Male rat	Female rat	Mouse
E and H-field measurement	normal	16.7	16.7	16.7
Field Control	normal	4.7	4.7	4.7
12 plane Waves vs. Random Planewaves	rect.	2.4	2.4	1.8
Numerical simulation	rect.	3.9	3.9	0.8
SAR sensitivity expression fit	normal	7.2	7.2	3.0
Scaling			3.9	1.9
Overall uncertainty			**19.7**	**17.8**
Expanded uncert			**39.4**	**35.6**

Rat:

$$\text{wbSAR (W/kg)/(V/m)}^2 = 1.45 \cdot 10^{-6} \cdot weight + 2 \cdot 10^{-5} \qquad \text{for } weight \leq 100\text{g}$$

$$\text{wbSAR (W/kg)/(V/m)}^2 = 2.45 \cdot 10^{-3} \cdot weight^{-0.58} \qquad \text{for } weight \geq 100\text{g}$$

Mouse:

$$\text{wbSAR (W/kg)/(V/m)}^2 = 9.2 \cdot 10^{-8} \cdot weight^2 - 10^{-5} \cdot weight + 4.15 \cdot 10^{-4},$$

Uncertainty Evaluation (Average Lifetime)

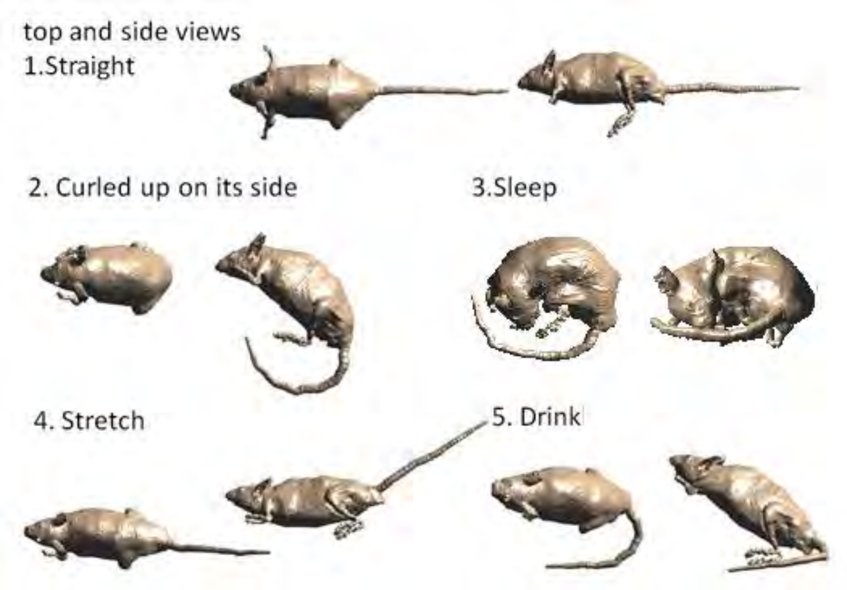
Contribution	Distribution	Standard Uncertainty %		
		Male rat	Female rat	Mouse
E and H-field measurement	normal	16.7	16.7	16.7
Field Control	normal	4.7	4.7	4.7
12 plane Waves vs. Random Planewaves	rect.	2.4	2.4	1.8
Numerical simulation	rect.	3.9	3.9	0.8
SAR sensitivity expression fit	normal	7.2	7.2	3.0
Scaling	rect.	3.9	3.9	1.9
Overall uncertainty		**19.7**	**19.7**	**17.8**
Expanded uncertainty k=2		**39.4**	**39.4**	**35.6**

Variation Evaluation (Average Lifetime)

Contribution	Distribution	Standard Variation %		
		Male rat	Female rat	Mouse
Postures	normal	5.4	5.4	5.0
Growth Rate	normal	0.50	0.40	0.40
Weight Std. Dev.	normal	5.40	6.40	3.80
Overall Std. Variation		**7.7**	**8.4**	**6.3**
Expanded Variation k = 2		**15.4**	**16.8**	**12.5**

Variation Evaluation (Average Lifetime)

Contribution	Distribution	Standard Variation %		
		Male rat	Female rat	Mouse
Postures	normal	5.4	5.4	5.0
Growth Rate				0.40
Weight Std. Dev.				3.80
Overall Std. Variation				**6.3**
Expanded Variation k = 2				**12.5**



- 5 postures based on the daily movement
- psSAR show larger std. dev. than wbSAR → rats:~30%; mice: ~10%
- organ specific SAR deviate from wbSAR with a log-normal distribution → rats: 0.2 dB std. dev.; mice: 0.3 dB std. dev.

