

# Effects of Radiofrequency Fields

*(current concepts and forthcoming questions)*

**Dr. György Thuróczy**  
*head of Dept.*

**National Research Institute for  
Radiobiology and Radiohygiene**

*Dept. of Non-Ionizing Radiation*

1221 Budapest, Anna u 5. Hungary

*Tel: +36 1 482 2019 fax: +36 1 482 2020*

*thuroczy@hp.osski.hu, [www.osski.hu](http://www.osski.hu)*



# Presentation outline

- **Exposure assessment to RF**
  - population exposure to RF radiation
  - GSM base station contributions in RF
- **RF dosimetry**
  - basic considerations
- **Established and proposed interaction mechanisms**
- **Biological effects**
  - cellular endpoints
  - other biological endpoints
  - dose response concepts
- **Forthcoming issues in RF research**
- **Hot issue in RF: Mobile phones**

# Human exposure to RF from various RF source

RF exposure ▶ RF source ▼	RF-CW	RF-AM	RF-FM	RF PM	RF UWB
Broadcasting		+++	+++		
Telecom			++	+++	
Medicine	++			+	
Industry	++			+	+
Home	+++				
Military			++	+	+
Emerging Technology		+	+	+	+

# Characterization of human exposure to RF

Exposure ▶ Source ▼	Long term- low level whole body	Intermittent whole body	Intermittent partial body	Intermittent Highly local	Short term Transient whole or partial body
Broadcast	+++	+			
Telecom	++		++	+++	
Medicine			+	++	
Industry	++		++	+	
Home			++		
Military			+	++	+++
Emerging technology			+	+	+++

# Environmental and public exposure to RF

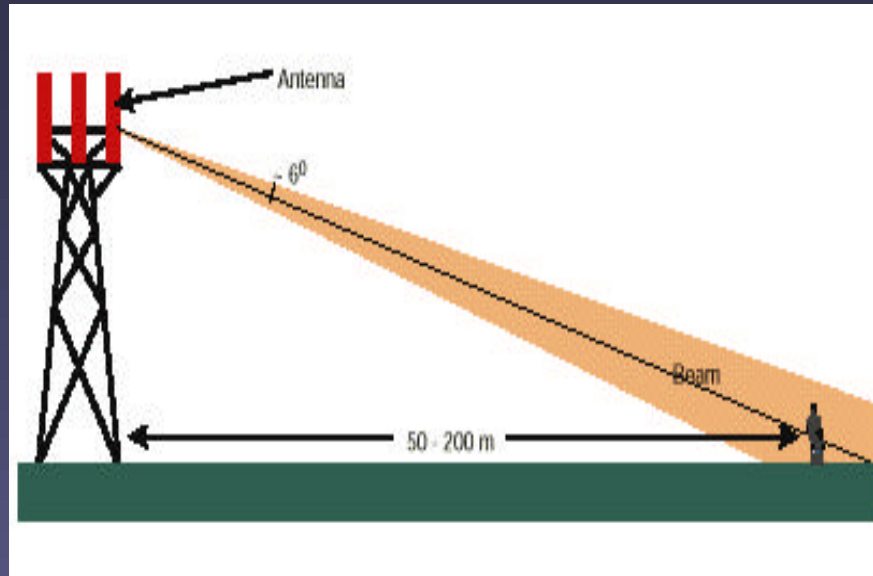
- **Environmental RF exposure:**
  - rapid proliferation of RF sources (i.e. base station, BS)
  - raise of ambient RF radiation: **1980 (USA): 50 mW/m<sup>2</sup>**  
**1999 (Sweden): 500 mW/m<sup>2</sup>**
  - An increasing contributions of GSM sources in the RF range (up to 39-61 %)
- **Public exposure to RF from broadcasts (*Tell RA, 1980, USA*):**
  - 486 locations, 15 large cities, 14 000 measurements, 50-900 MHz
  - median exposure level (that level to which half of the population is exposed greater than) **0.005 m W/cm<sup>2</sup> (50 mW/m<sup>2</sup>)**
  - for cumulative population represents the 20 % of total US population
  - approximately 1 % of population greater than **1 mW /cm<sup>2</sup> (10 000 mW/m<sup>2</sup>)**
  - FCC guidelines **> 200 mW/cm<sup>2</sup> (2 000 000 mW/m<sup>2</sup>)**

