

# Exposition des personnes aux ondes électromagnétiques: le défi de la variabilité et l'apport des statistiques en dosimétrie numérique

J Wiart, E Conil, A Hadjem, A Gati, MF Wong,  
N Varsier, A Gahmni, O Auiaz, Th Kientega, A El Habachi

<http://whist.institut-telecom.fr/>



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# Summary

- Dosimetry basic
- Exposure assessment.
- Complexity management
- conclusion

# Wireless Ubiquous world facing schizophrenia

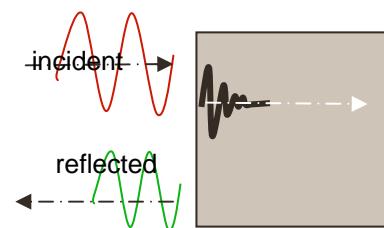
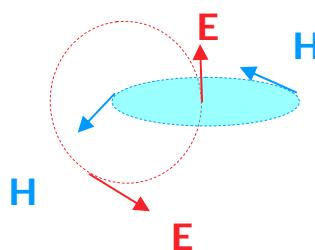
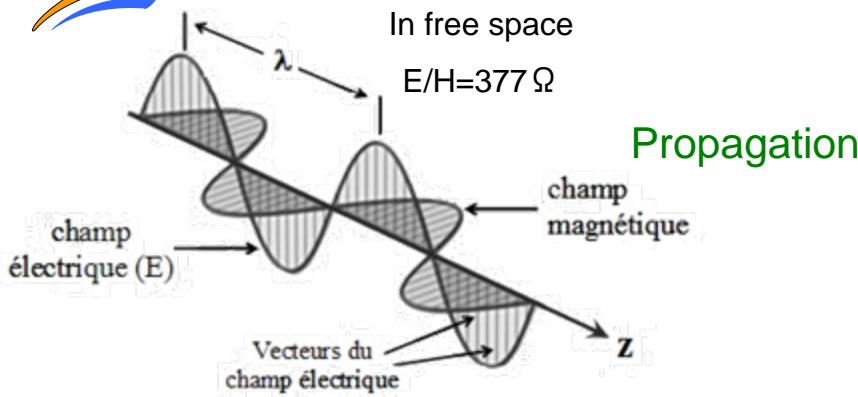


More than 5 billions users...  
More than 50 millions in France...

Limits have been established by Exposure  
assessment is a key question

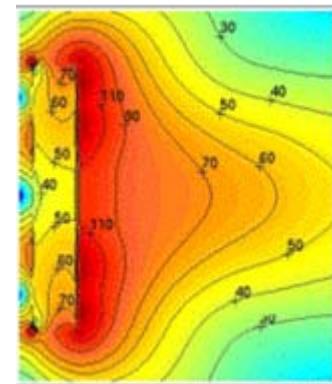
Eg Le Monde this week: « Ces ondes qui planent sur la tête de nos enfants »

# RF: Propagation, Absorption and Exposure

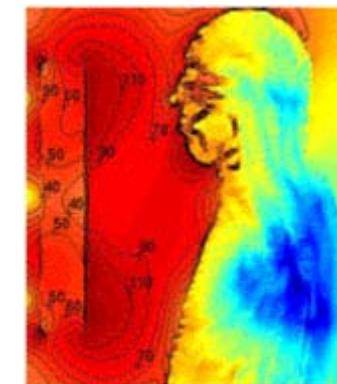


## Absorption

body in front of the antenna

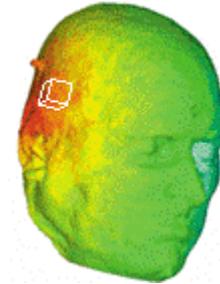


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## Exposure

$$SAR = \frac{\sigma E^2}{2\rho}$$



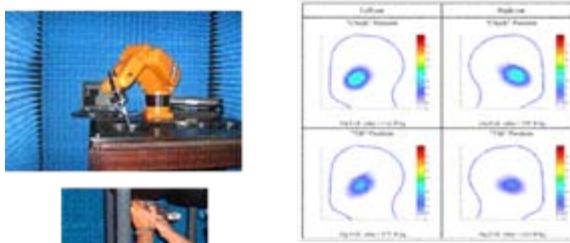
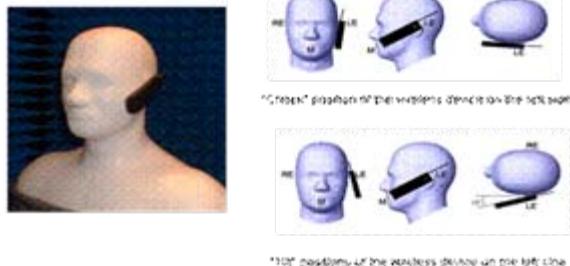
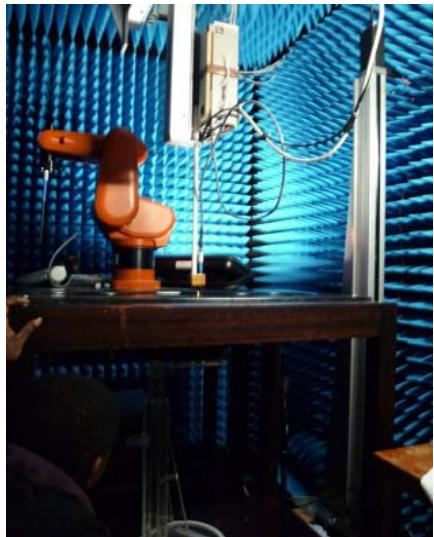
The SAR is often averaged over the whole body or over a small mass (eg 1 or 10 g)

$$SAR = \frac{d\left(\frac{dW}{dm}\right)}{dt}$$

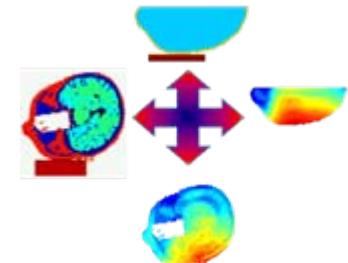


# Compliance: measurement and overestimation.

- Compliance tests have been defined using measurement and overestimation



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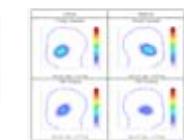
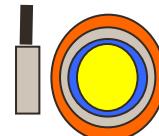


e.g phone test method:  
Shape and homogeneous liquid  
design to overestimate the SAR  
induced in a human  
heterogeneous head

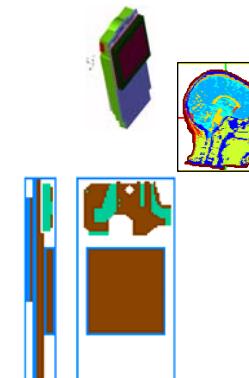
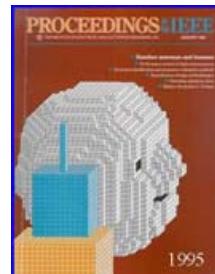


# Numerical dosimetry: more and more important

- Compliance tests are based on overestimations that are not adapted to complex configurations
- Simulation allows a comprehensive approach
- Twenty years ago....



- 15 years ago...
- Today...

