BIOLOGICAL AND HEALTH EFFECTS OF ELECTROMAGNETIC FIELDS

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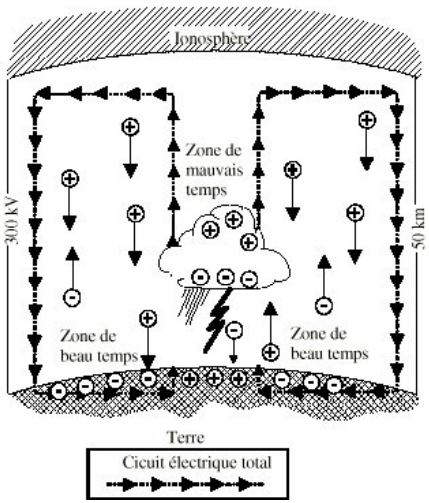
INTRODUCTION

•SOURCES OF ELECTROMAGNETIC FIELDS

•A big variety of sources :

•Natural fields : - earth magnetic field : 30 - 60 μT



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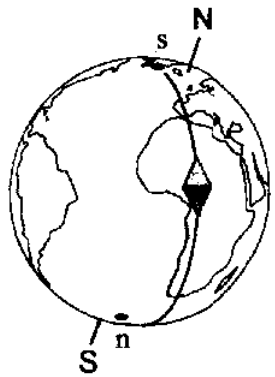
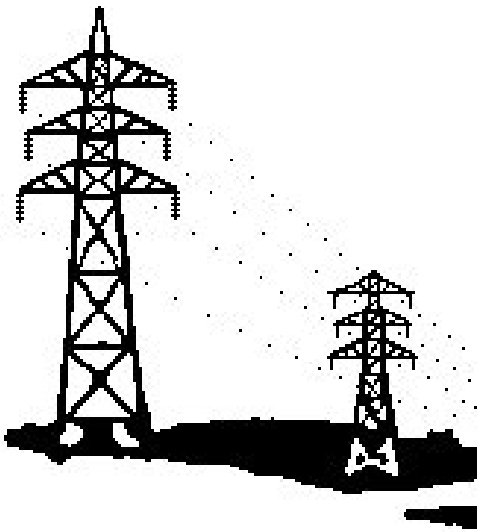


SOURCES OF ELECTROMAGNETIC FIELDS (con't)

Artificial fields : - in the 70's : main concern the fields due power lines and household devices;

- in the 90's : development of mobile phones the emitting antennas near the human head.



INTRODUCTION

•HOW TO APPROACH THE •PROBLEM

•Calculation and measurement ⇒ engineers.

•Biological effects ⇒ biologists + engineers.

•Effects on health ⇒ medical doctors + statisticians
• (for epidemiological studies).

•CLASSIFICATION

•- CW : - VLF fields due to power lines
(50 - 60 Hz)
• - mobile phones : 900 MHz - 2 GHz

•Impulse : - lightning, EMP,
• other short pulses

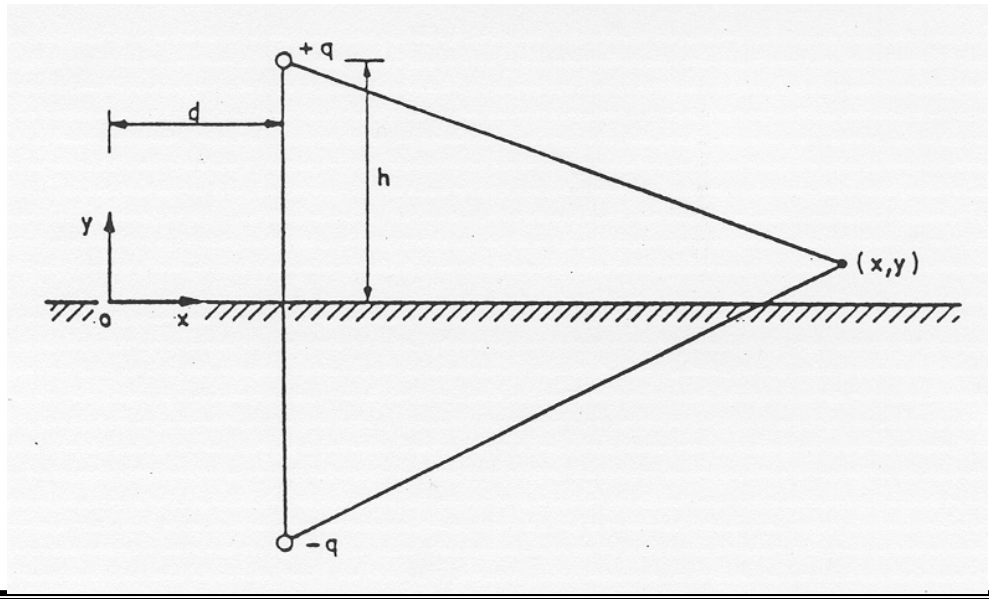
•Lightning : high energy but the direct thermal effects are much more dangerous for humans than the field.

•CALCULATION METHODS

•50/60 Hz fields

•For one line :

Quasi-static problem : the field can be calculate
a static field due to electric charges on the line



Power line magnetic fields

Magnetic field of a three-phase configuration

The total magnetic field results from the supperposition of three vectors, each for one phase.

If the current is in x – axis

$$B_y = -Re\left[\sum_{n=1}^{N} \frac{\mu_0 I_n e^{j(\omega t+\alpha_n)}(z-z_n)}{2\pi\left[(y-y_n)^2+(z-z_n)^2\right]}\right]$$

$$B_z = Re\left[\sum_{n=1}^{N} \frac{\mu_0 I_n e^{j(\omega t+\alpha_n)}(y-y_n)}{2\pi\left[(y-y_n)^2+(z-z_n)^2\right]}\right]$$

Power line magnetic fields (con't)

•Calculated magnetic field (in μT) for a worker in two positions with respect to a HV line

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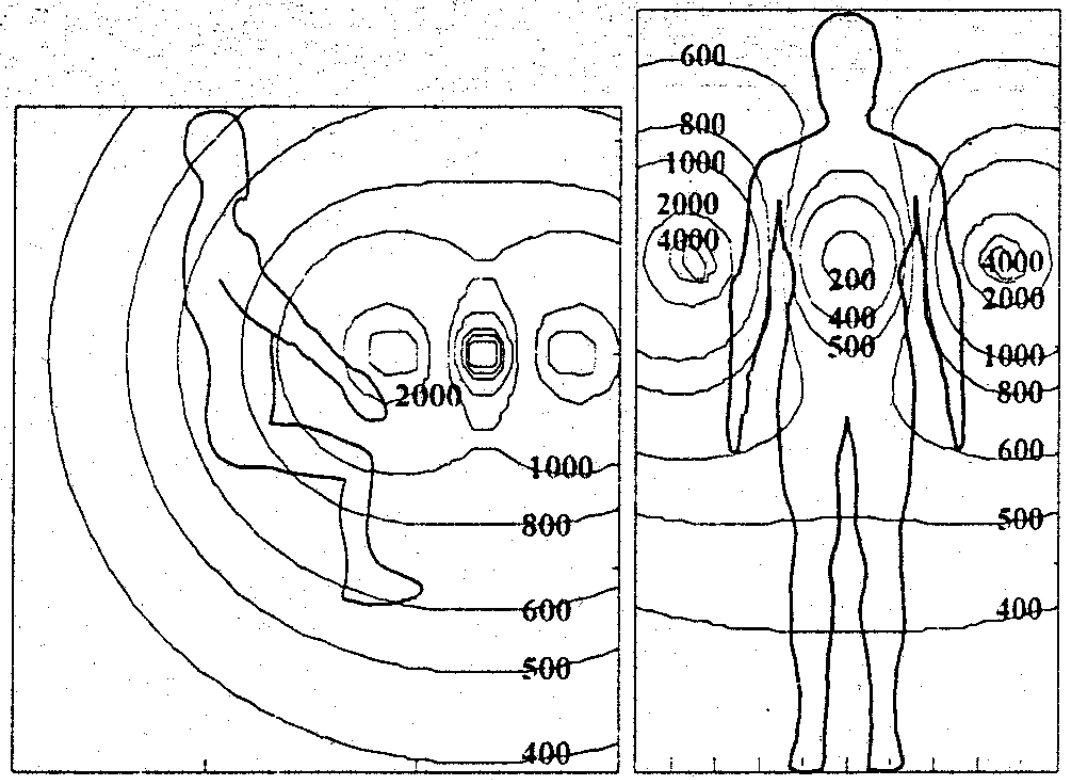

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Induced Current Calculations for Low Frequency EMF Exposure Assessment

The effect of low and intermediate frequency external E&H fields on humans ⇒ to induce currents in the human body.

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INTRODUCTION

In this frequency range, the limits of exposure of human bodies ⇒ expressed in terms of :

- induced currents densities;

- internal electric field.

These are called « basic restrictions ».

They are determined from biological and medical experimentation.

As it is not possible to introduce sensors inside the body to measure these currents it was decided to develop calculation methods.

CRITERIA FOR BASIC RESTRICTIONS

- Current densities of 100 mA/m^2 can result in reversible biological effects in sensitive tissues (nervous and cardiac).

-ICNIRP has defined the basic restrictions taking a security factor with respect to this value which gives an effect :

- factor 10 for professionals $\Rightarrow$ 10 mA/m^2 .

- factor 50 for the public $\Rightarrow$ 2 mA/m^2 .

ANALYTICAL MODELS

Models based on the following approximating assumptions :

- the real three-dimensional phenomenon (3D) is approximated by a one-dimensional relationship (1D) :

  - the human body a cross-section having the shape of a disk;

  - the external field given by a one dimensional wire;

- the human body $\Rightarrow$ a homogeneous structure;

- the different electrical conductivity of various organs $\Rightarrow$ not taken into consideration;

- the external field is homogeneous and harmonic at a single frequency.

ICNIRP analytical models for homogeneous fields

These models are based upon the assumptions listed above.

The objective of such a simple modelling is to propose a simple method, which gives conservatives values of external fields, with regard to a given level of induced currents.

ICNIRP analytical models for homogeneous fields

The calculation assumes that the exposed body with conductivity σ has a circular section of radius R perpendicular to the constant magnetic field.

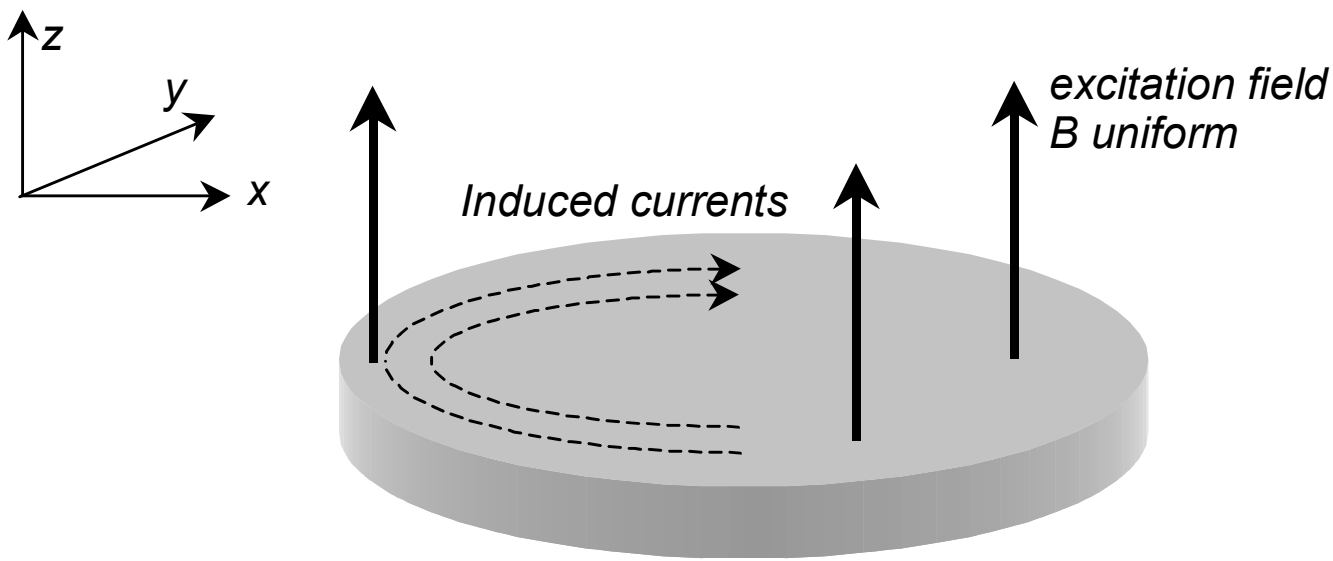
The induced current at radius r is given by

$$J(r) = \frac{r.\sigma}{2} . \frac{dB}{dt}$$

ICNIRP analytical models for homogeneous fields

For a certain frequency $$J(r) = (\mu_0.\sigma.\pi.r.f).H$$

The induced currents are distributed inside the disk, following rotation symmetry around the central axis of the disk.