**Mean contributions from different RF sources**  
 (mean percent part of the total ratio from RF environment  
 given in percent, 30 MHz-2100 MHz)

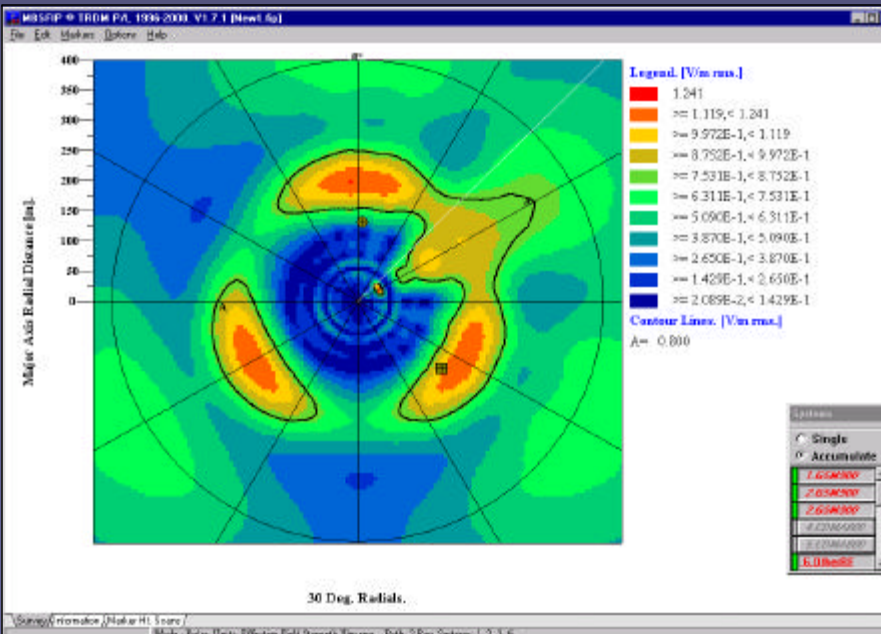
*Hamnerius, 1999,*

<b>System</b>	<b>City area %</b>	<b>Town %</b>	<b>Rural %</b>	<b>Residential %</b>	<b>Total %</b>
<b>Radio</b>	<b>13</b>	<b>1</b>	<b>11</b>	<b>20</b>	<b>15</b>
<b>Television</b>	<b>13</b>	<b>1</b>	<b>48</b>	<b>24</b>	<b>23</b>
<b>NMT 450</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>0</b>	<b>1</b>
<b>NMT 900</b>	<b>1</b>	<b>2</b>	<b>0</b>	<b>0</b>	<b>1</b>
<b>GSM 900</b>	<b>61</b>	<b>53</b>	<b>39</b>	<b>41</b>	<b>47</b>
<b>GSM 1800</b>	<b>4</b>	<b>9</b>	<b>0</b>	<b>5</b>	<b>3</b>
<b>Various</b>	<b>6</b>	<b>33</b>	<b>0</b>	<b>10</b>	<b>10</b>