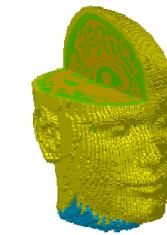
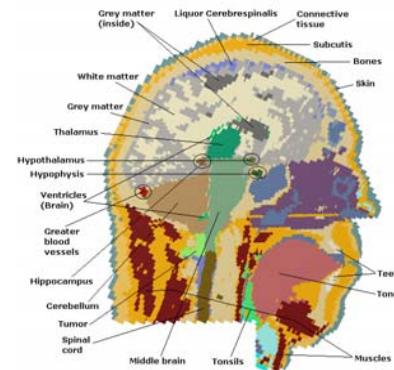
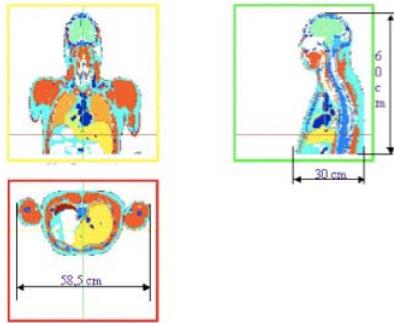


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# Human body : strong heterogeneity,

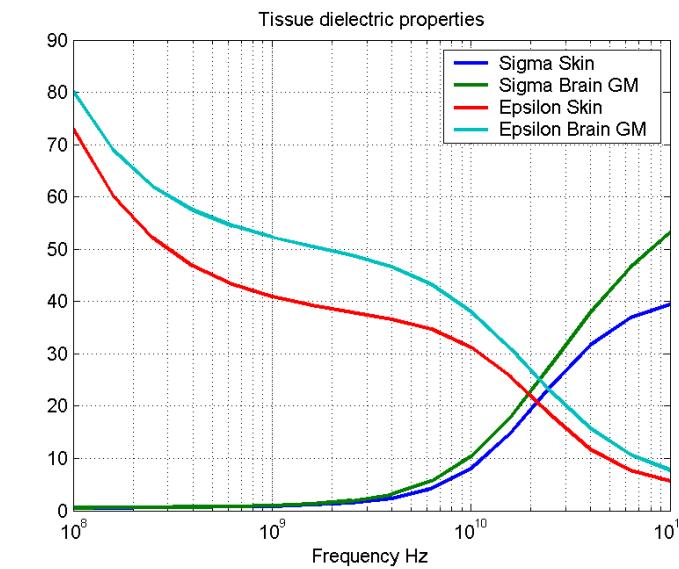


Dielectric properties are tissue and frequency dependant

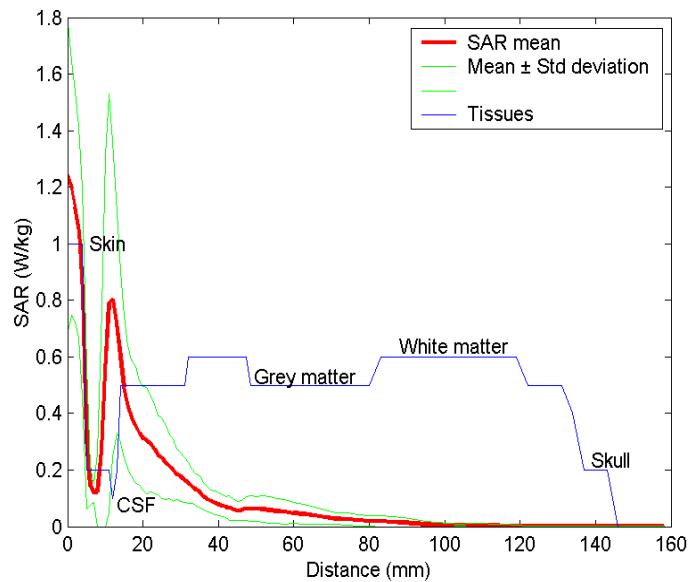
@ 900 MHz

Tissue	Epsilon	Sigma
Blood	61.3	1.53
Bone_Cortical	12.4	0.14
Bone_Marrow_Infiltrated	11.2	0.22
Bone_Marrow_Not_Infilt	5.5	0.04
Cartilage	42.6	0.78
Cerebro_Spinal_Fluid	68.6	2.41
Eye_Tissue(Sclera)	55.2	1.16
Fat	5.4	0.05
Grey_Matter	52.7	0.94
Muscle	55.0	0.94
Nerve(Spinal_chord)	32.5	0.57
Skin(Dry)	41.4	0.86
Skin(Wet)	46.0	0.84
Tongue	55.2	0.93
White_Matter	38.8	0.59

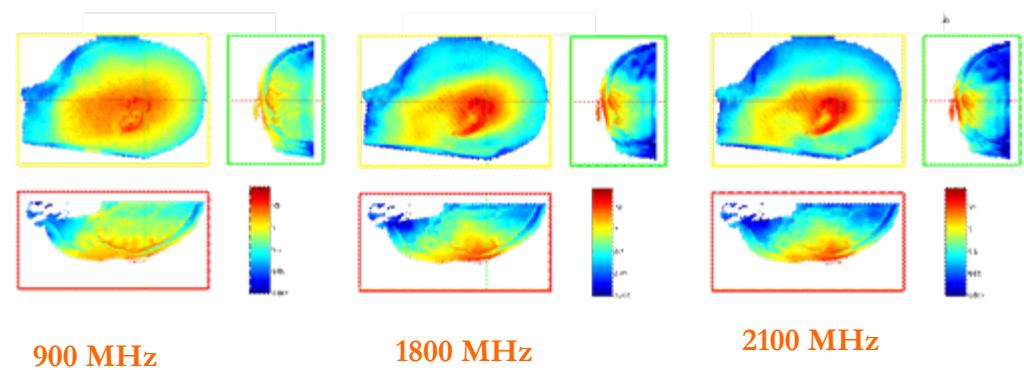
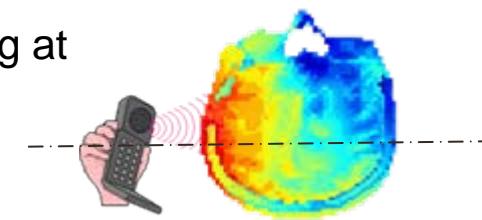
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# Example of absorption in head tissues



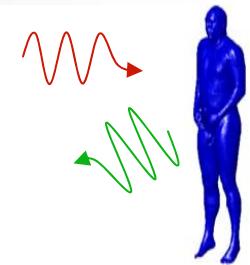
Handset operating at  
900 MHz



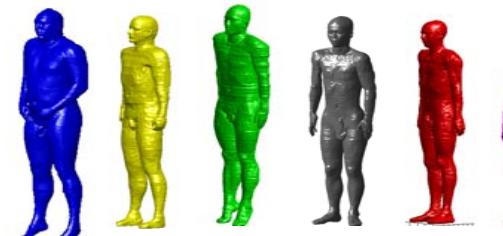
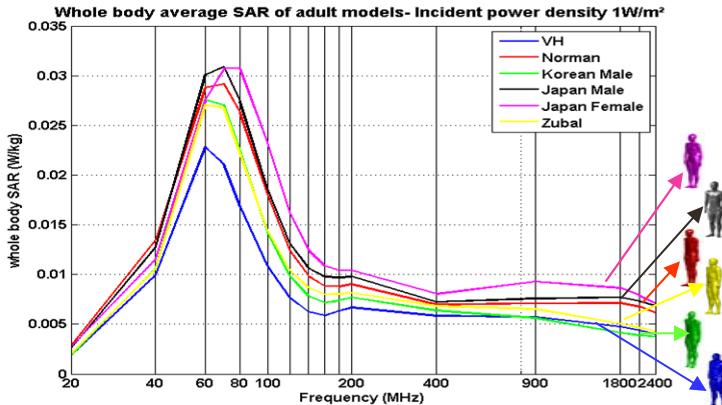


# Absorption depends on the shape

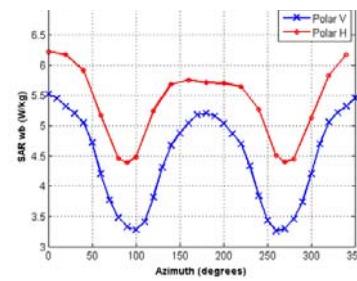
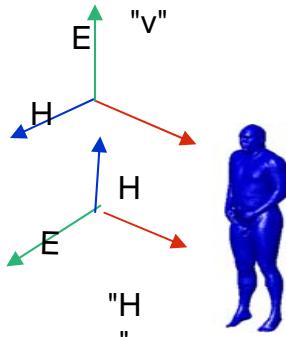
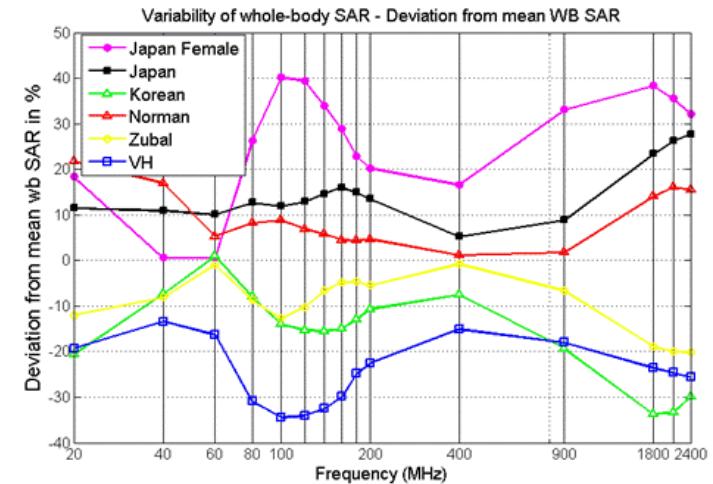
- The incident EM field is reflected and absorbed.
- Reflection and absorption depend on the tissues composition but also on the shape.