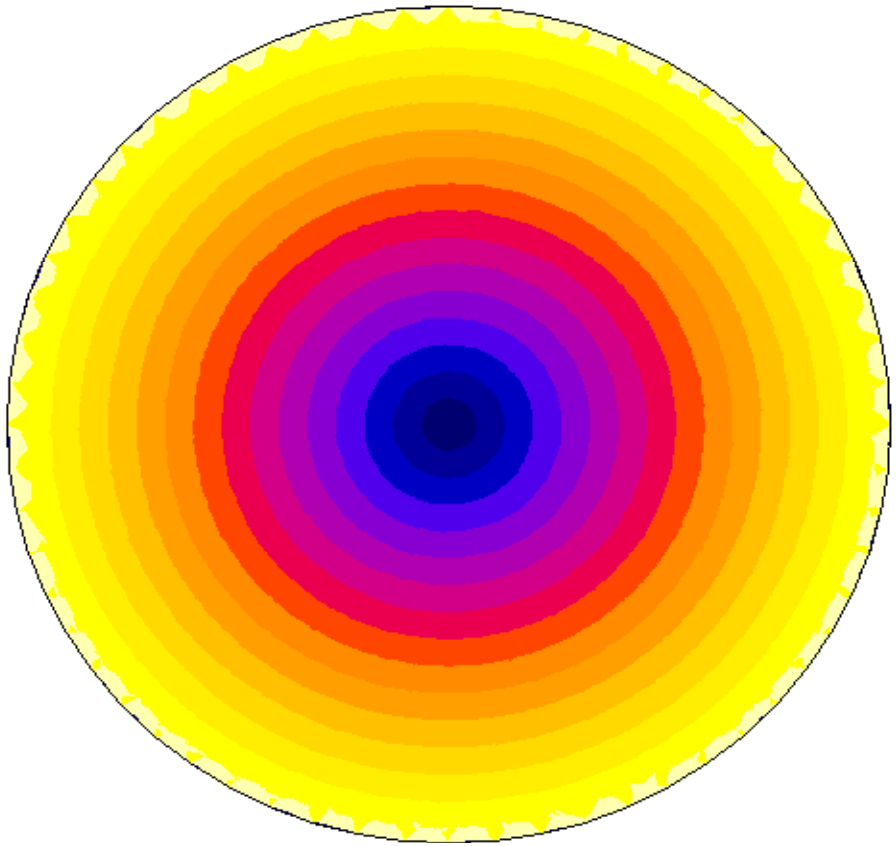
ANALYTICAL CALCULATION

NUMERICAL APPLICATION

For standard values of the typical parameters

- f = 50 Hz;
- H = 1 A/m
- R = 0.1 m
- σ = 0.4 S/m

This analytical calculation gives a non-realistic uniform distribution.



.NUMERICAL MODELS

The distribution can be described by a space-temporal differential equation, the solution of which is obtained by numerical methods.

$$\frac{1}{\sigma}.\nabla^2\vec{\mathrm{H}}\mathrm{r} - \mu 0.\frac{\partial\vec{\mathrm{H}}\mathrm{r}}{\partial \mathrm{t}} = \mu 0.\frac{\partial\vec{\mathrm{H}}\mathrm{ex}}{\partial \mathrm{t}}$$

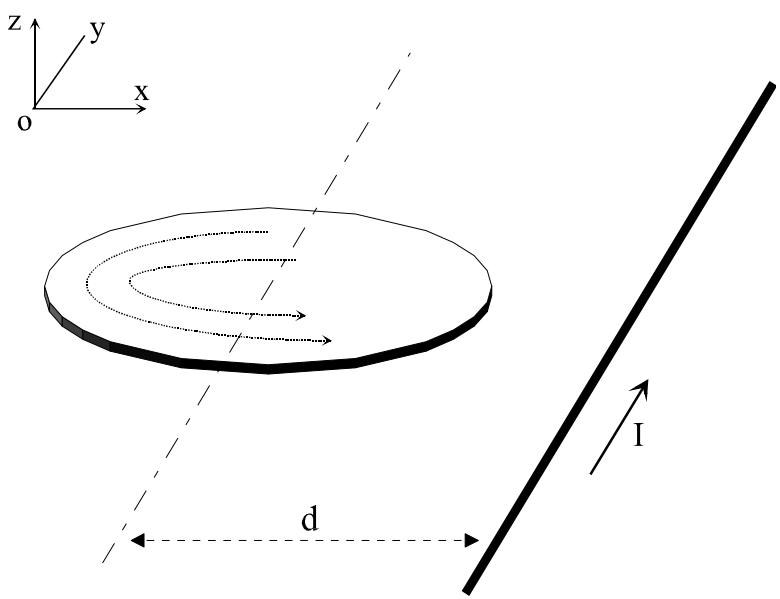
$$\vec{J} = Curl(\vec{H}_r)$$

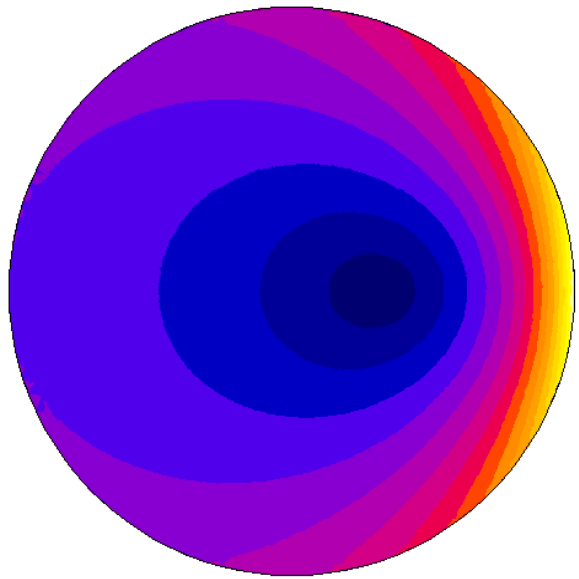
For the moment only 2-D models have been considered, but 3-D models might be applied is needed in a future development of a standard in preparation by the IEC TC 106.

NUMERICAL CALCULATIONS

Disk in the field of an infinite wire

Distribution of J in the disk, for d = 110 mm

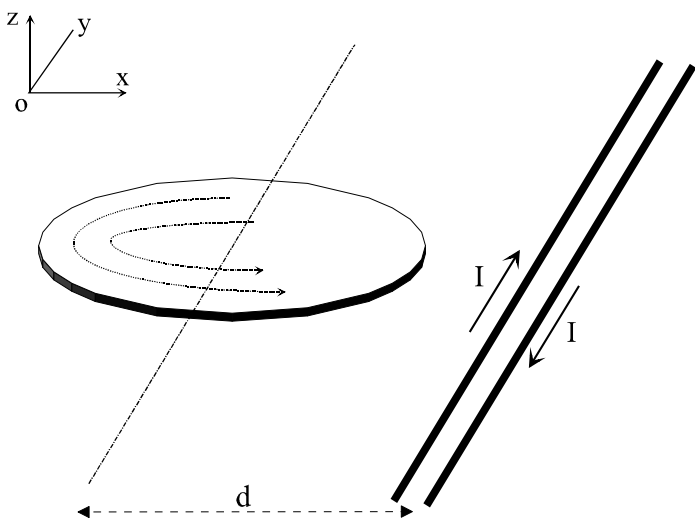


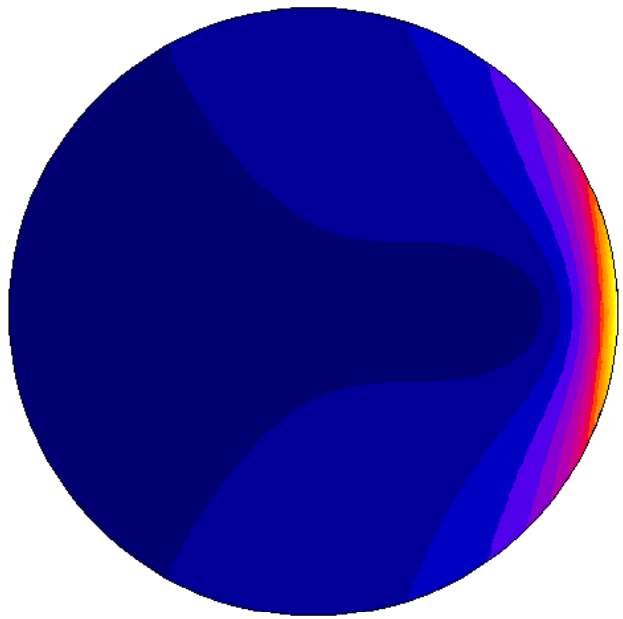


NUMERICAL CALCULATIONS

Disk inside a field created by two close infinite parallel wires with opposite equal currents.

Distribution of J in the disk, for d = 110 mm

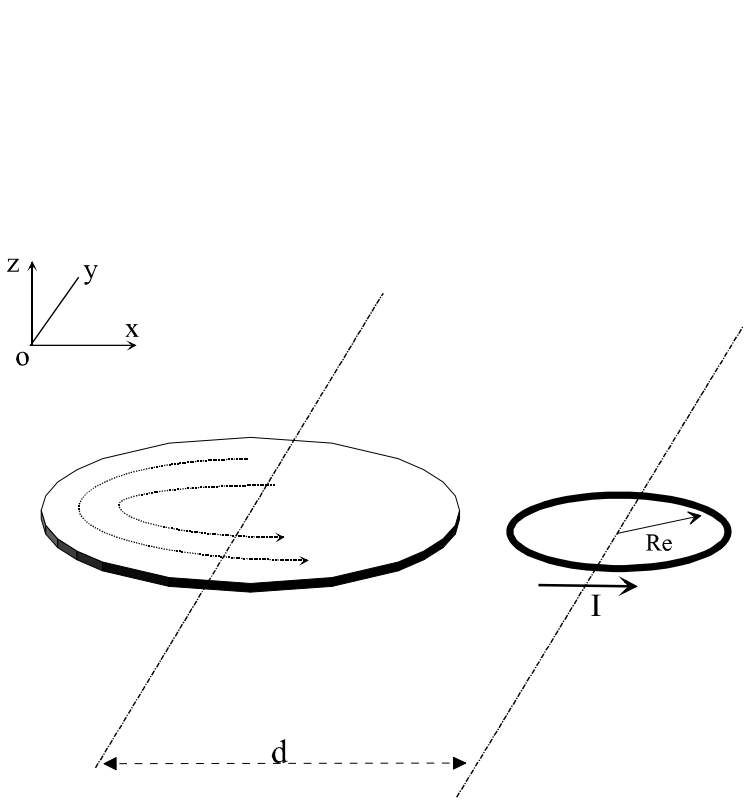


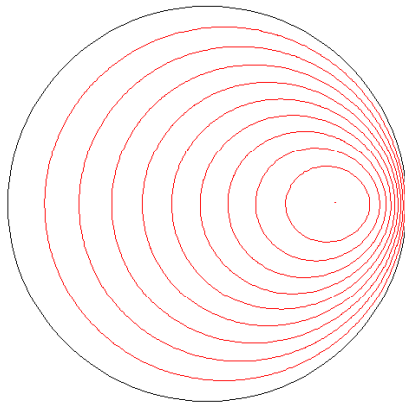


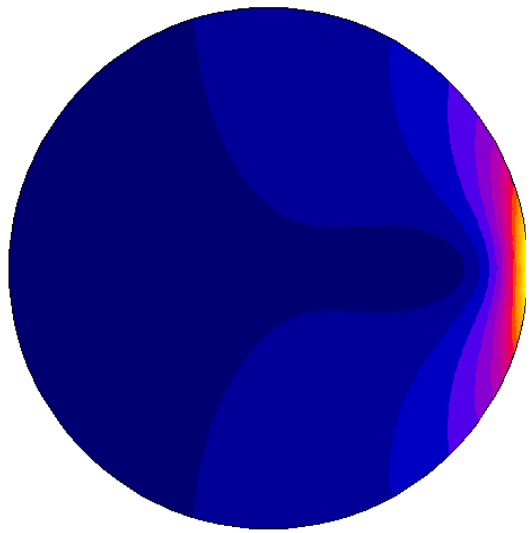
NUMERICAL CALCULATIONS

Disk inside a field created by a circular coil, *d = 110 mm*

Current density lines J and distribution of J in the disk







ADAPTATION OF THE ICNIRP MODEL

- the hypothesis of constant field is only valid when the distance between the source and the “human disk» becomes important;

- this distance can be estimated to about 10 times the size of the “ human disk”;

For shorter distances the ICNIRP model can be adapted by using a K factor :

$$J(r) = K.\mu_0.\sigma.\pi.r.f.H$$

where K = 1 for a constant field.

ADAPTATION OF THE ICNIRP MODEL

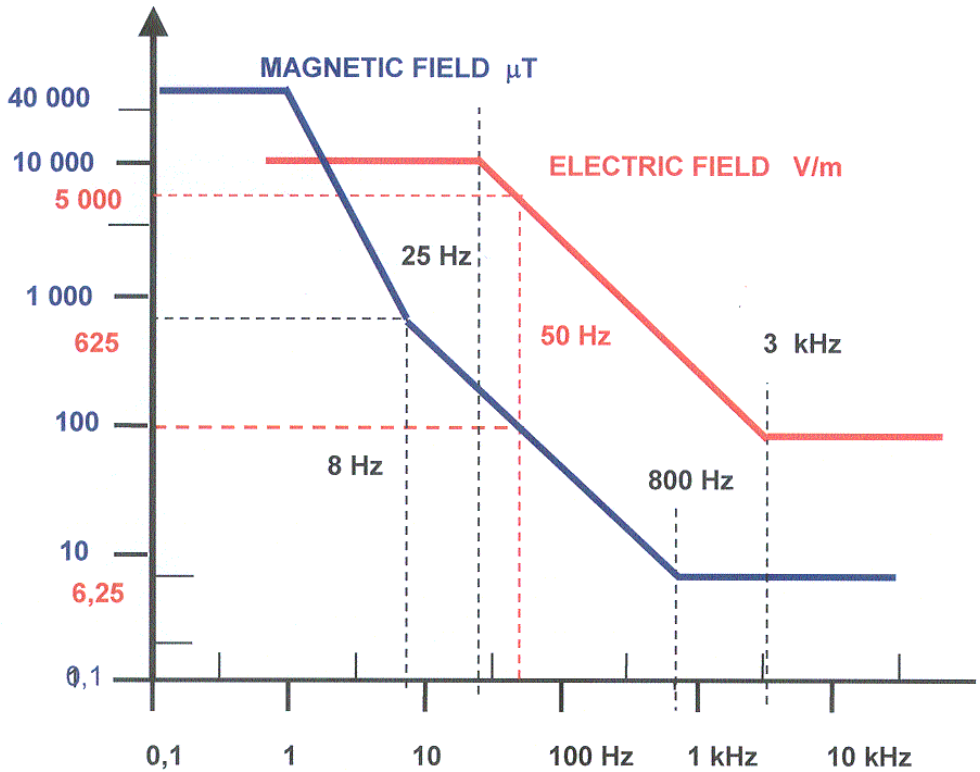
Factor K values for different configurations

Field source characteristics	J_{m0}/J_{mc}	K
H=const.(analytical calculation)	1	1
H = const. (numerical calculation)	1	0.9973
1 wire, d = 110 mm	3.6	0.2280
2 wires, d = 110 mm	8.4	0.0707
Coil R = 50 mm, d = 155 mm	7	0.0693
Coil R = 10 mm, d = 115 mm	14.9	0.0280

J_{m0} - local current density for simplified analytical calculation;
J_{mc} - current density obtained from a numerical calculation which takes into account the non-homogenous disk structure.