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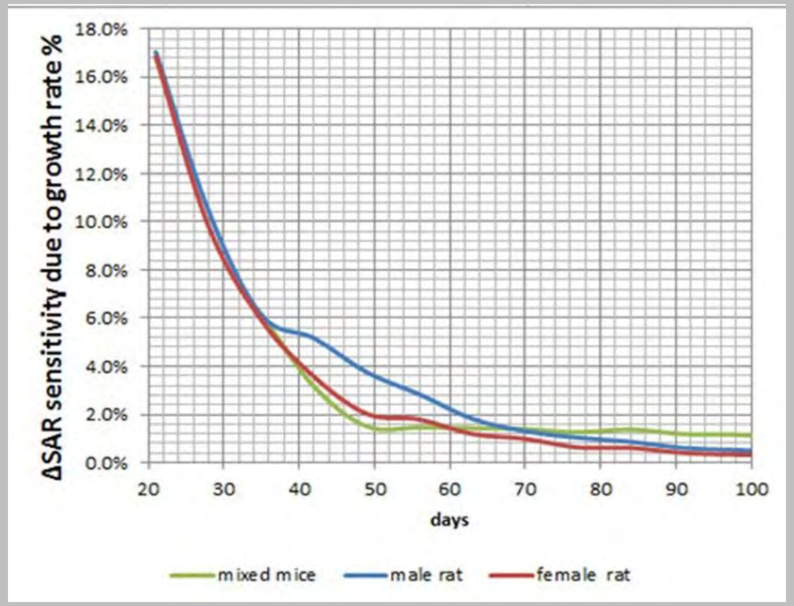
Variation Evaluation (Average Lifetime)

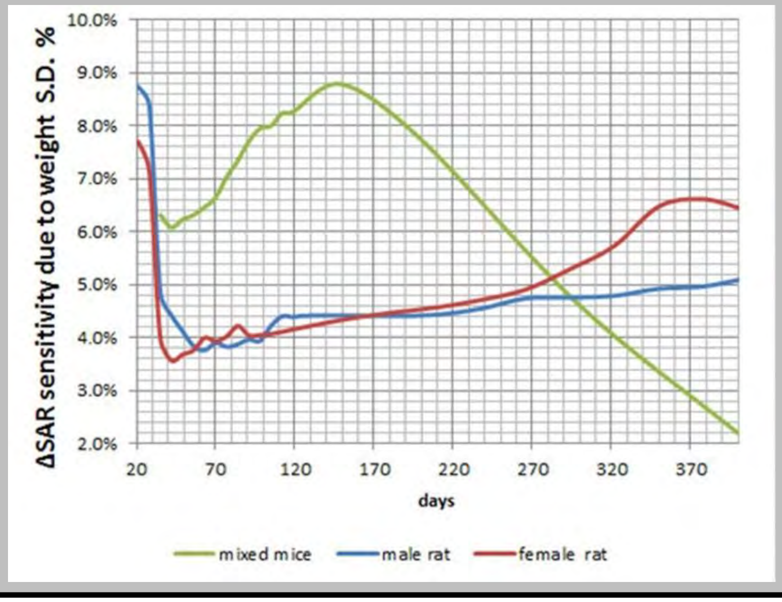
Contribution	Distribution	Standard Variation %		
		Male rat	Female rat	Mouse
Postures	normal	5.4	5.4	5.0
Growth Rate	normal	0.50	0.40	0.40
Weight Std. Dev.				3.80
Overall Std. Variation				**6.3**
Expanded Variation k = 2				**12.5**



- measurement for rats as twice per week, and mice as once per week during the fastest growth rate period
- the maximum variation (exposure period from 3-week-old rats and 5-week-old mice)→ rats:17% ; mice: 6.2%

Variation Evaluation (Average Lifetime)

Contribution	Distribution	Standard Variation %		
		Male rat	Female rat	Mouse
Postures	normal	5.4	5.4	5.0
Growth Rate	normal	0.50	0.40	0.40
Weight Std. Dev.	normal	5.40	6.40	3.80
Overall Std. Variation			**8.4**	**6.3**
Expanded Variation k =			**16.8**	**12.5**



- SARs deviate from the target level due to weights deviation from the mean
- the maximum variation → male/female rats: 8.2%/ 8.7%; mice: 8.8%