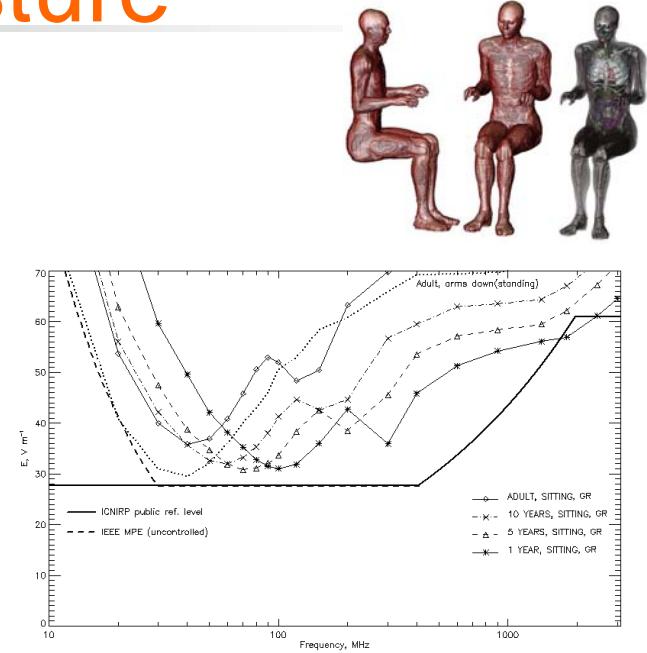
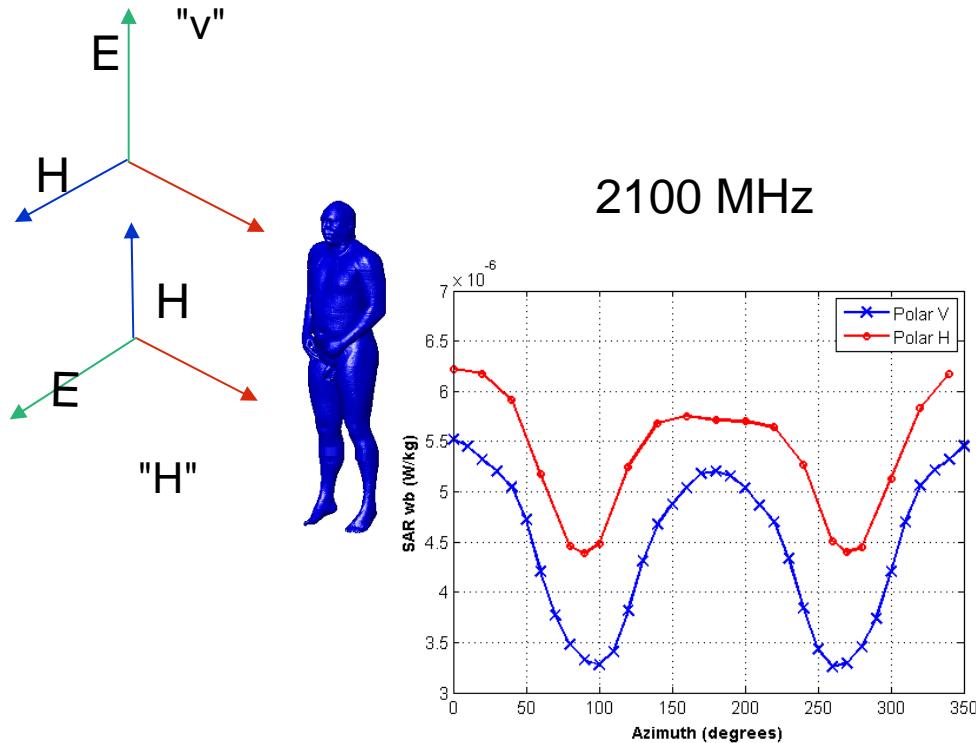
Total absorbed power divided by the weight



Large Variability



# Absorption depends also on the polarisation and the posture



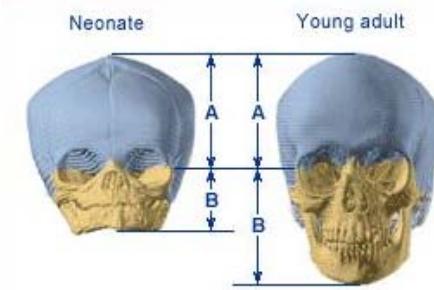
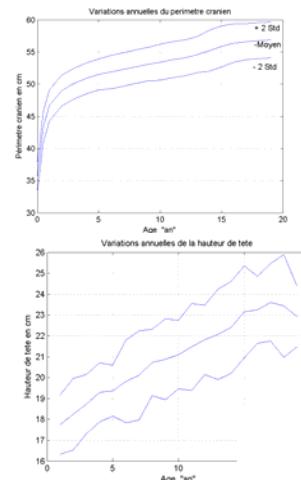
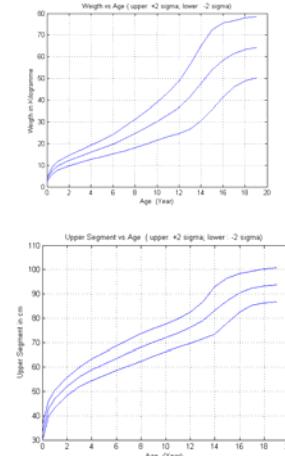
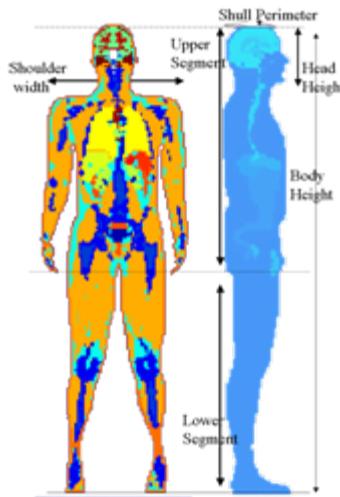
After Dr R P Findlay and Dr P J Dimbylow  
Health Protection Agency, UK.

Vertical polarization vs Horizontal...

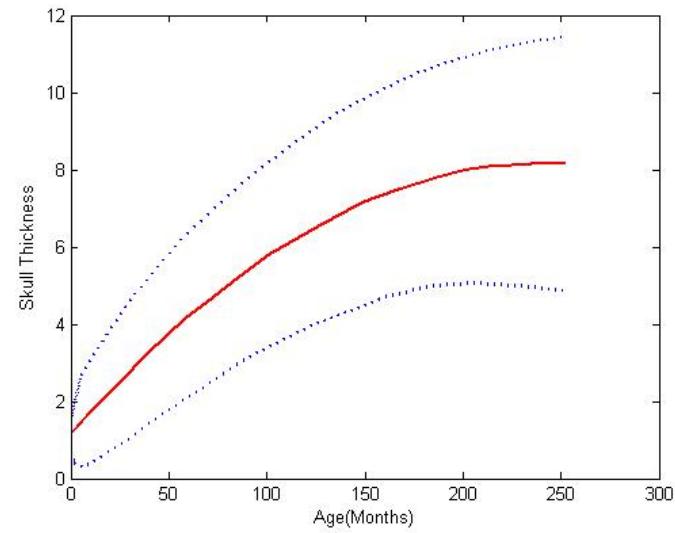
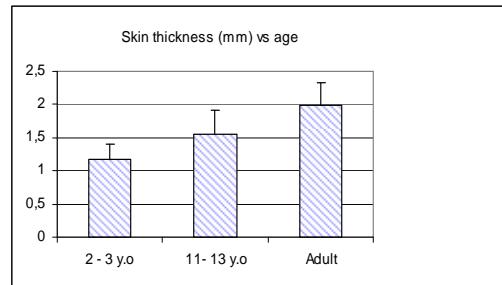
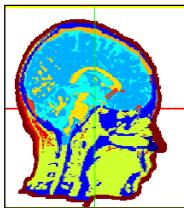


# Age dependant human Morphology

Head and Body shapes are age dependant

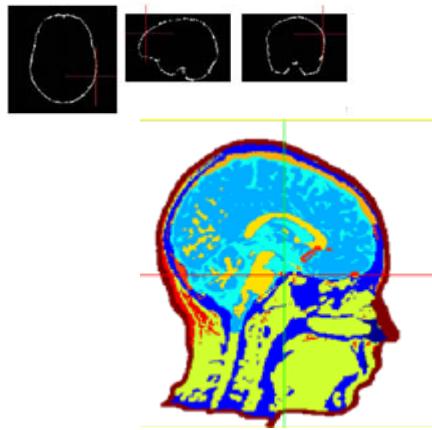


Internal anatomy evolves with age





# Human Anatomical models have been improved



MRI and computers facilities allow to built whole body and head models more and more complex.