# Typical exposure around base stations

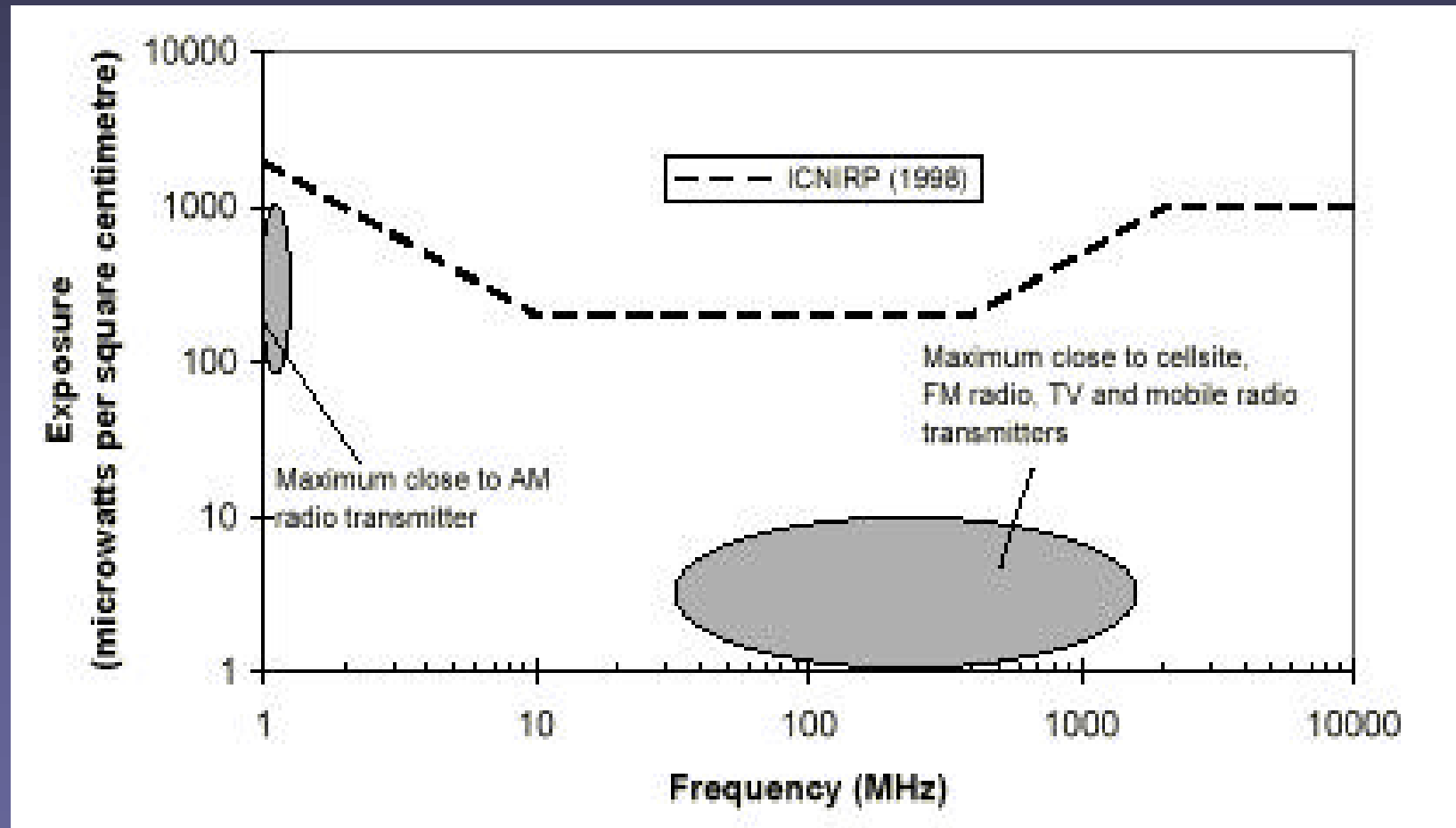


- The beam reaches the ground at 50-500 m approx.
- Power density decreases inversely with the square of distance in free space
- In the building area decreases to an exponent around 3.5



- at 30 m: **< 0.05 - 0.5 mW/cm<sup>2</sup>**
- at 50 m: **< 0.01 - 0.8 mW/cm<sup>2</sup>**
- on the roof: **0.1-10 mW/cm<sup>2</sup>**
- ICNIRP/EU guidelines for general public: **450 mW/cm<sup>2</sup>** (900 MHz) or **900 mW/cm<sup>2</sup>** (1800 MHz).

# Maximum human exposure to RF close to *AM, FM* and *base station transmitters* comparison to *ICNIRP* reference levels



## Recent studies on public exposure to RF in the living environment

- Hamnerius, Y. (Sweden, 2000)*: RF spectral measurement on 26 sites in four different environment (city, town, rural, indoor) in the RF range 30 MHz-2000 MHz in 1999-2000.
- Neubauer, G. (Austria, 2000)*: RF spectral measurements around base station mainly in Salzburg area. Cities and towns 100 sites, rural area 102 sites from 1997 to 1999.
- Line P. (Australia, 2000)*: RF spectral measurements at 14 different locations. 24 hour data logging, indoor, outdoor measurements (available: [www.arpansa.gov.au](http://www.arpansa.gov.au))
- Mann SM. (NRPB-UK, 2000)*: RF spectral measurements at 118 locations at the 17 sites in UK.
- Gajda G. and Thansandote A. (Canada, 1998)*: A survey of RF emissions at five Vancouver area schools. Date of survey 1997 December. Spectral measurements including AM broadcast to PCS systems.
- COST 244bis (A,B,F,G,H,S, 1999-2000)*: RF spectral measurements in six EU countries around base stations. Final report under preparation.