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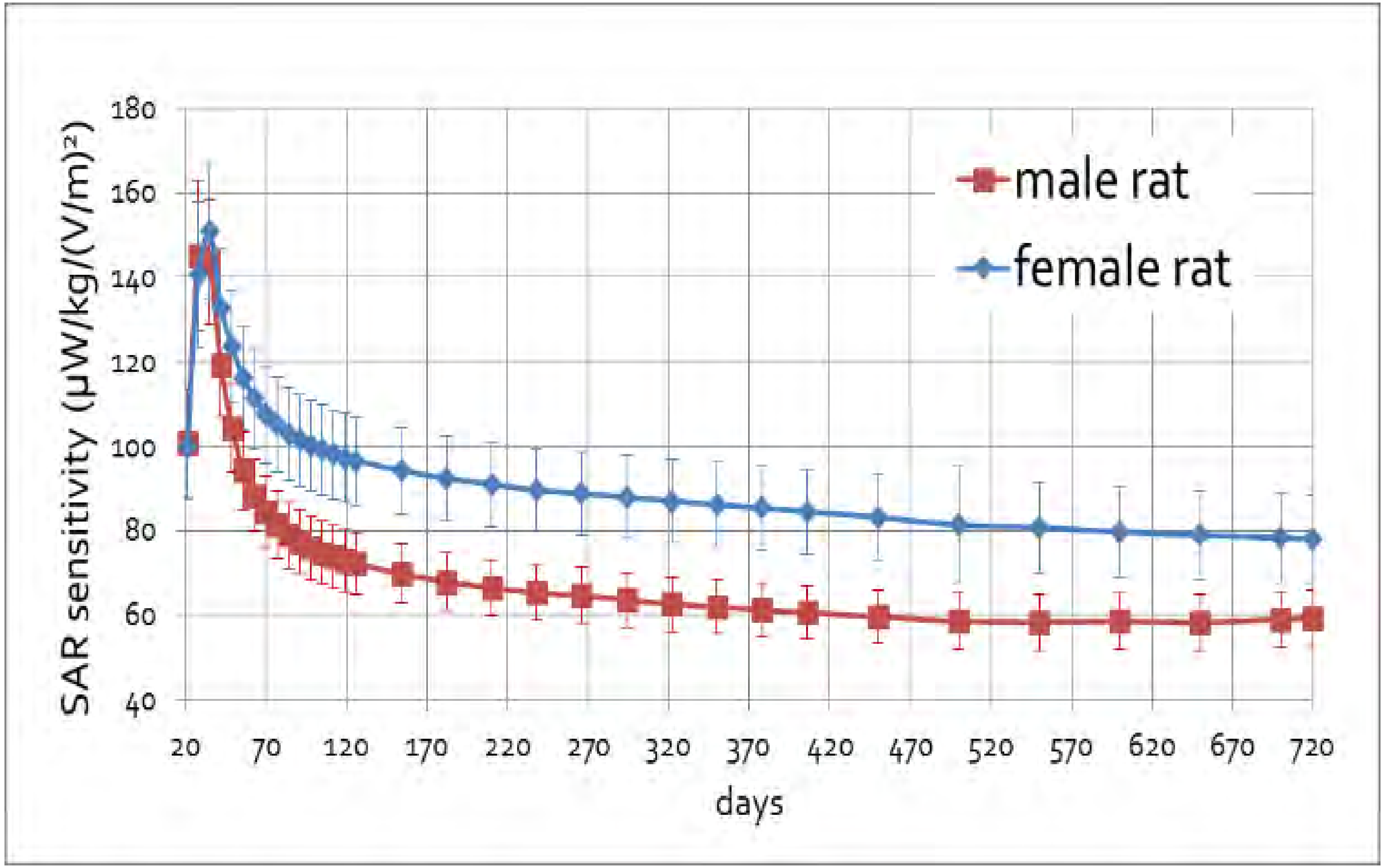
Variation Evaluation (Average Lifetime)

Contribution	Distribution	Standard Variation %		
		Male rat	Female rat	Mouse
Postures	normal	5.4	5.4	5.0
Growth Rate	normal	0.50	0.40	0.40
Weight Std. Dev.	normal	5.40	6.40	3.80
Overall Std. Variation		**7.7**	**8.4**	**6.3**
Expanded Variation k = 2		**15.4**	**16.8**	**12.5**