International effort to develop models



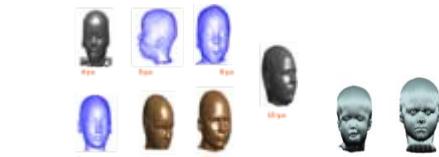
Adult male body models



Adult female body models



Child body models



Child head models



13 WA  
(US)



23 WA  
(MRI)



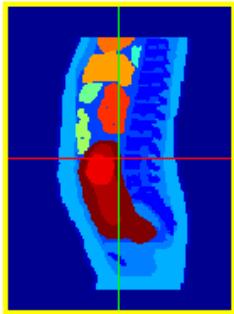
31 WA  
(MRI)



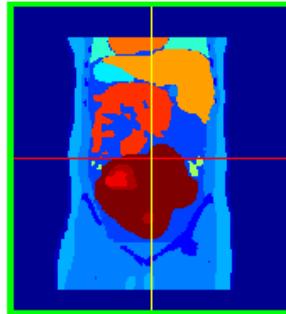
# Fetus exposure induced by multiple plane wave

Whist Lab

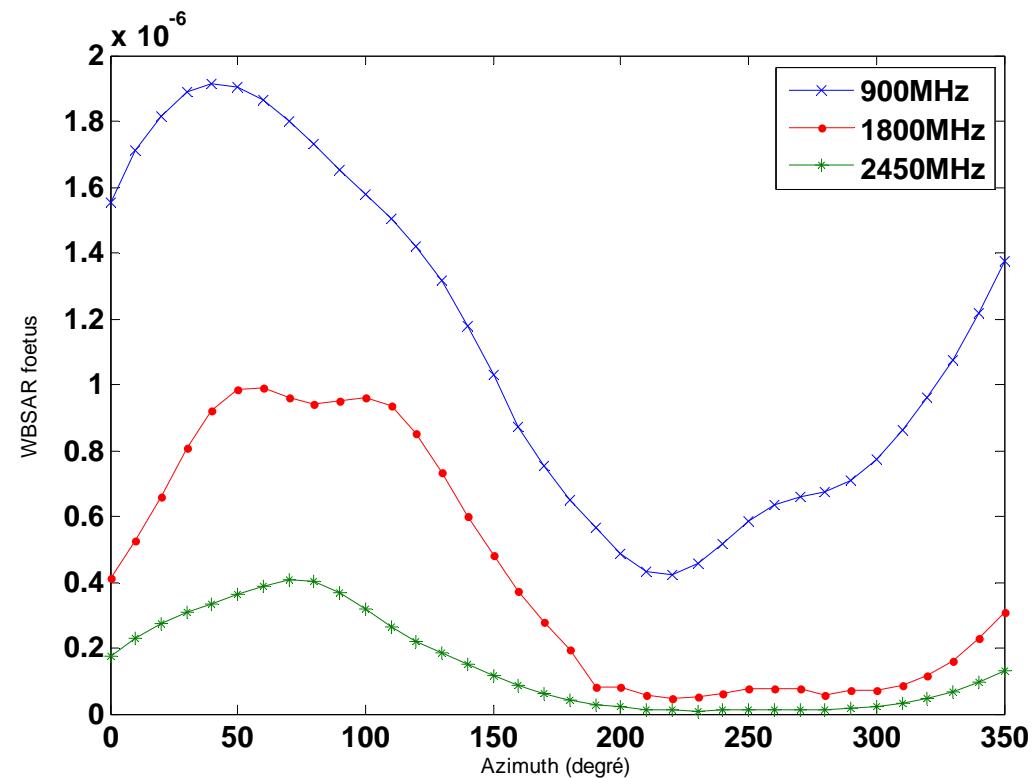
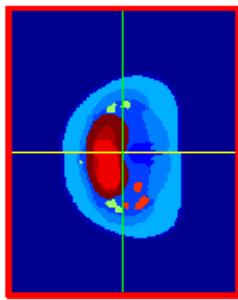
Slice X = 125 (125)



Slice Y = 100 (100)



Slice Z = 135 (135)





# EMF and Temperature rise

$$\rho.C \frac{\partial T}{\partial t} = \nabla(k\nabla T)$$

*Diffusion*

$$+ \rho.SAR$$

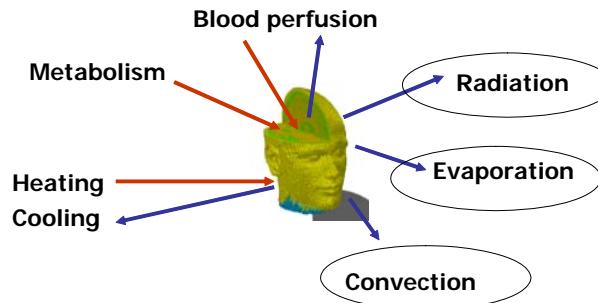
*EM field*

$$+ h_m$$

*Métabolism*

$$- b_f C_b (T - T_b) \quad \text{Thermoregulation}$$

$-(h_{RAD} + h_{CONV} + h_{EVA})$  *radiation, convection and evaporation*



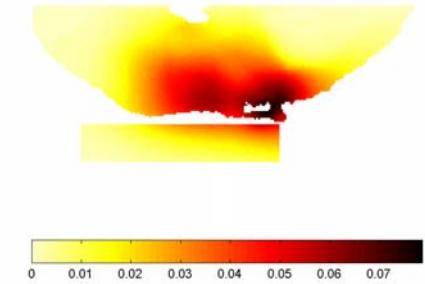
SAR



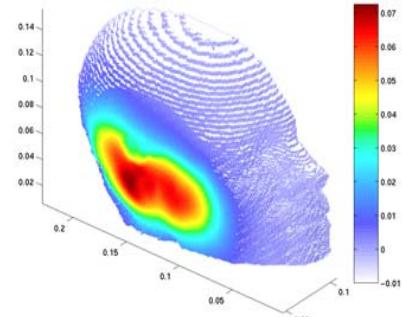
Rise of temperature due to EMF

*Solved with Alternating Direction Implicit Method*

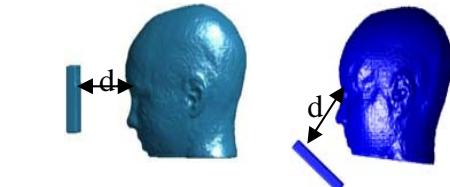
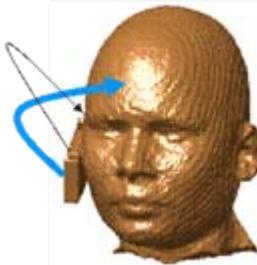
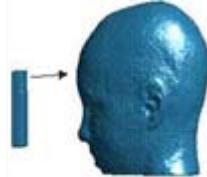
$$\left( \frac{T_{ijk}^{n+\frac{1}{3}} - T_{ijk}^{n-\frac{1}{3}}}{\Delta t / 3} \right) = \frac{k_{ijk}}{\rho_{ijk} C_{ijk}} \left( \begin{array}{l} \frac{T_{i+1,j,k}^{n+\frac{1}{3}} - 2T_{ijk}^{n+\frac{1}{3}} + T_{i-1,j,k}^{n+\frac{1}{3}}}{\Delta x^2} + \frac{T_{i,j+1,k}^{n+\frac{1}{3}} - 2T_{ijk}^{n+\frac{1}{3}} + T_{i,j-1,k}^{n+\frac{1}{3}}}{\Delta y^2} + \\ \frac{T_{i,j,k+1}^{n+\frac{1}{3}} - 2T_{ijk}^{n+\frac{1}{3}} + T_{i,j,k-1}^{n+\frac{1}{3}}}{\Delta z^2} + h_m + b_f C_b (T_b - T_{ijk}^n) \\ + \frac{h_n}{m_{ijk} C_{ijk}} - \frac{1}{m_{ijk} C_{ijk}} (h_{RAD_{ijk}} + h_{CONV_{ijk}} + h_{E_{ijk}}) + \frac{SAR_{ijk}}{C_{ijk}} \end{array} \right)$$