E&M fields

Field intensities corresponding to the basic restrictions



SAFETY IN E AND B FIELD: REFERENCE LEVELS

By courtesy of Prof. W. Van Loock

Protection against E&M fields

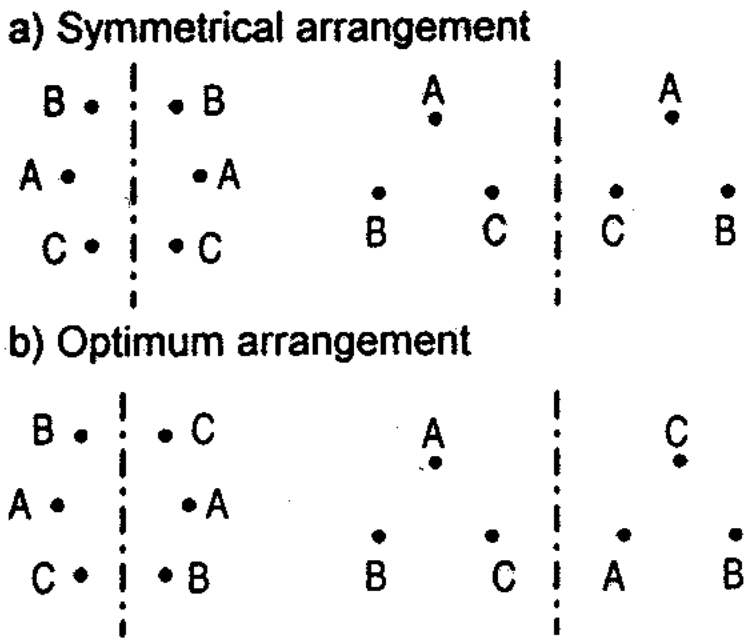
Several ways to decrease the field intensity :

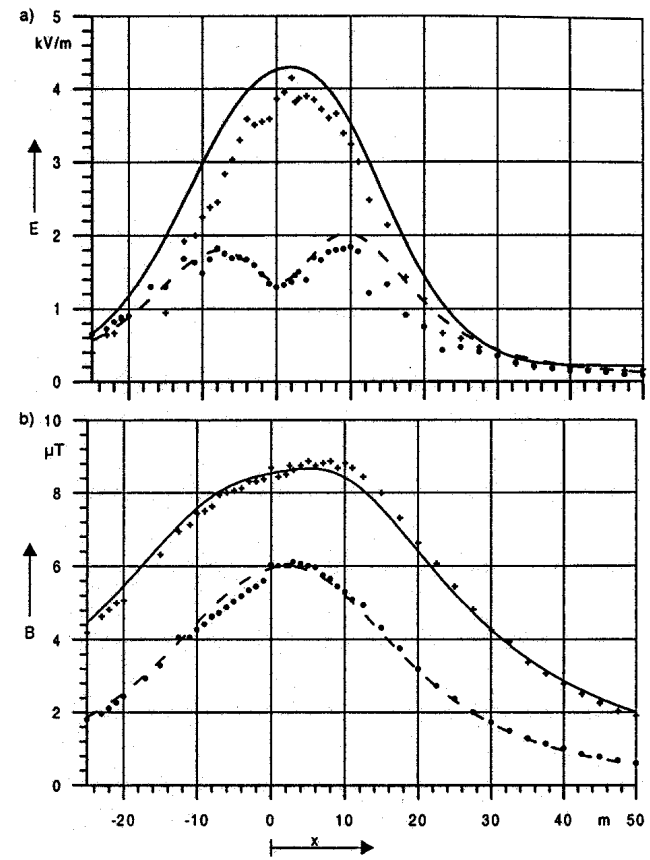
- increase the height of the line;
- optimize the phase arrangement;
- symmetrical phase arrangement;
- make the line compact:
- increase the voltage to reduce the current;

If all these solutions have been used, the only way is to put sensitive buildings at larger distances.

Protection against E&M fields

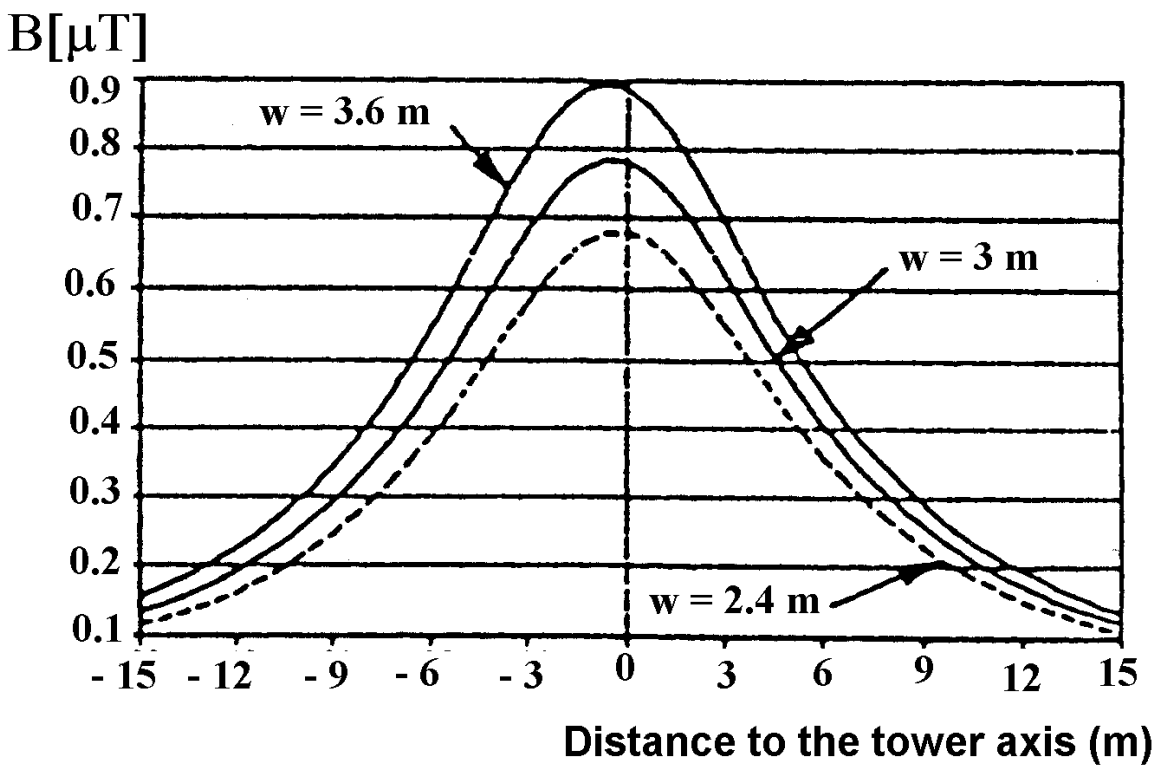
Optimization of the phase arrangement





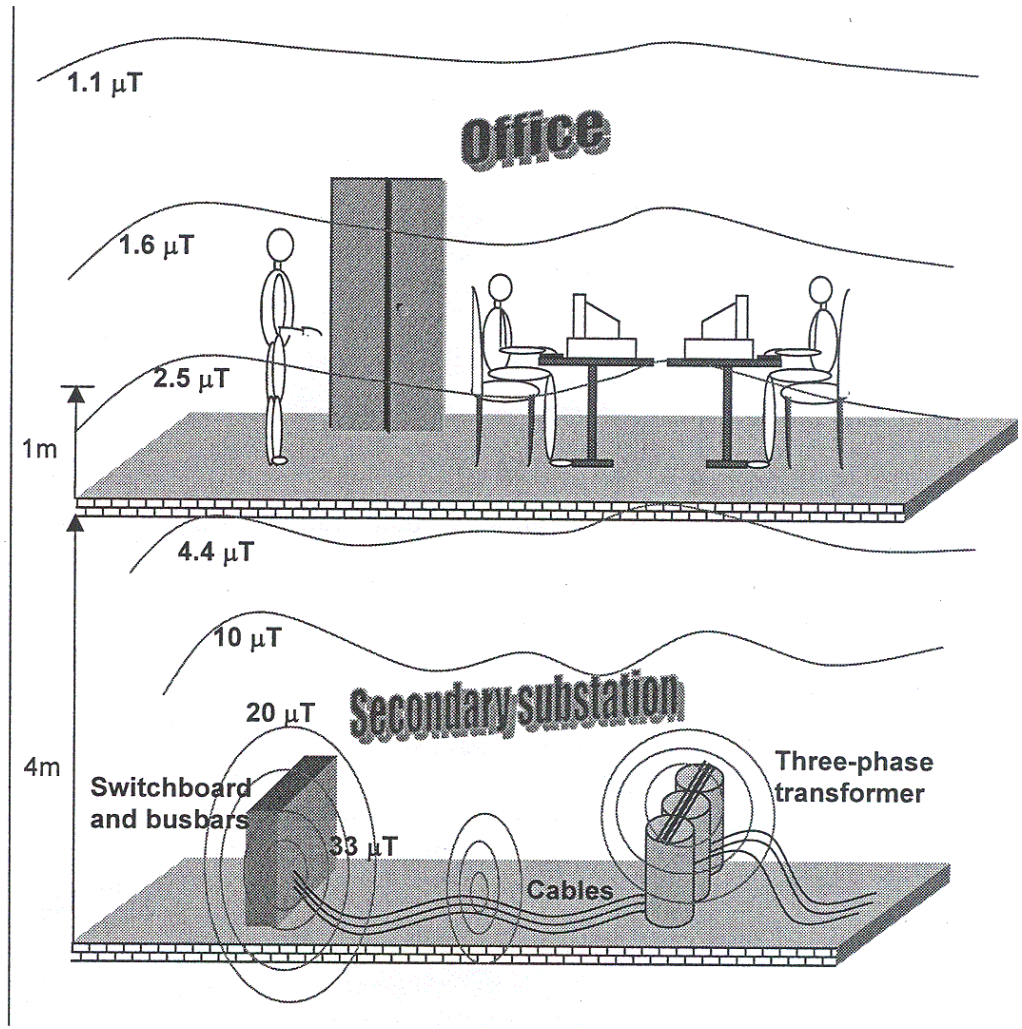
Protection against E&M fields

Phase compact arrangement



Protection against E&M fields

Protection inside buildings : LV power substations in a building.



CELLULAR PHONES

public health

Research intensifies as the public grows wary of one of its favorite communications tools

Are mobile phones safe?

A MOTORIST USING A wireless telephone might be worried about having an accident, even while being reassured that if one were to happen, he or she could call for help. Recently, some scientists and lay people have expressed alarm at another possible danger—that the use of mobile phones itself may harm the user's health, perhaps even causing cancer.

There is good reason to be concerned. The widespread use of hand-held mobile phones means that many people routinely place radio frequency (RF) transmitters against their heads—in some European and Asian countries, a majority of the adult population does so. That fact alone would warrant examination of the safety of this form of radiant energy.

Concern about the possibility of mobile phone's ill effects on health took shape in mid-1992 in a U.S. court. A lawsuit filed in Florida by David Reynard alleged that the use of a cell phone had caused his wife's fatal brain cancer. The suit was dismissed by a Federal court in 1995 for lack of valid scientific evidence, and similar suits since have been no more successful. But they have raised questions for which no entirely satisfactory answers existed at the time they were filed.

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University of Pennsylvania
&
JOHN E. MOULDER
Medical College of Wisconsin

PHOTOGRAPH: ROBERT LEWIS

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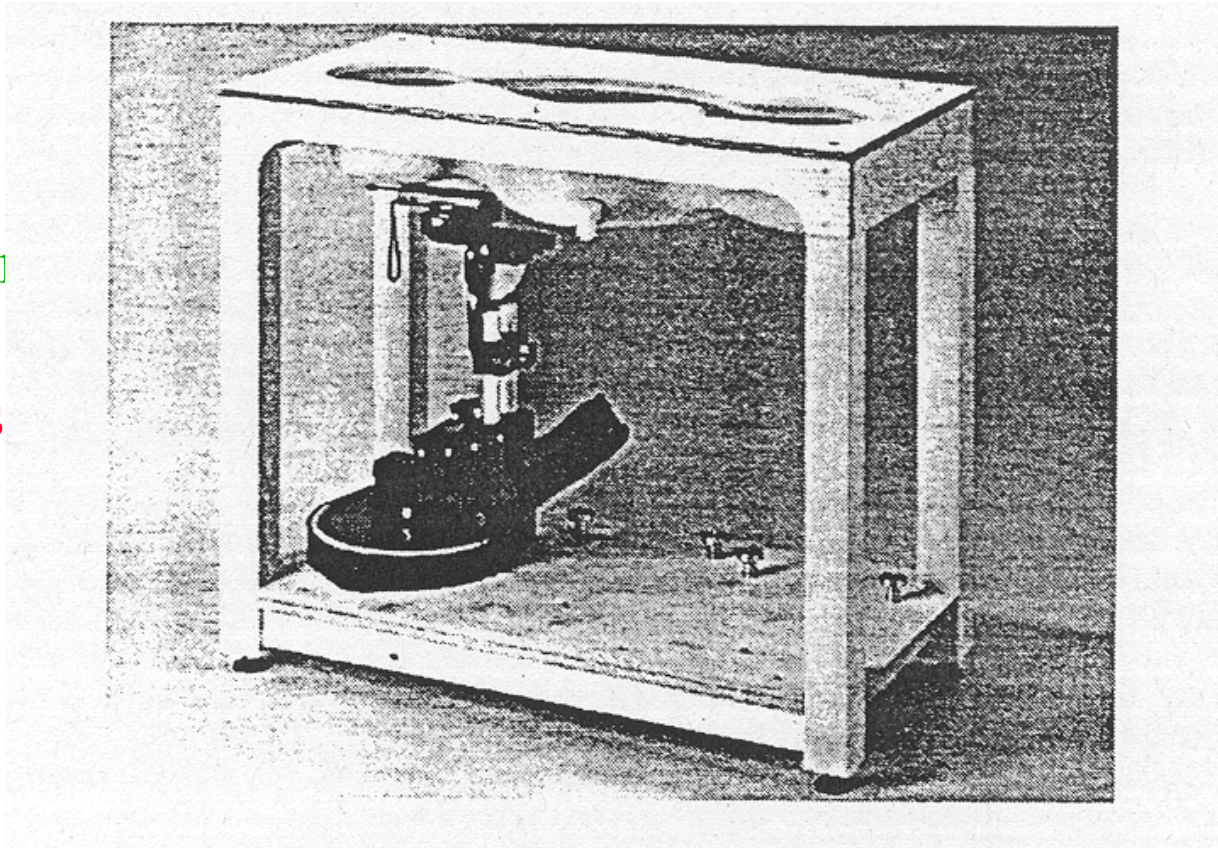
•Field measurements inside the head