SAR Sensitivity Uncertainty as a Function of Age for Rats



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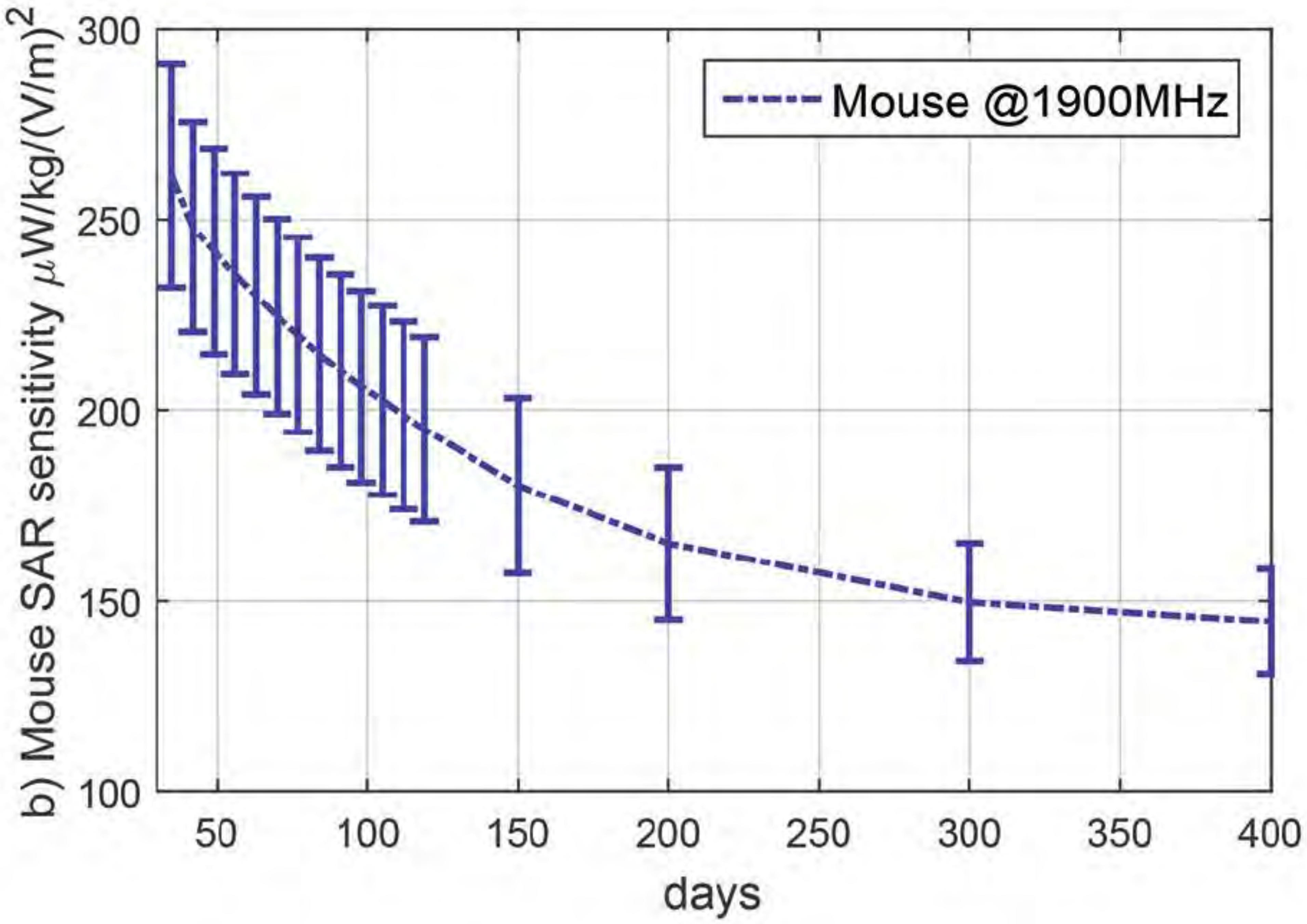
SAR Sensitivity Uncertainty as a Function of Age for Mice



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Variability and Uncertainty Over Chronic Study (Averaged over Entire Study)

SAR variation within study groups

Contribution	Distr.	Standard Variation %		
		Male Rat	Female Rat	Mouse
Postures	normal	5.4	5.4	5.0
Growth Rate	normal	0.50	0.40	0.40
Weight Std. Dev.	normal		6.40	3.80
Overall Std. Variation		5.40	**8.4**	**6.3**
Expanded Var. k = 2		**15.4**	**16.8**	**12.5**

average lifetime SAR uncertainty

Contribution	Distr.	Standard Uncertainty %		
		Male Rat	Female Rat	Mouse
E and H-field measurement	normal	16.7	16.7	16.7
Field Control	normal	4.7	4.7	4.7
12 plane Waves vs. Random Planewaves	rect.	2.4	2.4	1.8
Numerical simulation	rect.	3.9	3.9	0.8
SAR Sensitivity Expression Fit	normal	7.2	7.2	3.0
Scaling	rect.	3.9	3.9	1.9
Overall Uncertainty		**19.7**	**19.7**	**17.8**
Expanded Unc. k=2		**39.4**	**39.4**	**35.6**