Analysis of the Temperature Increase Linked to the Power Induced by RF Source A  
*Ibrahem, C. Dale, W. Tabbara and J. Wiart Progress In Electromagnetics Research 52, 2005 pp 23-46 , (<http://cela.mit.edu/PIER/PIER52>)*

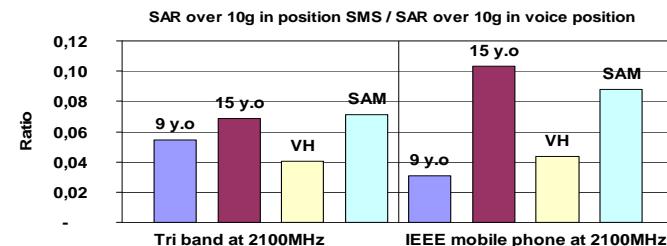


# Usage evolve

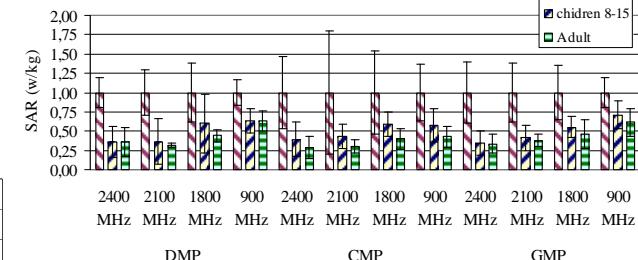
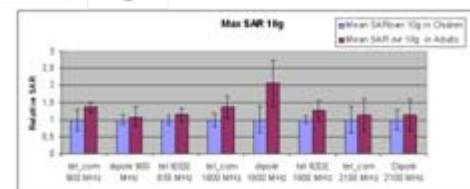
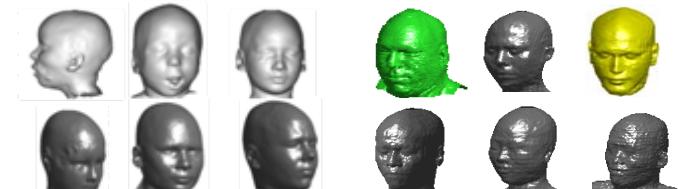


head	SAR1g in frontal Brain aera aera Usage "SMS - 10cm" GSM 900MHz VH	SAR1g frontal Brain aera Usage "SMS - 40 cm"	in frontal Brain aera Usage "SMS - 10cm"	SAR1g frontal Brain aera Voice	Ratio (sms10cm /voice)	Ratio (sms40c /Voice)
GSM 15 ans 900MHz 9 ans VH	1,54E-02 <b>1,64E-03</b>	2,38E-03 2,18E-02	2,15E-03	1,04E+00	<b>7,62E-01</b>	
GSM 15 ans 1800MHz 9 ans z VH	1,13E-03 <b>4,40E-04</b>	3,73E-03 1,11E-03	3,99E-04	1,28E+00	<b>1,10E+00</b>	
UMTS 15 ans 2100 MHz VH	3,11E-03	5,47E-03	<b>8,39E-04</b>	8,97E-01	<b>2,79E-01</b>	
		2,93E-03	3,30E-04	1,22E+00		

The exposure of the frontal area induced by the phone close to the ear is comparable to the exposure induced by the phone at 40 cm



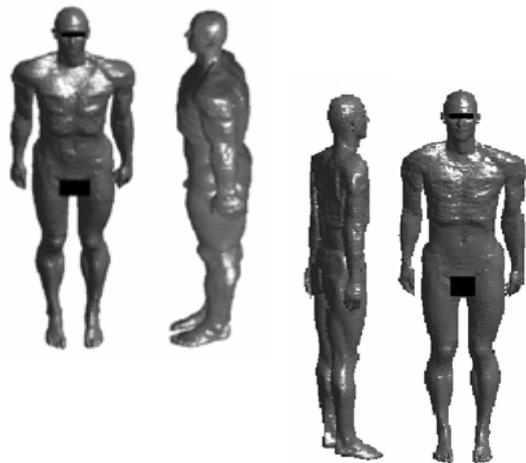
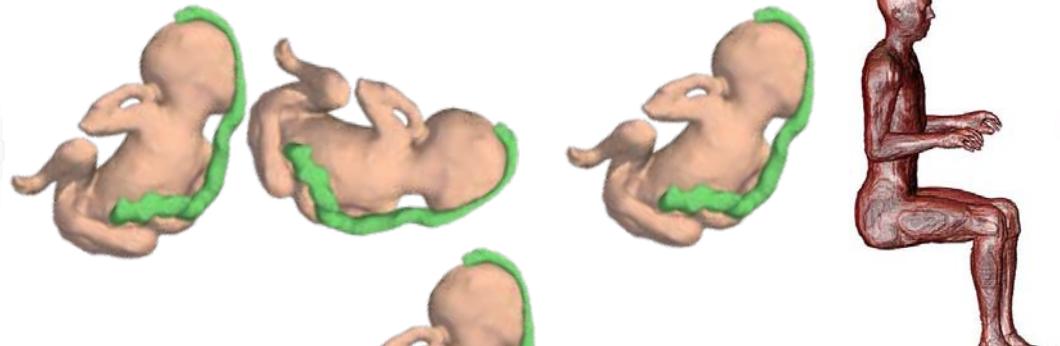
## Children vs Adults exposure