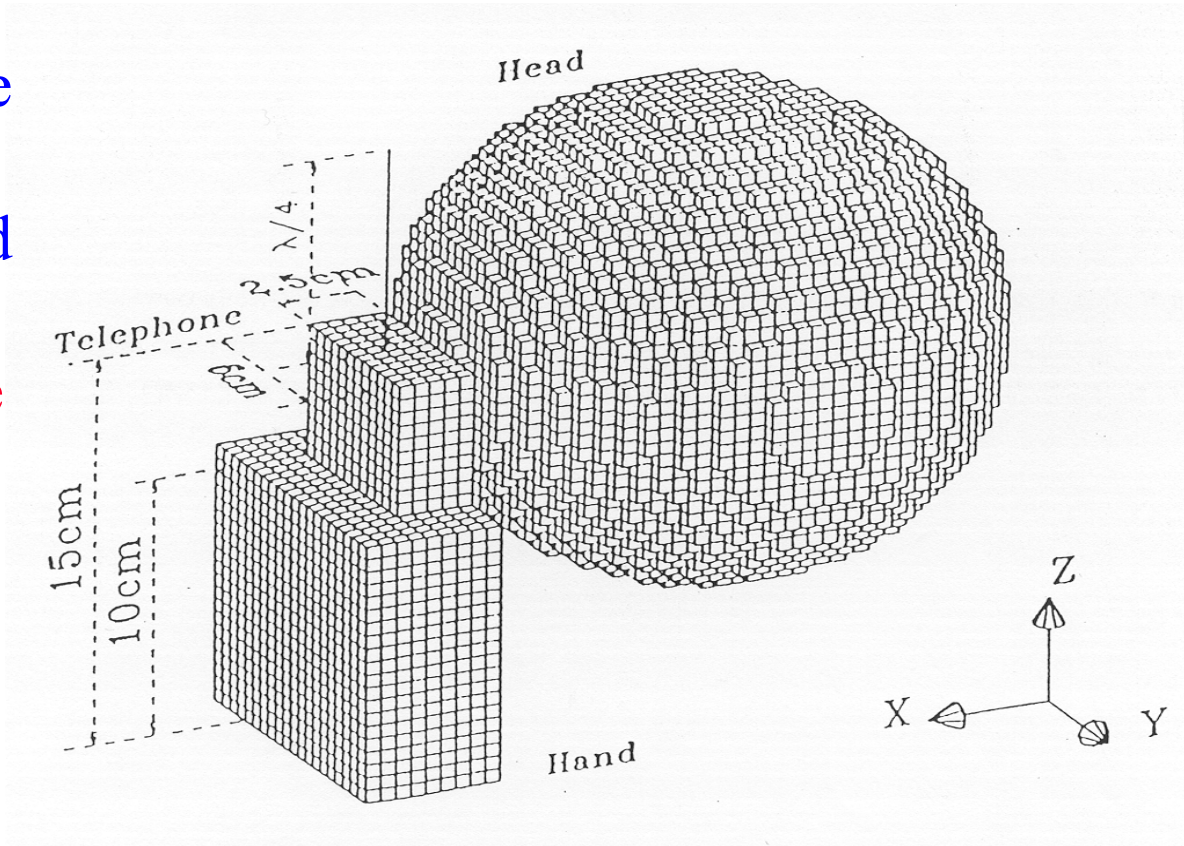
Phantoms simulating the tissue are used for measurements.

Very fine sensors are introduces inside the phantom.



•Model for numerical calculation

- the antenna and the metallic box of the phone are modelized with $E_{tang} = 0$
- for the arm and the head the model takes into account the dielectric properties of the tissues.



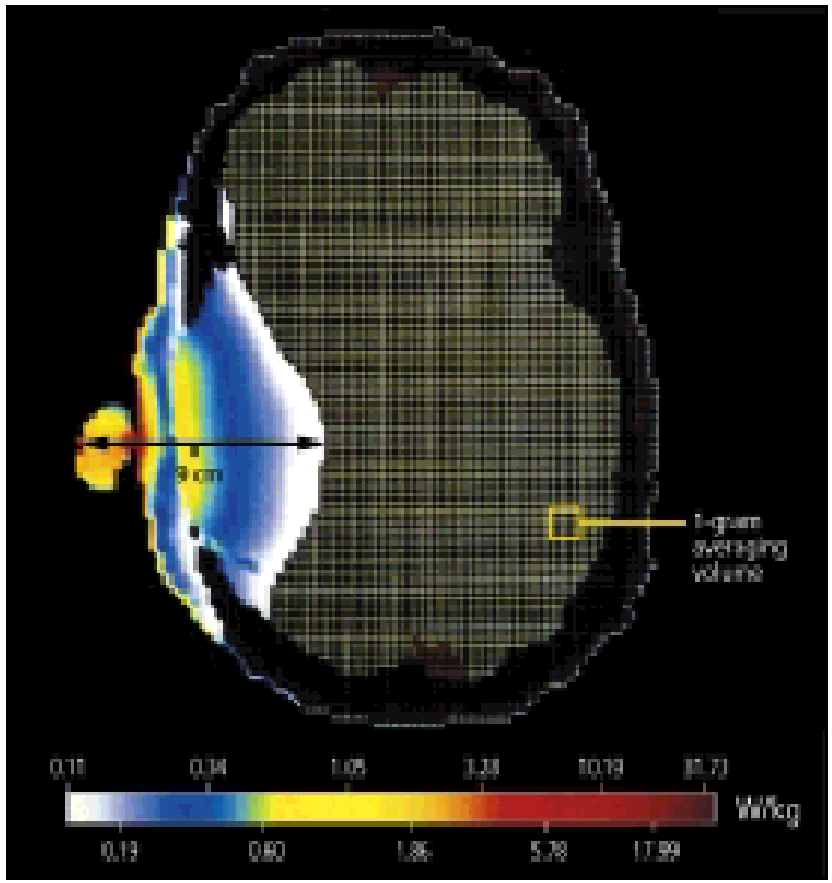
CELLULAR PHONES

•Results :

- the Specific Absorbtion Rate (SAR).

- temperature increase;

Temperature elevations of about 1 degree have been found.



CELLULAR PHONES

•Presence of other frequencies :

• modulation frequencies of 2, 8, 217, 1734 Hz + harmonics;

• The Time Division Multiple Access (TDMA) has a f = 217 Hz;
•The Discontinuous Transmission DTX) component produced when the user is connected but does not speak has a f = 2 Hz;

These ELF components :
• pulse the RF carrier wave;
•generate ELF magnetic field via battery;

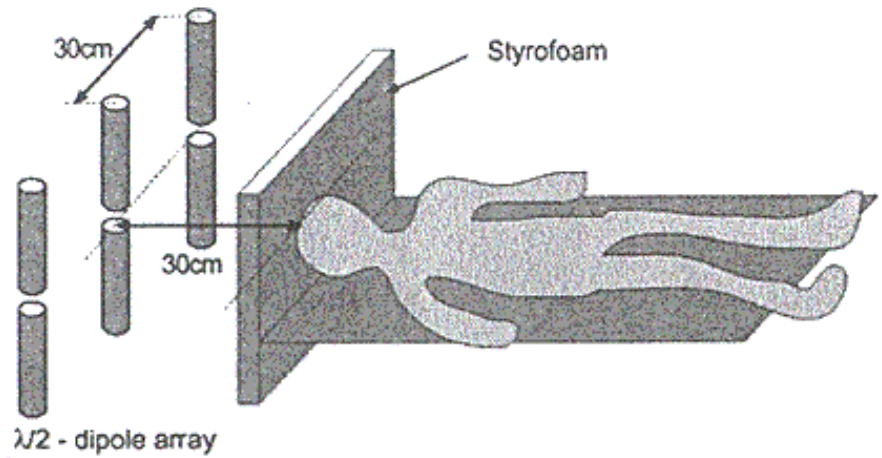
Recent study on the effects of cell phones on regional cerebral blood flow at ETH Zurich

Effects :

- modifies brain physiology and sleep behavior;
- increases regional cerebral blood flow;

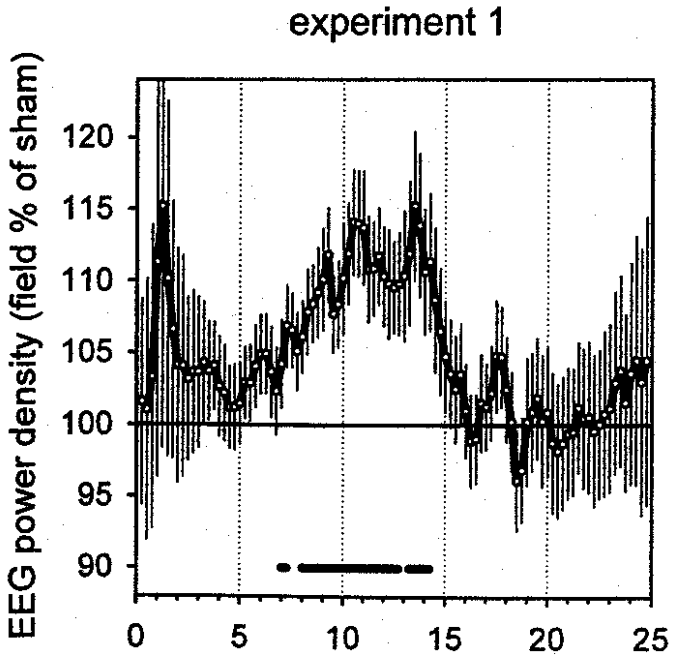
Exposure conditions :

- SAR : 1 W/kg;
- handsets : 1 time slot/8.
- base stations : 7 time slots/8;



Recent study on the effects of cell phones on regional cerebral blood flow at ETH Zurich

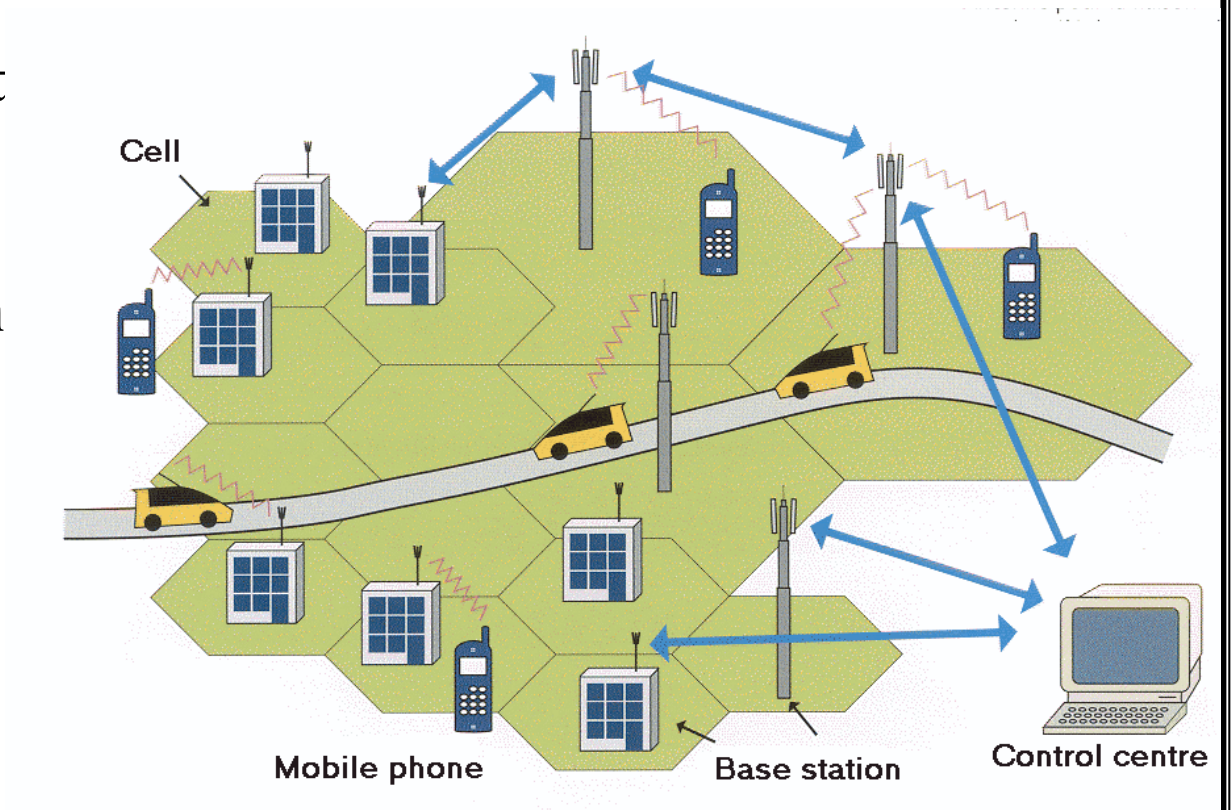
Effect on the electroencephalogram (EEG);
- the black bar indicates significant differences between EMF exposure and sham exposure.