# RF exposure assessment: conclusions

- All studies support that in all examined positions RF exposure at the sites accessible to public were *many times below* (ten thousands to millions of ICNIRP reference levels) *the exposure limits* of the ICNIRP/EU guidelines.
- Otherwise the *continuous rise of ambient RF radiation* levels have been detected.
- Because of the proliferation of base station antennas the *contribution of RF exposure due to GSM technology* is increasing.

# RF exposure assessment: conclusions

- The exposure of population show a very large variation. Basically there are three different sources of such variations:
  - **large scale variation** because of variations of exposure between different places and between different times at a given location (influenced by how the measurement sites were selected)
  - **signal variations** induced by propagation path and technology
  - **uncertainty in measurements** due to the measurements techniques
- Therefore any **studies (i.e. epidemiological) of populations** with residential exposure from RF sources **present difficulties**, because of the low RF fields, high variations of exposure and bias.

# RF dosimetric considerations

- Current concepts :
  - The physical quantity of absorbed RF exposure as *Specific Absorption Rate SAR (W/kg)* is accepted.
  - The *whole body and local SAR* have been computed and measured widely in order to estimate the RF absorption of the examined object from the ambient RF exposure (from *Power Density* to *SAR*).
  - The current *SAR* measurement and computing are *macroscopic* .
  - The current development in RF dosimetry:
    - improving the *local SAR measurements* (mobile, experiments etc..)
    - partial body exposure and SAR in *highly non-uniform* RF field
    - trials for *microscopic* (cellular, subcellular) RF dosimetry and local microscopic EM fields

# RF interactions with biological systems: Scales

## Level of mechanisms

EM interaction  
biophysics  
biochemistry  
biology  
physiology  
health



## Level of site

molecule  
membrane  
cytoplasm  
cell  
organ  
organism



Do the biological effects lead to any adverse health effects ?

# RF interactions and mechanisms

- Established interactions and mechanisms:
  - Evidence: The *quantum energy* of RF fields is far too low to directly break molecular bonds.
  - Established EMF interaction: the forces that *electric fields exert on charges* and charged particles which depends on the :
    - magnitude and time dependence of the force → *frequency dependence*
    - properties of the system → *threshold due to “kT problem”*
    - the rate at which the structure losses energy to its environment → *time-delay of the response*
  - Deposition of RF power in biological objects *leads to heating*. Heating proportional to SAR, thus power density.
  - Indirect auditory response due to heating: *thermoelastic expansion*

# RF interactions and mechanisms (cont'd)

- Other proposed interactions and mechanisms:
  - **Rectification**: nonlinear detectors may exist → a biophysical process is produced at the modulation frequency of RF field
  - **Resonance**: sharp frequency (carrier and/or modulation) dependence related to charged species and RF frequency.
  - **Calcium oscillations**: Experimental findings on the effects on  $\text{Ca}^{++}$  efflux and intracellular deposition. Major role for  $\text{Ca}^{++}$  as a messenger in the transmembrane signal transduction (AM, FM signals to the cell) have been suggested.

# RF interactions and mechanisms (cont'd)

- Other proposed interactions and mechanisms:
  - **Magnetite-based mechanisms:** Supposed mechanical forces on magnetic particles as the interaction with EMF. Little evidence on RF (more in the ELF range). The role of magnetite in humans unclear (*work by Kirschvink*).
  - **Radical pair mechanisms:** Supposed effects on the recombination rate of radical pairs
  - **Temporal and spatial consistency:** “memory” of cellular receptors introduced on ODC enzyme activity, effects destroyed by noise (*work by Litowitz*). Attempts at replication have failed so far.
  - Others.....

# RF interaction mechanisms and health effects

- Thermal vs. “non-thermal” and other concepts :
  - The *non-thermal physical mechanisms* in the EM interactions are well established (i.e. field-charge, field-dipole interactions etc.)
  - The *non-thermal health effect* and non-thermal biological interactions are ambiguous:
    - mechanisms is not related to temperature increase (?)
    - the absence of temperature rise in the observed biological effects (?)
  - Effects of *weak-field* or *low-level* : many cases lack of interpretation of the interaction mechanisms and theory.  
*What does the weak field or low level means?*
    - below the 4 W/kg threshold (?)
    - below the guidelines (?)
    - below the medium environmental levels (?)
    - below endogenous EM level (?)
    - below thermal noise (kT) (?)
    - below ..... (?)