# The Challenge

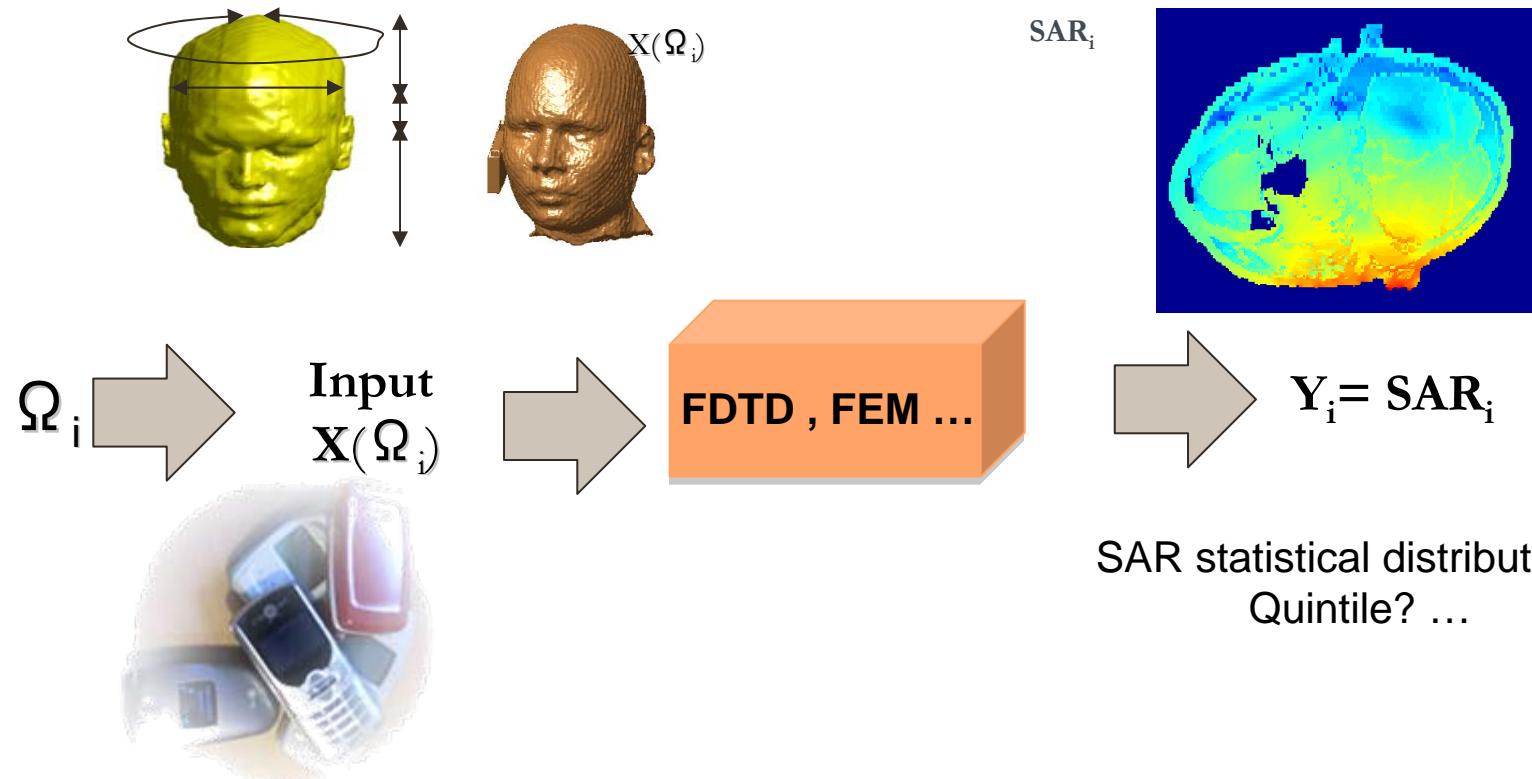
- Manage the variability



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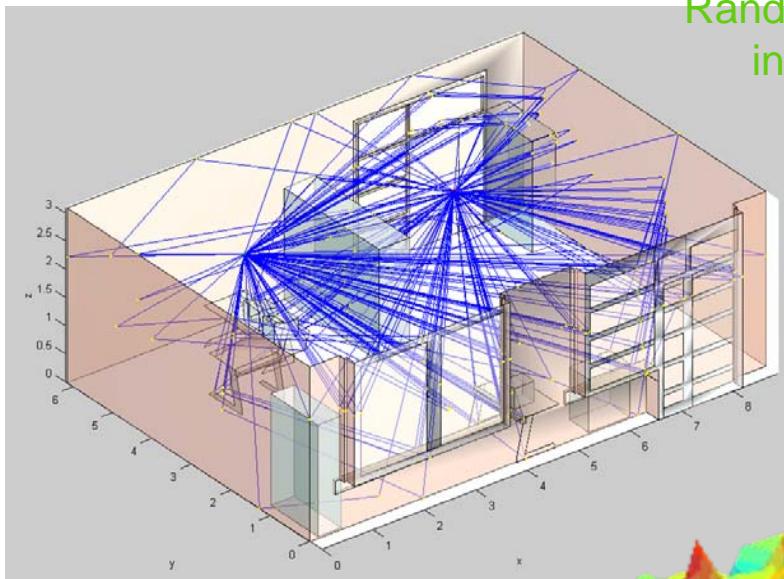


# Stochastic Dosimetry...

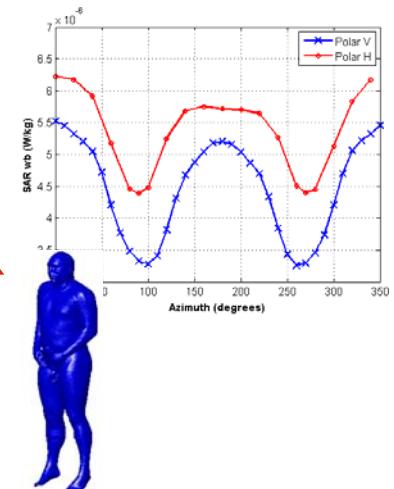
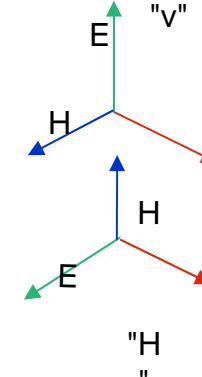
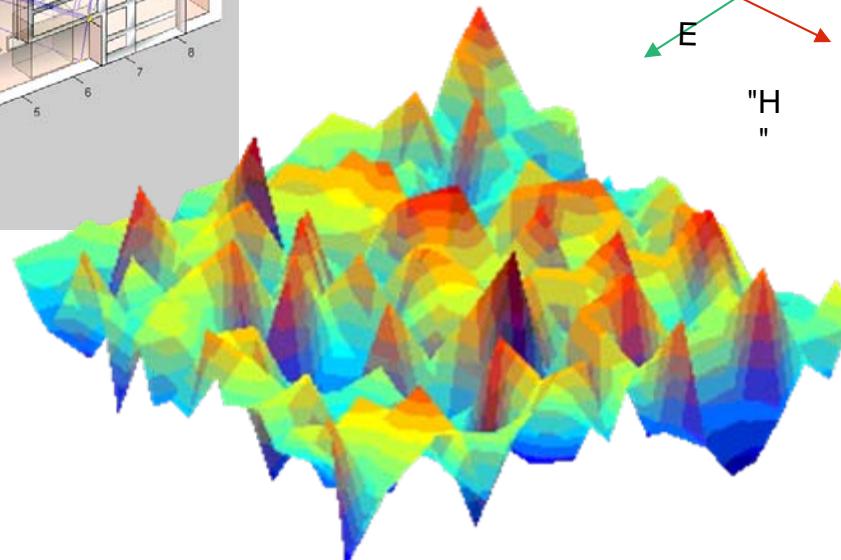


**Limited phantoms number, posture preparation, simulation time .... are not compatible with Monte Carlo**

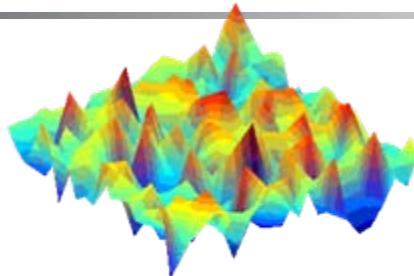
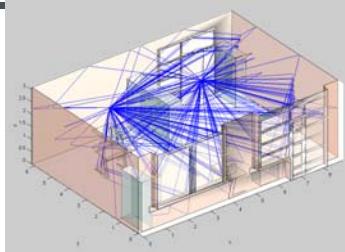
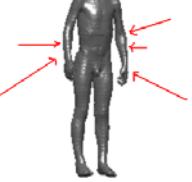
# Multi plane waves exposure



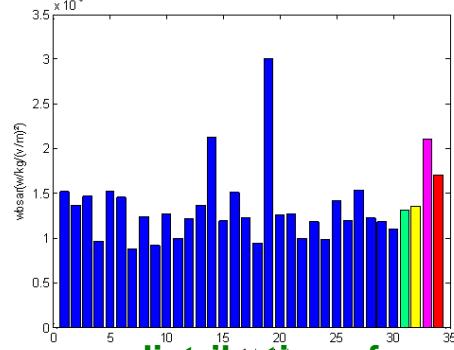
Random E field structure  
induced by fading



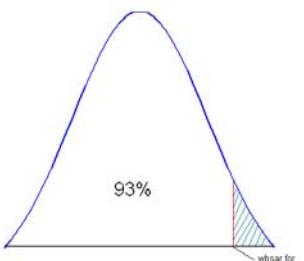
# Exposure to multiple random plane wave.