CELLULAR PHONES

•Base stations

In order to respect limits :
Cellular concept of the base station arrangement on a given territory.



•BIOLOGICAL EFFECTS

•Due to :

• ELF or LF fields : a few Hz to 500 Hz

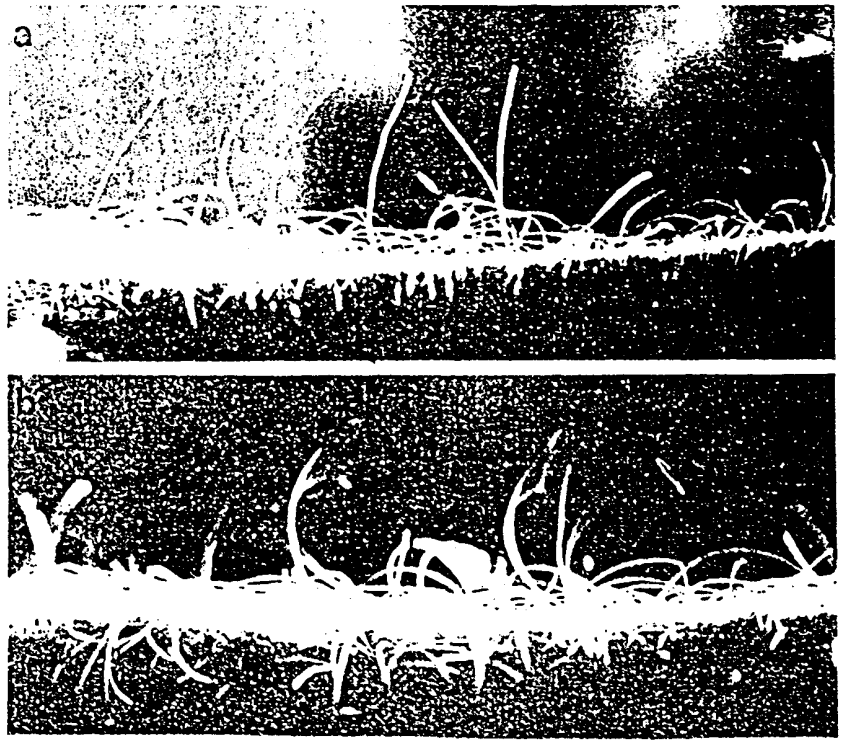
•HF fields : 900 MHz to a few GHz;

Biological effects due to 50/60 Hz

•Biological effects due to LF electric field :

•1) Electrostatic forces at the body surface ⇒ vibration of the hair system of humans and animals for E > 12 kV/m

•2) Microdischarges between the clothes and the skin.

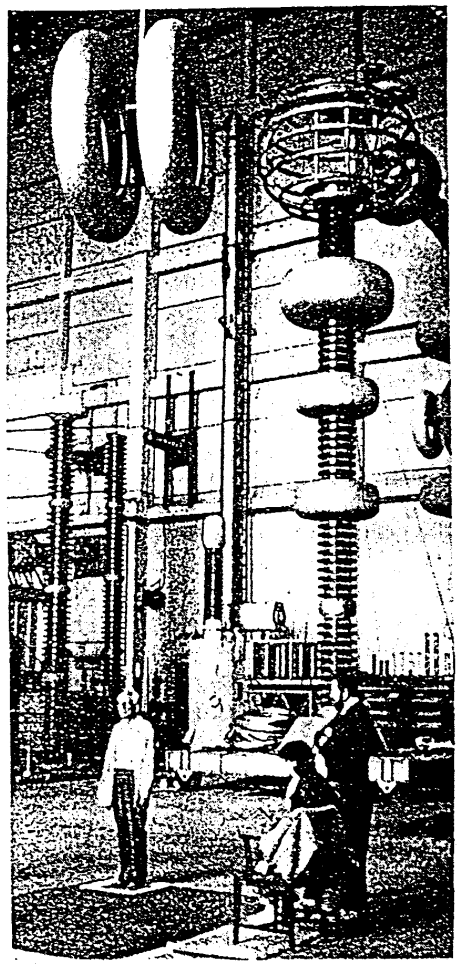


Biological effects due to 50/60 Hz

- Biological effects due
- to the electric field :

- 3) Effects on pacemakers :

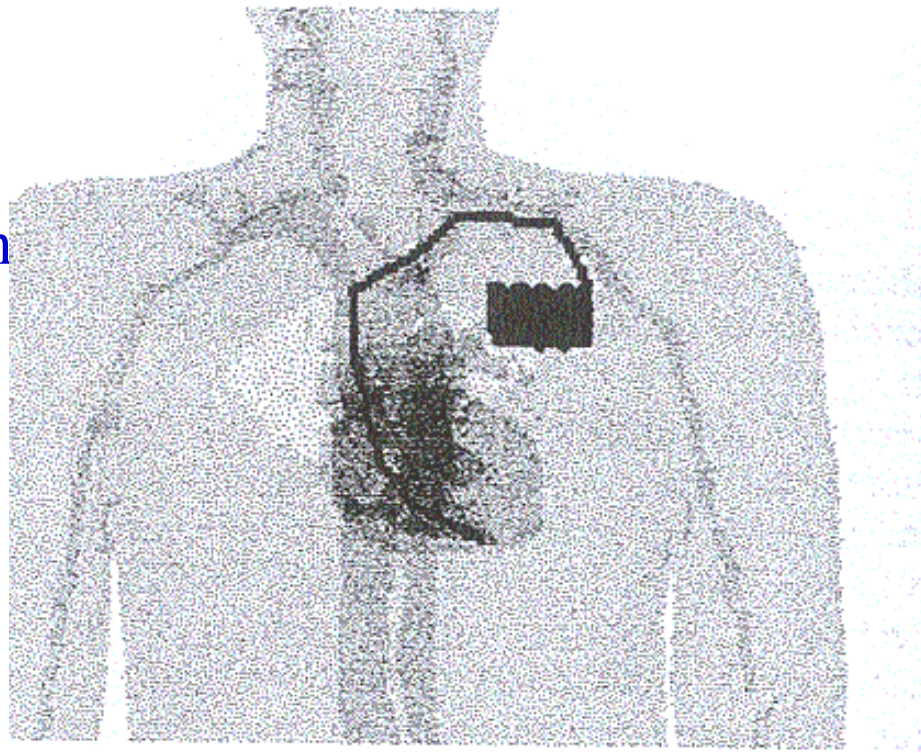
- Experimenntal studies in HV laboratories



Biological effects due to 50/60 Hz

- Effects on pacemakers :

- Pacemaker implementation modelling

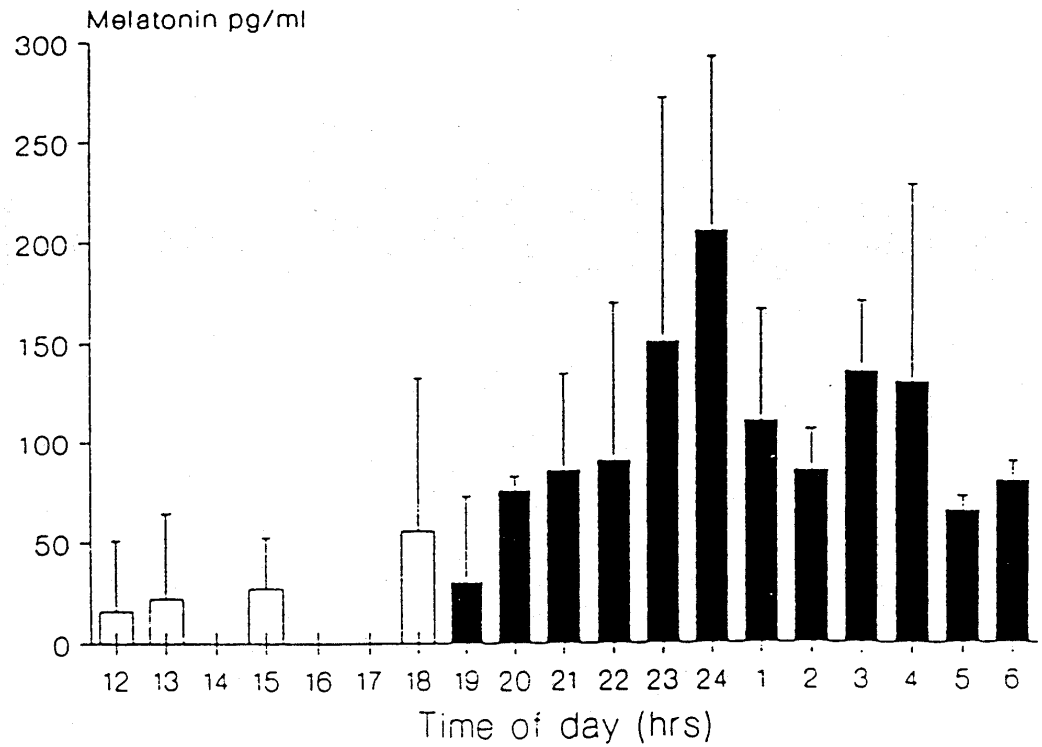


Biological effects due to 50/60 Hz

•Biological effects due to the magnetic field :

The melatonin : produced by the pineal gland.

Normal day to night variation of the melatonin.

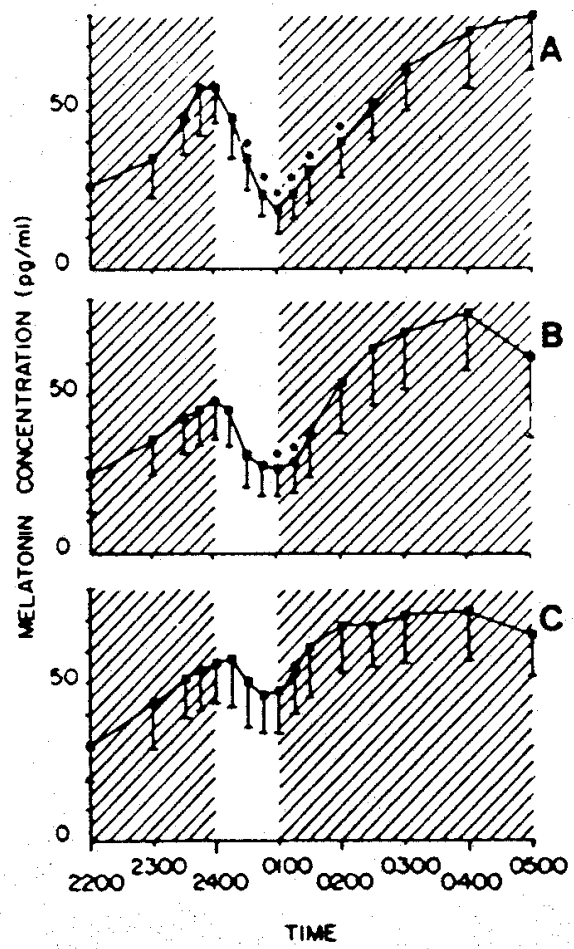


Biological effects due to 50/60 Hz

- Effect of light on the melatoni

- one hour of light exposure dur the night.
- Light intensity :
- A : 3000 lux
- B : 1000 lux
- C : 500 lux

- A very clear effect ⇒ decreas the melatonin.



Biological effects due to 50/60 Hz

Chronic 50 Hz magnetic field

↓

Pineal gland : reduced melatonin production

↓

Ovary : increased estrogen production
Pituary gland : increased prolactin production

↓

Increased turnover of breast
epithelial stem cells at risk

↓

Increased mammary carcinogenicity

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Influence of LF electromagnetic fields on the development and the molecular biology of the moss *Physcomitrella patens*

•Project participants :

•Prof. J-P. Zrÿd, Ecological Institute - University of Lausanne

•Dr. F. Rachidi, Prof. M. Ianoz, Power Systems Laboratory-Swiss Federal Institute of Technology - Lausanne

•Dr. Elena Comino and students - Politecnico di Torino

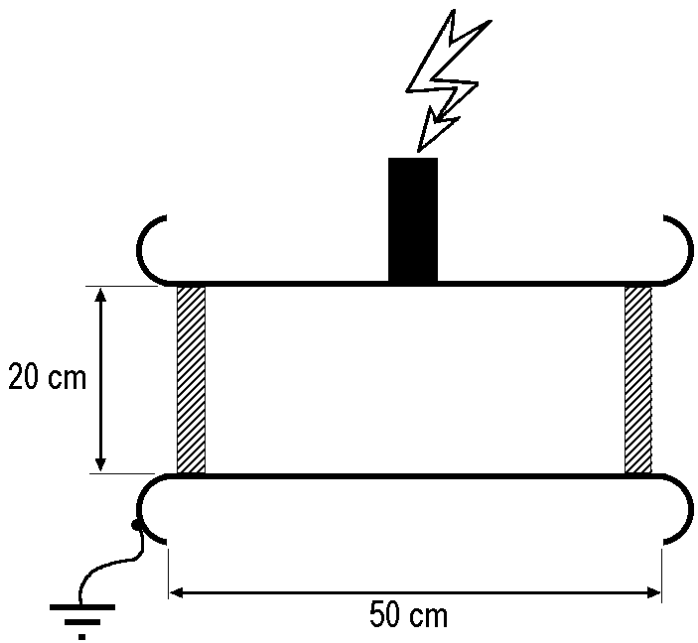
Biological effects due to 50/60 Hz

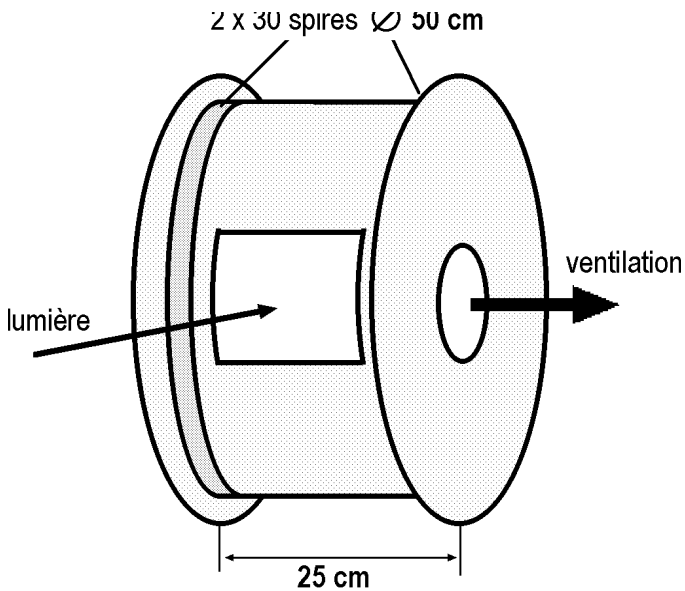
- Why vegetals ?
- - originality with respect to other tests
- - simple structures
- Choosed vegetals :
- a moss
- Psychomitrela patens