# Cellular effects and endpoints due to RF exposure

- DNA strand breaks: no *replicated evidence* of DNA and/or repair damage due to RF exposure (*Lai vs. Malayapa*).
- Genotoxic potential: Most of RF studies concluded that RF exposure *is not genotoxic* or *mutagenic*. Otherwise the *gene expressions* in response to stressful challenges as a sensitive early marker of the cellular response have been studied recently. The most investigated issue the set of genes producing *heat shock proteins (HSP)*, even without detectable elevation of temperature due to RF exposure (*de Pomerai, 1999, 2000*)
- Other indirect cytogenic indicators: no evidence of induction *chromosomal aberrations* and *micronuclei* after RF exposure (*recently Vijayalaxmi, 2001*). Some positive findings occurred under conditions in which RF exposure elevated the temperature.

# Other biological effects and endpoints due to RF exposure

- Cancer induction/promotion: Most of studies have not shown that RF exposure can increase cancer incidence or promotion. The positive result on *transgenic animals* is under replication. Difficult to interpret in terms of its implications for human health.
- Other cell proliferation indicators: Modest increase of *ornithine decarboxylase (ODC)* activity only at specific AM modulation frequencies but DNA synthesis was not subsequently increased.

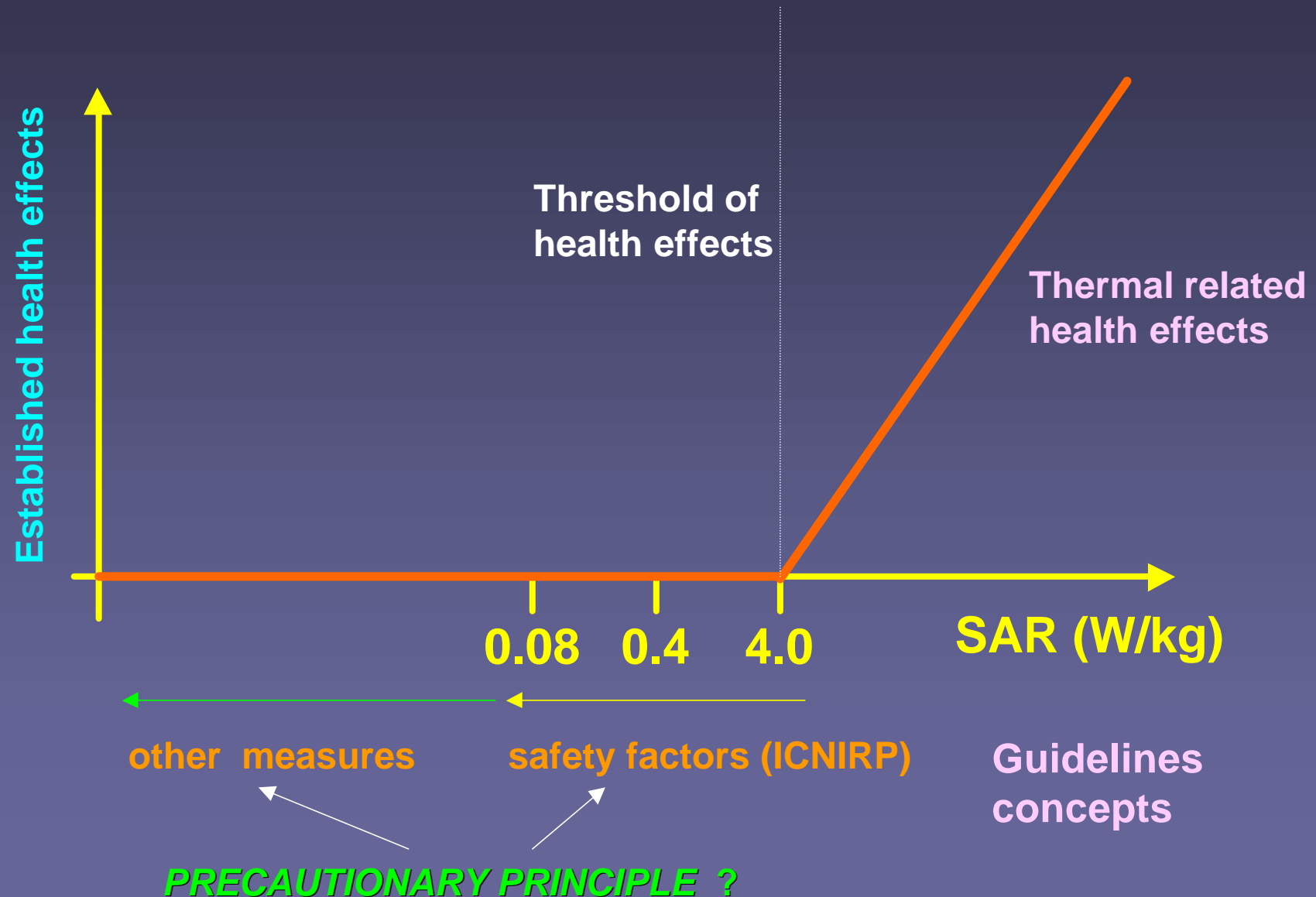
# Nervous system related effects and endpoints due to RF exposure