Amplitudes: Log-Normal distributed  
phases :Uniformly distributed  
Angles : Uniform distribution

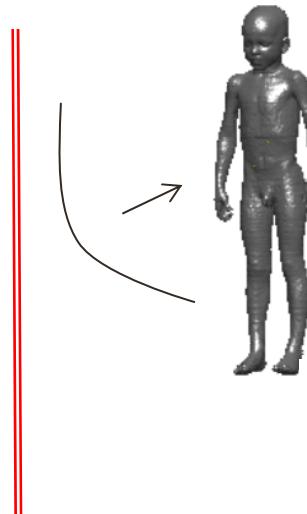


**Exposure distribution of narrow band coherent signal transported by multiple plane waves**



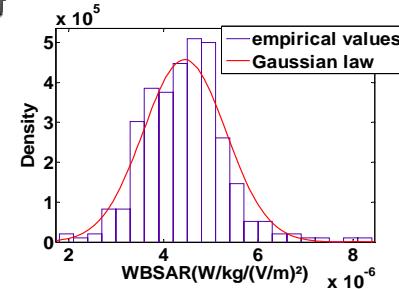
In case of multiple non coherent signals ( ie multiple transmission channels) the emission is close to mean value

using an experiment plan  
 36 FDTD simulations performed each  
 $10^\circ$  (0:10:360)



**LHS design**

17 sets of 5 azimuth angles chosen between 36 are designed. 20 sets of 5 amplitudes having Log-Normal distribution and 5 phases having Uniform distribution are designed to obtain Y (WBSAR).

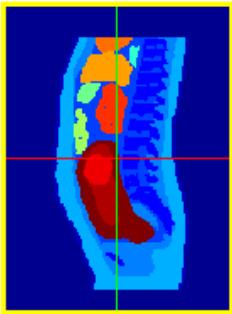




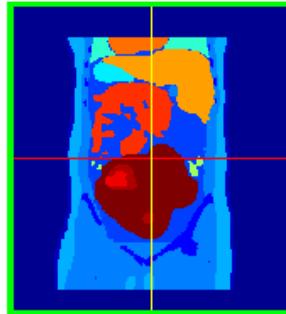
# Fetus exposure induced by multiple plane wave

Whist Lab

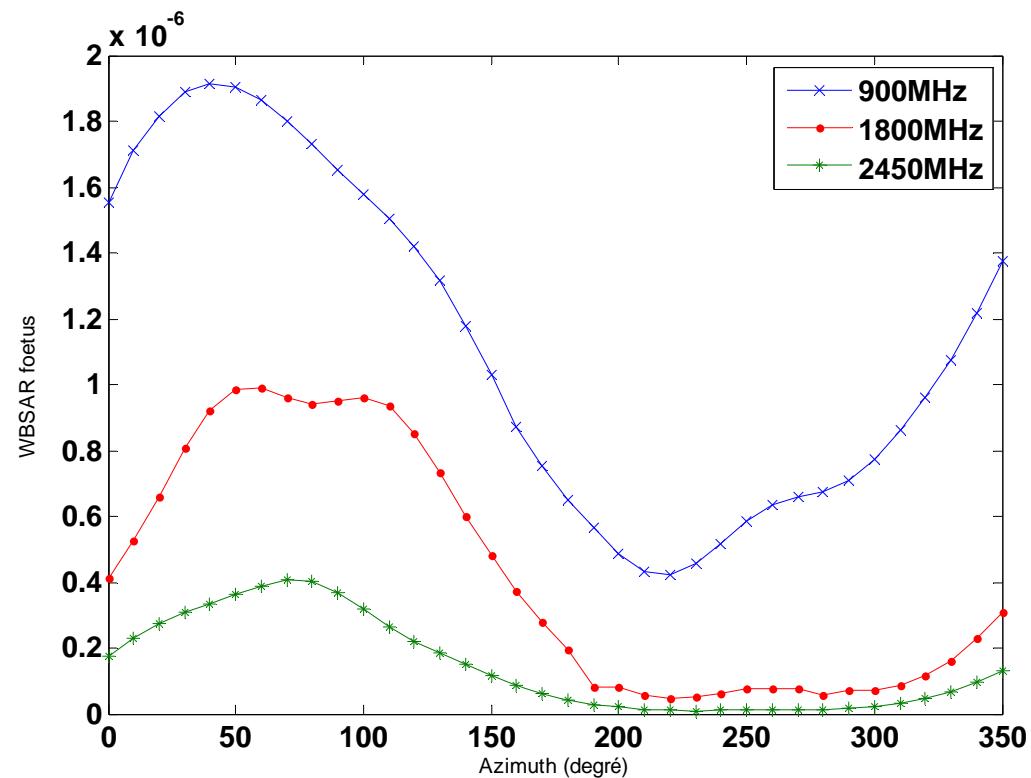
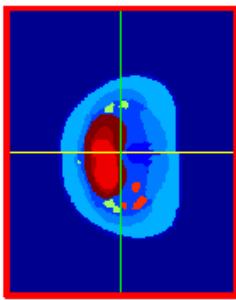
Slice X = 125 (125)



Slice Y = 100 (100)



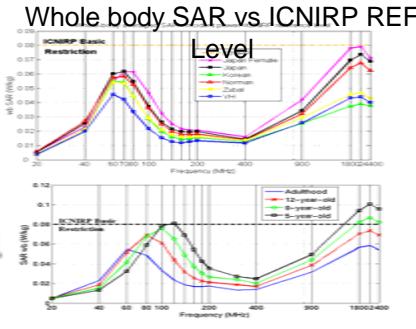
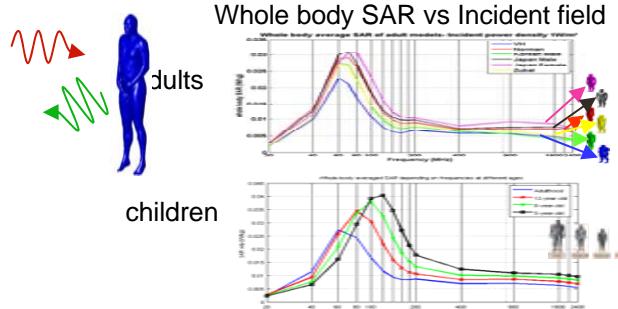
Slice Z = 135 (135)





# Whole Body exposure vs incident field

- Simulations show large variability. What is the maximum exposure?.



- Heterogeneous models: limited number.
- Limited statistical information on internal organs
- Statistical information on external morphology parameters exists



recherche & développement

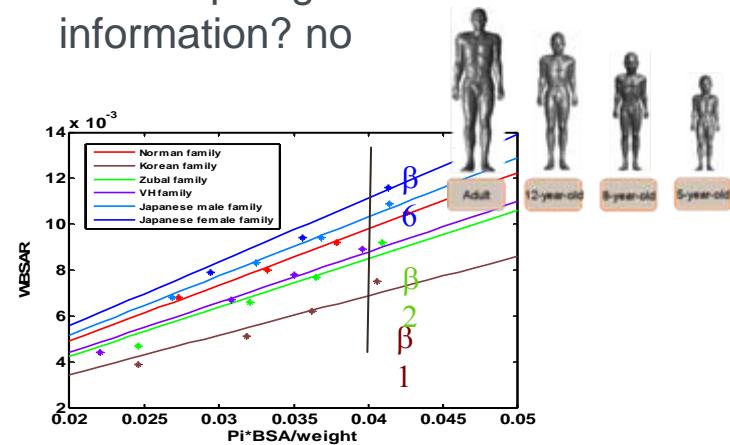
- What is the validity of a model based on external morphological parameters

$$Y = \beta X + \epsilon$$

(X == BSA/weight, BMI<sup>-1</sup> and weight<sup>-1/3</sup>)

- Statistical analysis with the existing heterogeneous phantoms: uncertainty 30%....