Why ? The moss behaviour well known by the biologists

Biological effects due to 50/60 Hz

Experimental arrangement at 50 Hz

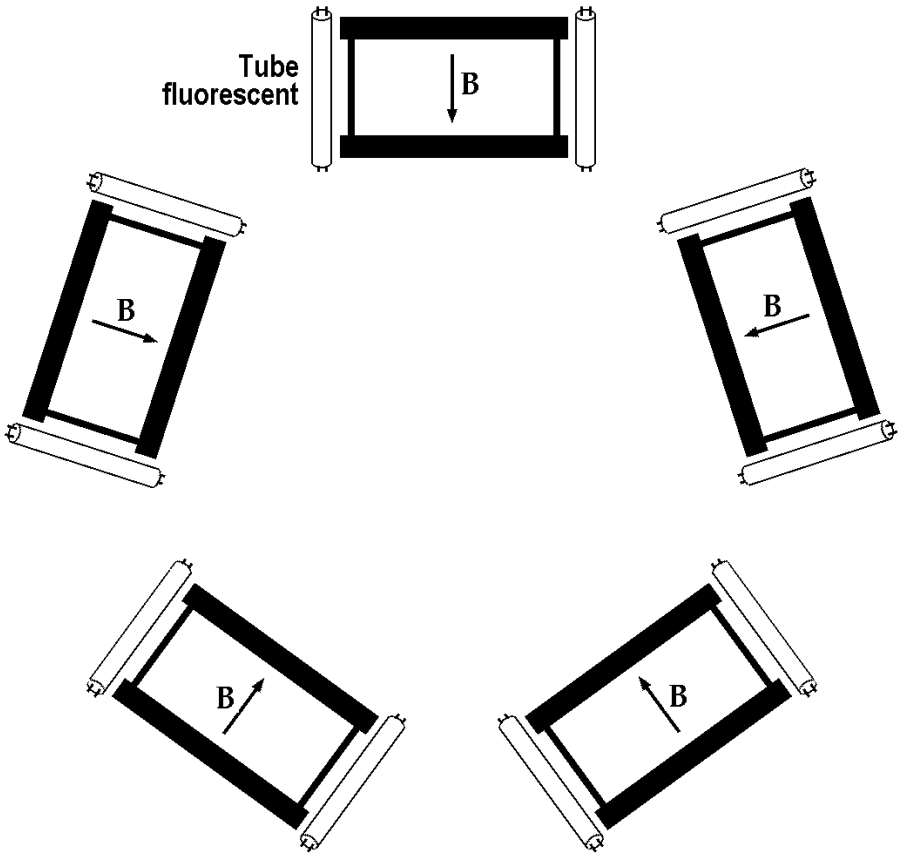




V_{max} = 80 kV; E_{max} = 400 kV/m I_{max} = 8 A; B_{max} = 1.2 mT

Biological effects due to 50/60 Hz

Coils arrangement

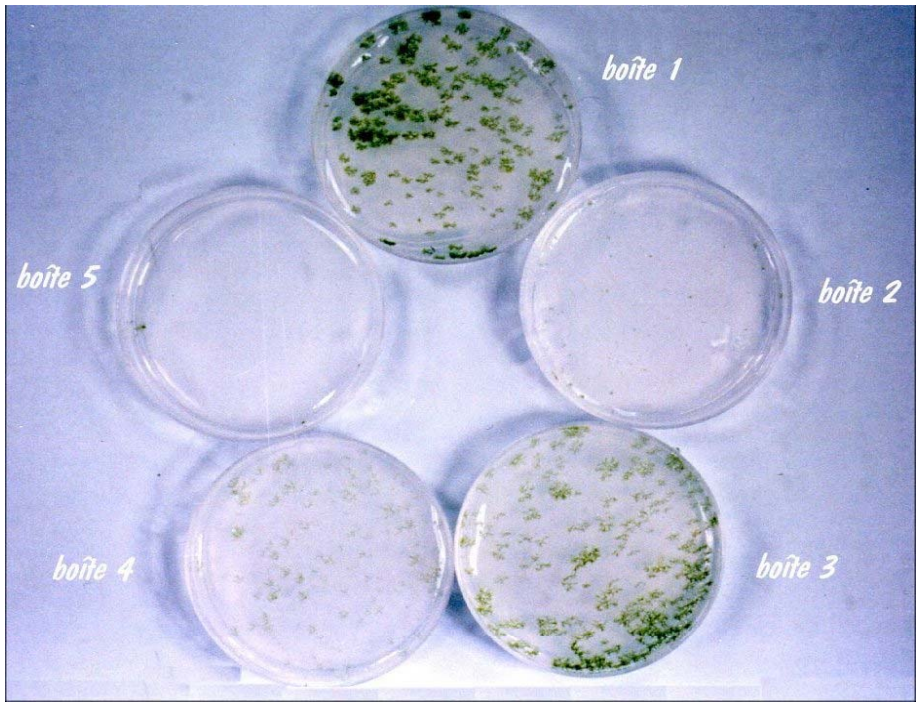


Temperature : 25 C
Lighting : 16h/day
Duration : 2 to 3 weeks

Fields : 50Hz and DC
50 Hz values :
0 - 0.6 - 0.9 - 1.2 mT

Biological effects due to 50/60 Hz

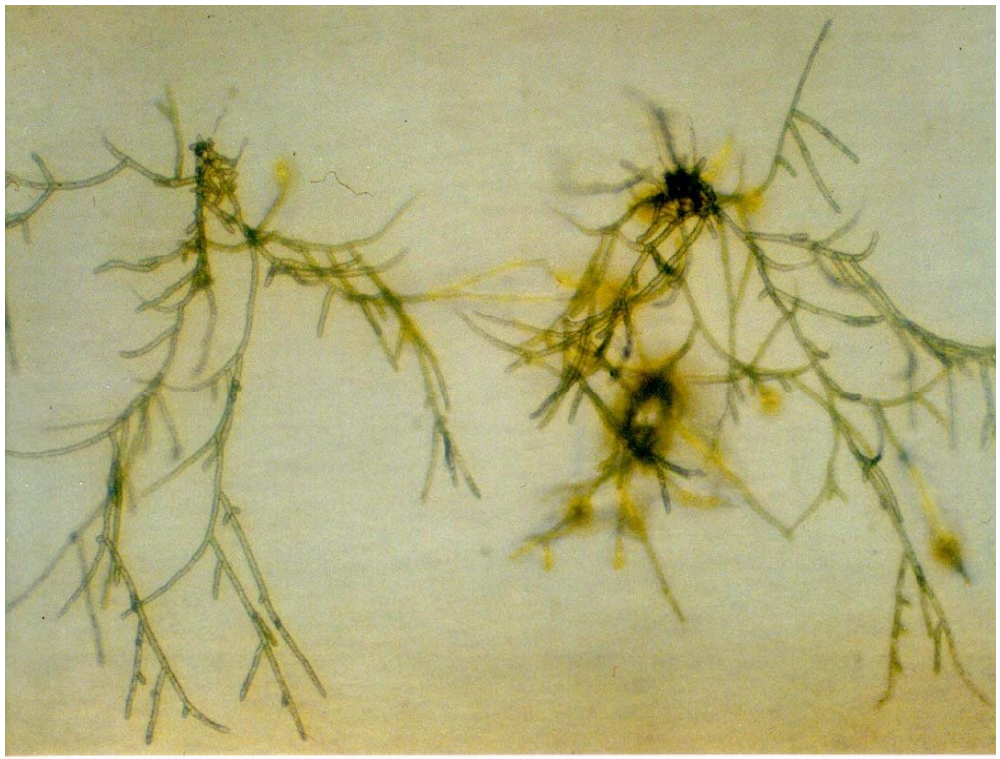
Mosses in plastic boxes



Aspect of mosses growth after a different number of days.

Biological effects due to 50/60 Hz

Normal and exposed moss aspect



Left : aspect of the moss during normal development.

Right : aspect of the moss with partial dead cells after MF exposure.

Biological effects due to 50/60 Hz H-Field

A longer time statistic has shown

No. Exp.	Control	6A/DC	6A/16Hz	6A/50Hz-1.07	6A/50Hz-1.2	6A/400Hz
1	100%	82%	87%	93%	-	107%
2	100%	77%	91%	82%	-	99%
3	100%	98%	78%	138%	-	167%
4	100%	84%	75%	114%	-	131%
5	100%	44%	56%	58%	-	108%
6	100%	74%	74%	97%	-	119%
7	100%	80%	66%	112%	-	141%
8	100%	99%	65%	75%	77%	119%
9	100%	72%	81%	68%	69%	122%
10	100%	106%	75%	74%	75%	116%
11	100%	120%	81%	89%	80%	132%

No influence

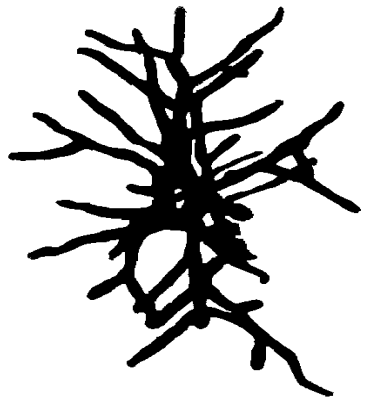
Delayed growth

Accelerated growth

Biological effects due to 50/60 Hz H-Field

A new tool : use of fractal characterization

Non-exposed plant
Fractal dimension = 1.64



Plant exposed at 50 Hz
Fractal dimension = 1.51

Experiment at 900 MHz

Experiments performed on :

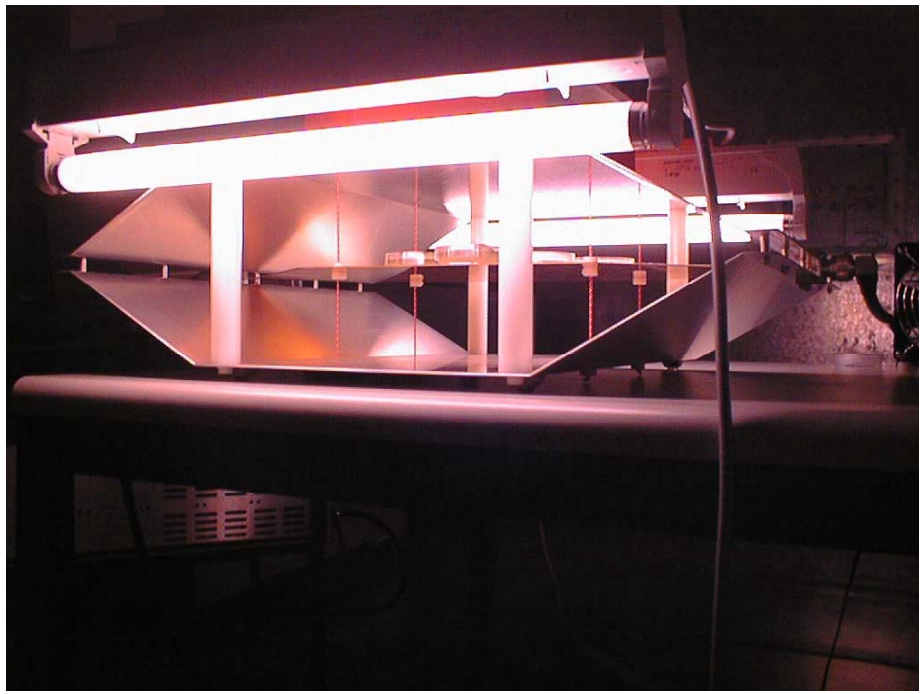
-- the moss *Physcomitrella patens*

-the nematode *Coenorhabditis elegans* .