Overall Variability (Maximum Instantaneous Variation Analysis for Whole Body SAR)

Variation Sources	Distr.	Instantaneous Variation		
		male rats	female rats	mixed mice
		900MHz	900MHz	1900MHz
Experimental SAR Uniformity	R	7.4%	8.4%	7.4%
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%**	**13.0%**
Expanded Variation k=2		**25.0%**	**25.0%**	**26.0%**

Maximum SAR Uncertainty Over Whole Lifetime

Contributions	Distr.	Standard Uncertainty %			
		Rat@900MHz		Mouse@1900MHz	
		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%	12.0%	20.0%
Anatomical Model Dosimetry	R	3.9%	3.9%	0.8%	0.8%
Rodent Growth Rate (max.)	R	17.0%	17.0%	6.2%	6.2%
Combined Standard Uncertainty k=1		**24%**	**24%**	**18%**	**24%**
Expanded Uncertainty k=2		**47%**	**48%**	**36%**	**49%**

Chronic Study Exposure Levels

- rat exposure groups
  - 6.0 W/kg
  - 3.0 W/kg
  - 1.5 W/kg
  - 0 W/kg
- 7 chambers for male rats
- 7 chambers for female rats

- mouse exposure groups
  - 10 W/kg
  - 5.0 W/kg
  - 2.5 W/kg
  - 0 W/kg
- 7 chambers, male and female exposed together

NIEHS
Mouse Full Time Period Exposure Evaluation.
Start: Jun 18, 2012
End: Jul 09, 2014

Chamber		Weight Range [g]	Target [W/kg]	Mean [W/kg]	Stdev [W/kg]
Ch01	Mouse IS95 High	18.9 - 56.0	10.00	9.97	0.04
Ch11	Mouse GSM High	18.9 - 56.0	10.00	9.62	0.11
Ch02	Mouse IS95 Med	18.9 - 56.0	5.00	4.99	0.03
Ch12	Mouse GSM Med	18.9 - 56.0	5.00	4.97	0.07
Ch03	Mouse IS95 Low	18.9 - 56.0	2.50	2.49	0.05
Ch14	Mouse GSM Low	18.8 - 56.0	2.50	2.51	0.04
Ch13	Mouse Sham	18.8 - 56.0	0.00	0.00	0.00

NIEHS
Male Rat Full Time Period Exposure Evaluation.
Start: 2012
End: 2014

Chamber		Weight Range [g]	Target [W/kg]	Mean [W/kg]	Stdev [W/kg]
Ch06	IS95 High	59.2 – 646.7	6.00	5.96	0.04
Ch07	GSM High	60.9 – 670.7	6.00	5.93	0.08
Ch08	IS95 Med	63.0 – 691.1	3.00	2.98	0.04
Ch05	GSM Med	62.0 – 679.5	3.00	2.97	0.07
Ch10	IS95 Low	62.1 – 678.5	1.50	1.49	0.04
Ch09	GSM Low	63.9 – 691.2	1.50	1.49	0.06
Ch04	Sham	-	0.00	0.00	0.00

NIEHS
Female Rat Full Time Period Exposure Evaluation.
Start: 2012
End: 2014

Chamber		Weight Range [g]	Target [W/kg]	Mean [W/kg]	Stdev [W/kg]
Ch07	IS95 High	55.9 – 457.3	6.00	5.97	0.04
Ch17	GSM High	58.0 – 475.1	6.00	5.97	0.07
Ch18	IS95 Med	59.6 – 473.2	3.00	2.98	0.04
Ch16	GSM Med	58.7 – 471.6	3.00	2.98	0.06
Ch21	IS95 Low	59.3 – 456.9	1.50	1.49	0.04
Ch20	GSM Low	59.4 – 476.1	1.50	1.49	0.05
Ch15	Sham	-	0.00	0.00	0.00

Summary

- numerical dosimetry was performed and validated experimentally
- a safe water system was designed and validated
- the uncertainties of the dosimetry and exposures were determined
- the variations introduced by posture and animal weight spread was analysed
- summary full time period exposure data was presented

Conclusions

- exposure groups were chosen with a factor two difference in SAR levels
- uncertainty in the incident exposure field 0.59 dB (~ ±14%)
- exposure variation due to weight variation within exposure groups and posture induced SAR variation ~0.35 dB (~ ± 8%)
- no overlap between exposure groups

- uncertainty in exact whole body and organ specific SAR is higher and depending on exposure group and available anatomical models and varies between 0.35 – 0.8 dB (± 8- 20%)