- Are morphing models able to add information? no



# Baysian approach and iterative planning experiment



## WBSAR vs external parameter

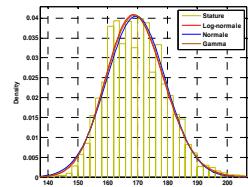
Anthropometric database of 3800

individuals :

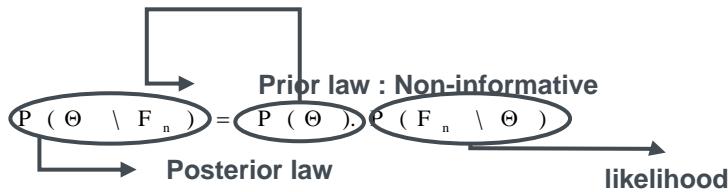
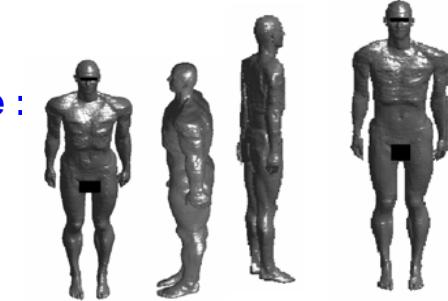
$$\text{WBSAR} = \theta_1 \text{Height} + \theta_2 \frac{\text{chest}}{\text{front shoulder breadth}} + \theta_3 \frac{\text{waist}}{\text{front shoulder breadth}} + \theta_4$$

$$\Theta = [\theta_1, \theta_2, \theta_3, \theta_4]$$

$$X = [\text{Height}, \text{chest}, \dots]$$

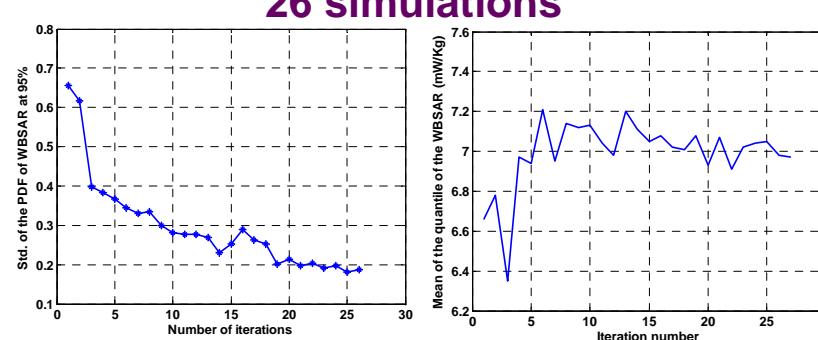


Extending the phantoms database :  
Morphing technique



Choice of candidates that  
allows reducing the  
variance of the PDF  
WBSAR at 95%

$$F_n = (X_i, \text{WBSAR}_i)_{i=1,\dots,n}$$



Chaos polynomial can also be used...  
recherche & développement



# Polynomial chaos applied to dosimetry

Random vector can be decomposed in the chaos polynomial

$$Y = M(X)$$

$$Y = \sum y_i \psi_i(X)$$

Legendre polynomial

$$\text{WBSAR}(\Omega) = \sum_{k=0} \beta_k \cdot \Psi_k(\Omega)$$

$$\hat{P}_{n+1} = \frac{\sqrt{(2n+1)(2n+3)}}{n+1} x \hat{P}_n - \frac{n}{(n+1)} \sqrt{\frac{2n+3}{2n-1}} \hat{P}_{n-1}$$

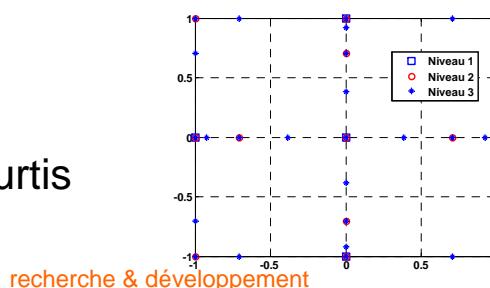
$$\hat{P}_0 = 1, \quad \hat{P}_1(x) = \sqrt{3}x$$

$$\int_{-1}^1 \hat{P}_m(x) \hat{P}_n(x) dx = 2 \cdot \delta_{m,n}$$

Coefficients estimation  
Using projection and quadrature.

Smolyak

Clenshaw Curtis



	3 D	4 D
Ordre 1	7	9
Ordre 2	25	41
Ordre 3	69	137
Ordre 4	177	401
Ordre 5	441	1105

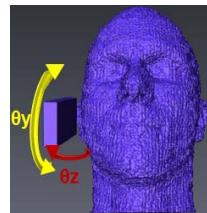
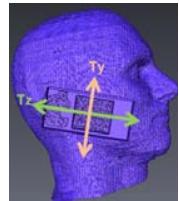
# In progress



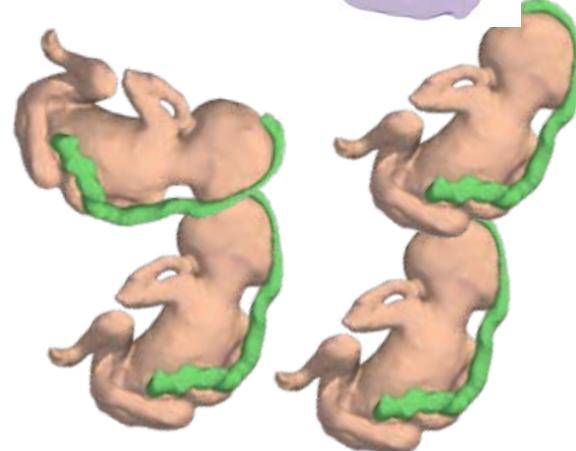
## Influence of mobile position

4 input parameters

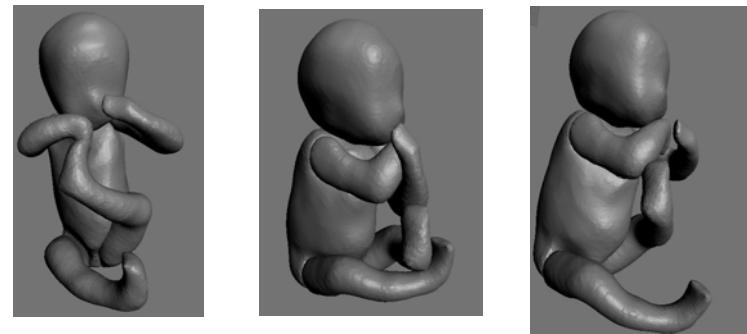
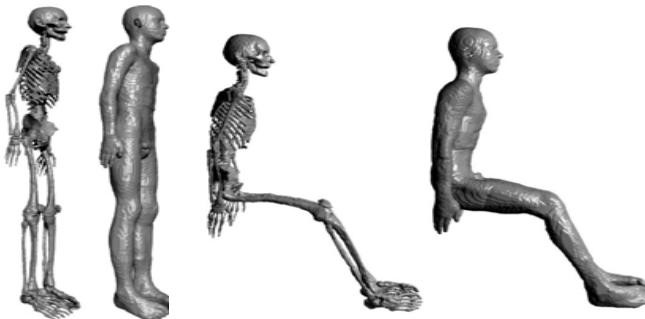
X,Y positions  
relatively to the ear



## Fetus exposure



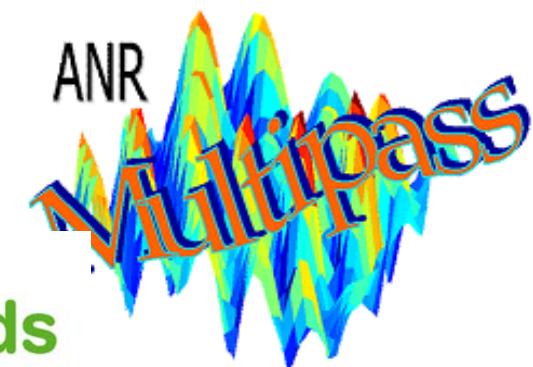
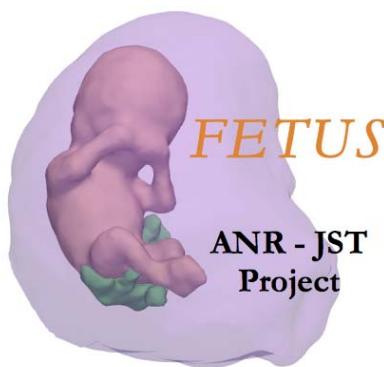
## Children exposure





# Conclusion

- Simulation tools have been improved, they are now facing the complexity challenge.
- Looking for human exposure management dosimetry is moving from deterministic to stochastic
- Several ANR and FP7 projects are



<http://whist.institut-telecom.fr/en/collaboratif.html>

# As conclusion



Dans la confusion trouver la simplicité  
De la discorde faire jaillir l'harmonie  
Au milieu de la difficulté se trouve l'opportunité

Albert Einstein,  
*Trois règles de travail*