- Field source : a TEM cell

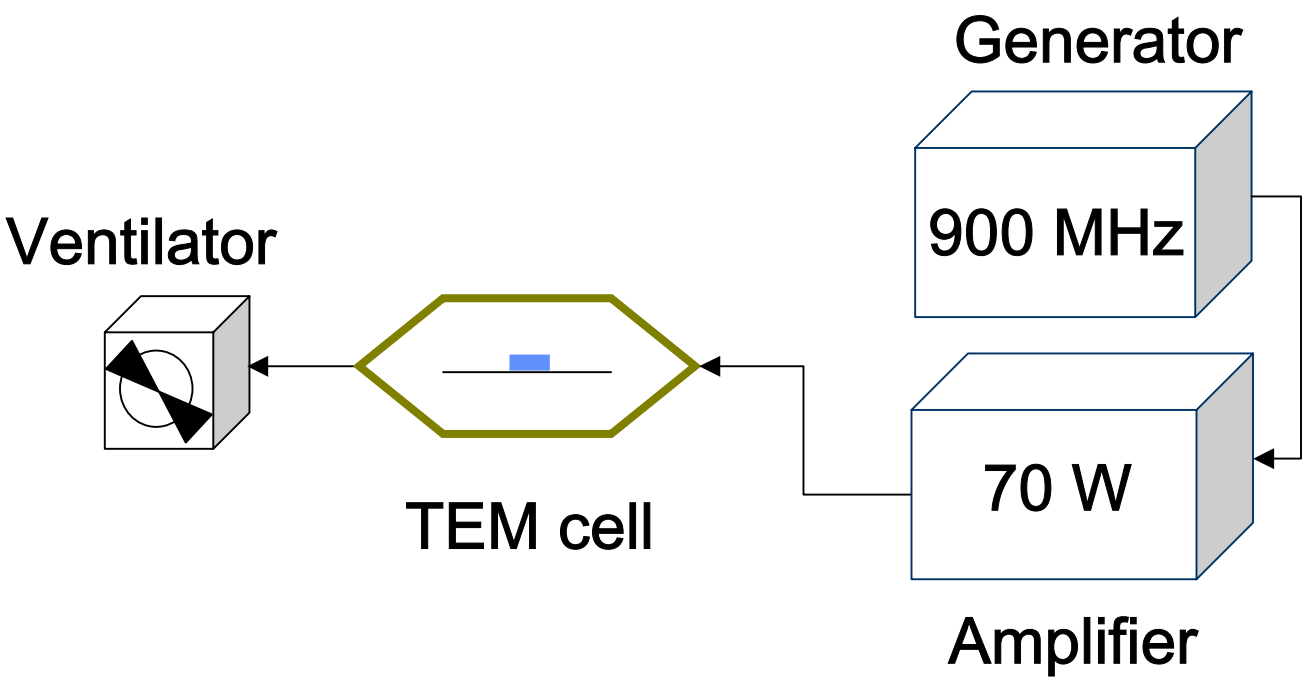
f = 900 MHz

E = 1000 V/m



Experiment at 900 MHz

EXPERIMENTAL DISPOSAL



Experiment at 900 MHz

- the HF criteria is usually the SAR.

Methods for the SAR evaluation :

- direct temperature measurement
- electric field measurement using sensors

Due to the *P. patens* configuration and the very tiny size of the *C. elegans*, none of the above methods is really suitable.

WORKING METHOD

- *Physcomitrella patens* cultivation in Petri dishes (6 days);

- Chlorophyll fluorescence measure with PLANT EFFICIENCY ANALYZER before the exposure to the field :

Moss exposure to the EMF;

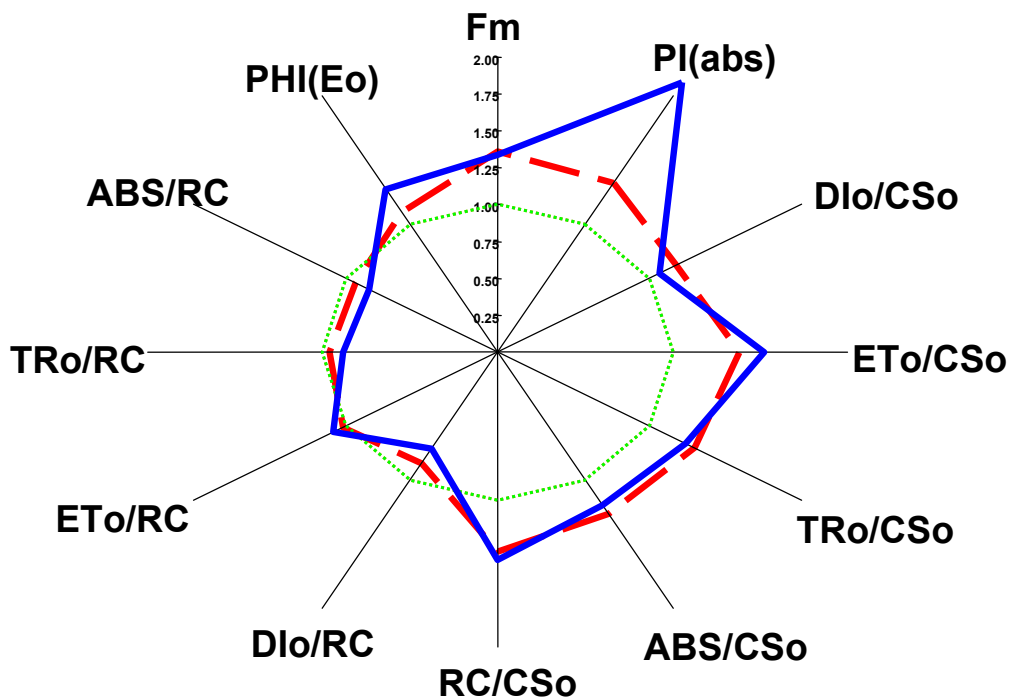
- Chlorophyll fluorescence measure after the exposure; (T_{exp} = 24h; 48h).

- Data processing with BIOLYZER.

Experiment at 900 MHz

Radar plot

T_{exp} = 24 h



control

EMF

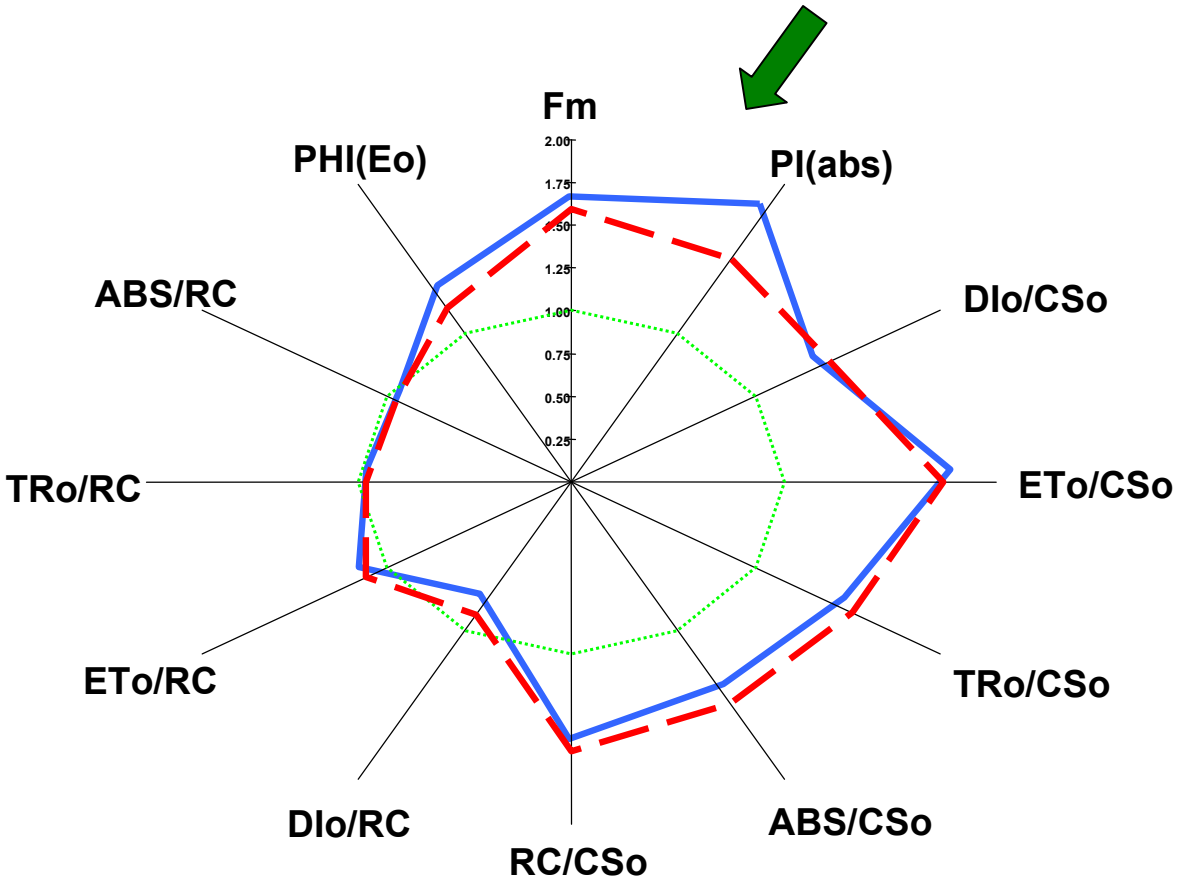
T_0

T_0

Experiment at 900 MHz

Radar plot

T_{exp} = 48 h



control

EMF

T_0

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Experiment at 900 MHz

EMC SOCIETY

The EM field exposure resulted in:

1. *Decrease* of performance index (PI)
2. *Increase* of inactive reaction centers (RC)
3. *Decrease* of electron transport (ET)

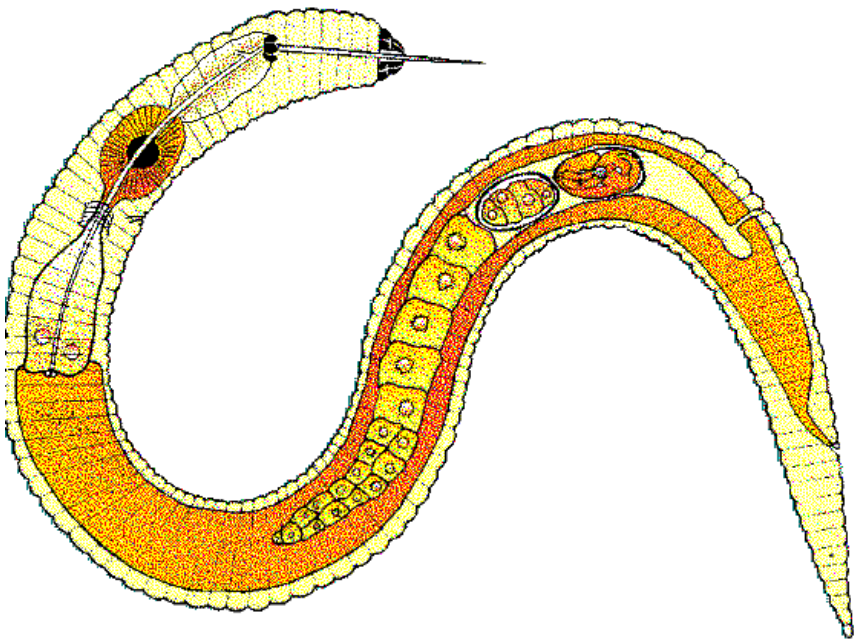
Perturbation of *Physcomitrella patens* photosynthetic activity after exposure to high frequency EMF

Method based on fluorescence measure is non invasive and useful to test the biological effect of environmental stress.

Experiment at 900 MHz

Another experimental approach :

Use of the nematode *Caenorhabditis elegans.*

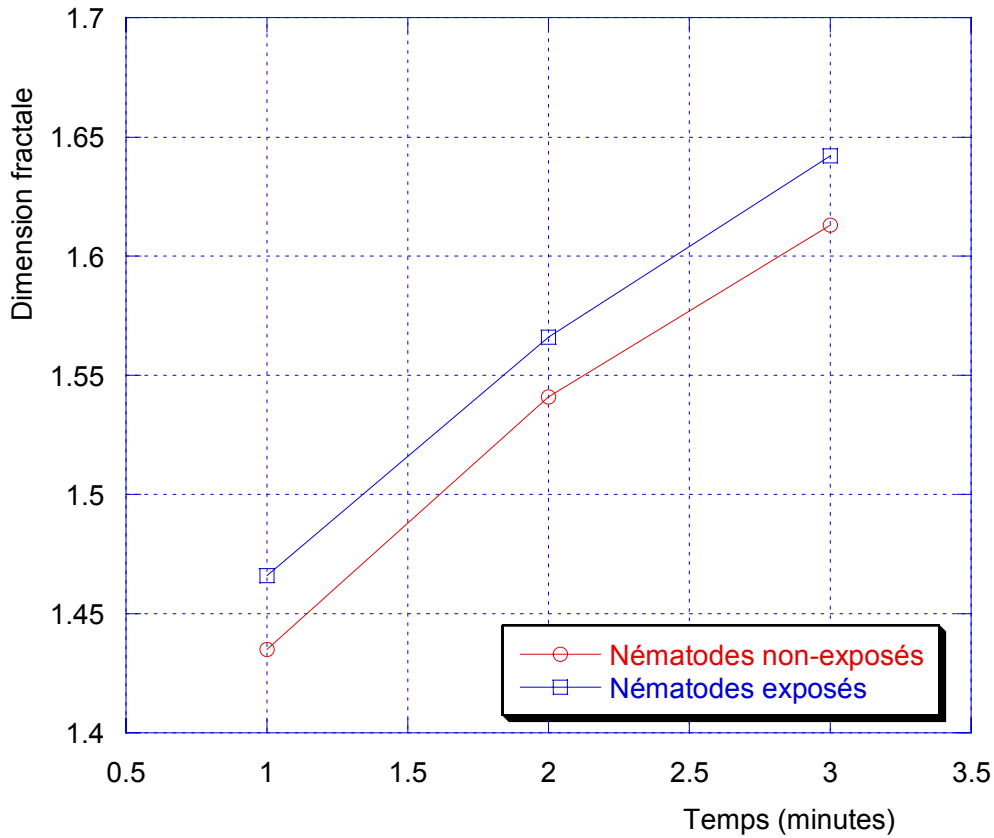


Advantage :
- completely known genome.

Experiment at 900 MHz

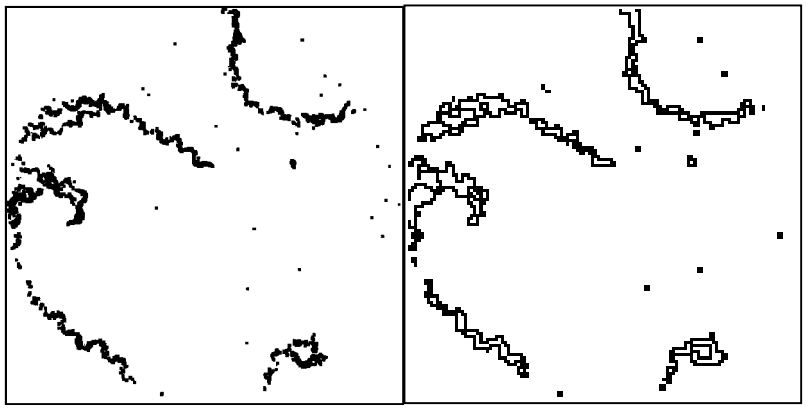
Preliminary results for C. elegans

Fractal dimension associated to the C. elegans mobility for 20 Petri dishes after a 3 days exposure.



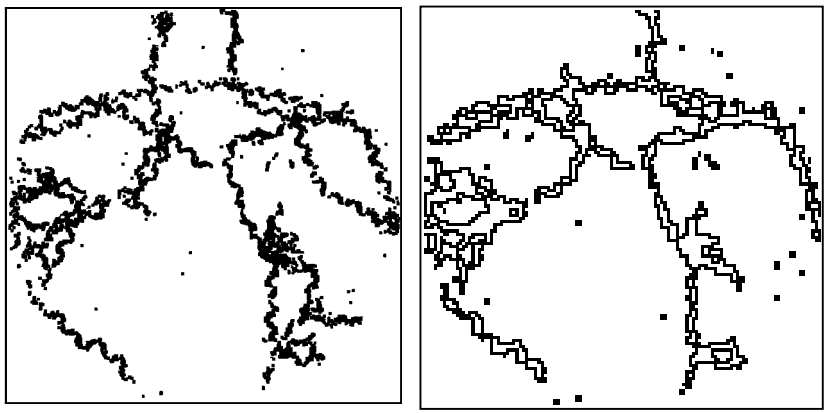
Experiment at 900 MHz

Fractal dimension associated to the C. elegans mobility



After 1 minute

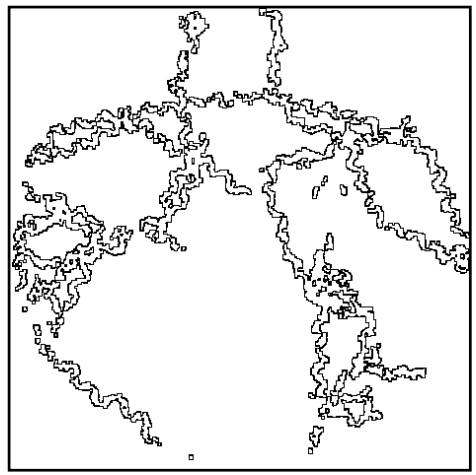
Fractal dimension 1.382



After 3 minutes

Fractal dimension 1.626

Use of an iterative filter



PRELIMINARY CONCLUSION

- need to provide the public and industry with more knowledge about the possible effects of cellular phones.

- thermal effects are known to exists.

- are there also other side effects ?

- the project is intended to open roads for future developments.

HEALTH EFFECTS

Health effects

Can be evaluated in three ways :

1) Epidemiological studies

2) Experiences on animals

3) Correlation of biological and health effects.

The first two methods have been used, the 3rd one begins now.

Health effects

Epidemiological studies

First studies of this type : the Wertheimer & Leeper study of 1979 and Savitz et al. of 1988 which seem to show evidence of higher leukemia rate for children living in the proximity of HV powwer lines.

Further epidemiological studies could not clearly confirm this result :

- in Scandinavian countries;
- EDF + Hydro-Québec + Ontario Hydro;
- american and swedish studies.

Health effects

Relative risk (RR) in epidemiological studies :

RR < 1.5 non significative risk
RR = 2 - 3 a risk difficult to evaluate
Example : RR for a heavy smoker = 40

The epidemiological studies gave usually for the electromagnetic fields a RR = to 1.5 - 3.

HEALTH EFFECTS

Swedish Study on *Childhood cancer and ELF Magnetic Fields*

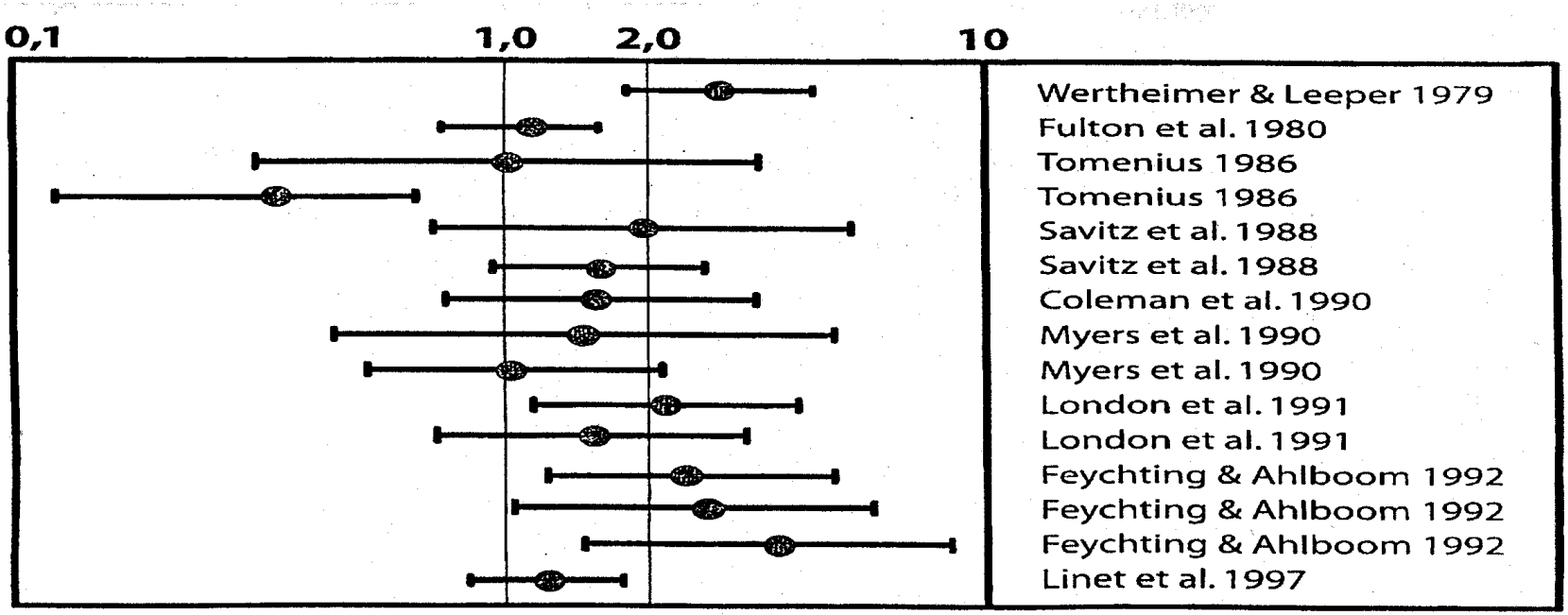
Population located within 300 m from 220 and 400 kV lines during the period 1960 to 1985.

Diagnosis	< 0.1 μT		0.1 - 0.19 μT		> 0.2 μT	
	No	RR	No.	RR	No.	RR
All cancer	117	1	12	1.5	12	1.1
Leukaemia	27	1	4	2.1	7	**2.7**
Brain tumors	29	1	2	1	2	0.7
Lymphomas	16	1	1	0.9	2	1.3

Only Leukaemia RR = 2.7 for B > 0.2 μT indicate a very small possible adverse effect.

HEALTH EFFECTS

Review of child leukemia studies related to power lines



Health effects

Ahlbom et all. Study on child leukemia : 4 categories :

- < 0.1 μT ⇒ used as non-exposed group
- 0.1 – 0.2 μT
- 0.2 – 0.4 μT
- > 0.4 μT mean RR = 2 (1.27 – 3.13)

Field mean values on 24 or 48 hours, during the year before the illness was declared.

The International Center on Cancer Research (ICCR) has adopted for the moment the **0.4 μT value as cut off value**.
Impossible to chose a higher value because populations exposed to B > 0.4 μT are too small to be statistically significative.

Health effects

Why do the epidemiological studies give aproximative results :

- it is imposible to separate other factors like pollution;

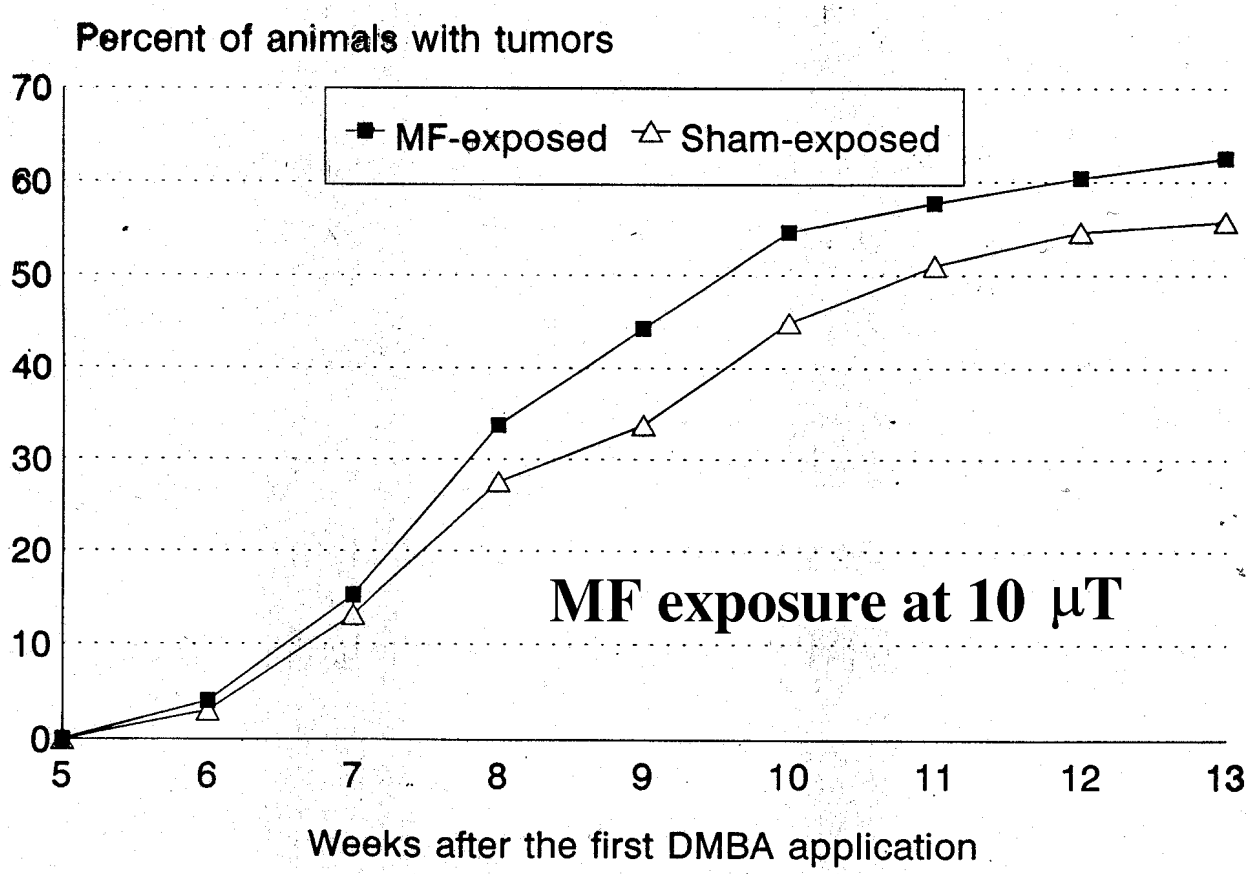
- field values in residential environments ⇒ very low (of the order of 0.1 μT)

- lack of toxicology data to prove the potential cancerogenic effect of the magnetic field.

Epidemiology is not an experimental science but a statistical approach ⇒ low statistical evidence.

Effects on health

Animal studies on 50/60 Hz field effects on induced cancer :



STANDARDIZATION
AND
LIMITS

STANDARDIZATION

Not any IEC or CENELEC approved standard giving limits for any kind of electric or magnetic fields.

TC106 of IEC has the task to produce standards on «Measurement methods for EM fields».

Official documents on limits have been published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Standardization and limits

- **Maximum E-field values at f = 50 Hz for human exposure**
-
- Short time (kV/m) 8 or 24 hours (kV/m)
- ICNIRP
- profesional 10
- public 5
- ----------
- ORNI
- (Switzerland)
- immition value for public 5

Standardization and limits

- **Maximum B-field values at f = 50 Hz for human exposure**
-

	Short time (μT)	8 or 24 hours (μT)
ICNIRP		
occupational		500
public		100

ORNI for public	
(Switzerland)	
immition	100
emission	1

Standardization and limits

PUBLIC HEALTH AND STATIONARY ANTENNAS

	SAR (W/kg)		FREQ. (MHz)	POWER-FLUX W/m²	E-FIELD V/m
SF 50	4				
public	0,08	calcul →	900	4,5	41
			1800	9	58
			2450	10	62
HF 4					
public	0,02	→ calcul	900	1,1	21
			1800	2,3	29
			2450	2.5	31

BELGIUM

Standardization and limits

PUBLIC HEALTH AND STATIONARY ANTENNAS

Country/ freq.		900 MHz	1800 MHz	2,45 GHz
EU, WHO		4,5 W/m²	9 W/m²	10 W/m²
Belgium (F)	4	1,13	2,25	2,3
Italy (G)	50	0,1	0,2	0,2
Switzerland	100	0,042	0,095	0,1
Belgium (W)	200	0,024	0,095	0,1
Paris	200	0,024	0,095	0,1
Austria (S)	4500	0,001	-	-

By courtesy of Prof. W. Van Loock

Standardization and limits

- The low emission value based on the precautionnary principle.

- The precautionnary principle says that lack of certainity, given the current scientific and technological knowledge shall not delay effective and proportionate actions to prevent hazards, taking into account cost - benefit considerations.

Standardization and limits

- **Examples of the use of the precautionnary principle :**

- The laws and measures concerning Genetically Modified Organisms.

- Example of cost - benefit consideration :

- Cost of HV power line mitigation in Italy a few bilion USD
- Benefit : 1 child leukemia case/year.

Standardization and limits

- **Examples of the use of the precautionnary principle :**

- Children garden on the ground floor of a building over a train track in the town of Geneva.

- Magnetic field measurements :

- **2.4** μT average value, with peak values during short periods of **12** μT.

- **Municipality decision : move the children garden.**