- Blood-brain barrier (BBB): The early positive results of the RF effects on BBB confounded by various factors (temperature, cerebral blood flow etc.). Recently an increased BBB permeability have been reported at low level RF (SAR as low 0.016 W/kg). Replication is failed so far. The agreement seems to be that *high SAR* may cause *permeability increase*.
- Nervous system and behavior: Controversial results relevant to excitable cerebral tissues interaction with RF and AM modulated RF using a variety of model systems. More consistent evidence is on the changes in *behaviors* (*spontaneous and learned*) when the RF exposure *induces significant heating*. Recent studies focused on the memory task and learning.

# RF dose-response considerations

- Current concepts and questions of “dose”:
  - The current established RF dose-response concept based on the *threshold principle*.
  - The current concept of dose based on, that the RF exposure as such *can not be accumulated with time*.
  - The concepts of dose : the “dose” can be defined as a *transformation* of exposure that corresponds *to biological efficiency*.

# Current dose response concepts of RF exposure: threshold of health effects



# RF dose-response considerations (cont'd)

- Further questions and concepts of “dose”:
  - Otherwise the *time scale* in dose concept may be relevant. Namely: a biological effect may fade with time because of physiological (heating-cooling) and other (repair) mechanisms.
  - Therefore the “dose” concepts in RF as *dose=exposure x duration* and the *reciprocity* (lower exposure longer duration = higher exposure shorter duration) are *not fully relevant* and applicable.
  - Moving from the physical quantity to biological: exposure → dosimetry → *biological effective quantity*

# Forthcoming issues in RF research

## – RF exposure assessment and dosimetry:

- more detailed *environmental RF exposure* assessment because of rapid proliferation of GSM, 3G wireless and emerging technology
- more accurate *local SAR* models and measurement of *non-uniform* partial body and *highly localized* RF exposure
- moving toward to *microscopic* (cellular, sub-cellular) RF dosimetry
- more accurate *thermal modeling* relevant to dosimetric evaluation
- variations in the tissue *dielectric properties* due to age and other impacts
- efforts moving from physical quantities toward a biologically relevant quantity for implementation of the *dose concepts*
- finding the widely accepted *dose-response* models
- debates on thermal vs. non-thermal explanations

# Forthcoming issues in RF (cont'd)

## – Interaction mechanisms:

- new relevant model models describing the *transient effects*, improving the time-scale (time-delay) evaluation of RF interaction
- more detailed interaction models by *local microscopic EM field* at cellular, sub-cellular and cell membrane levels
- efforts to *validate the theories* experimentally

## – Biological effects and health impacts

- studies on possible *epigenic, promotional* effects of RF
- new techniques is coming from the *genetic image analysis*
- waiting for the *replications* of transgenic in-vivo studies
- *individual variation* in the human response to RF (hypersensitivity)
- evaluation of the health impact of the findings in the *cognitive studies*
- waiting for more epidemiological studies on mobile (*WHO/IARC*)
- interpretation of gaps in published epidemiological studies (“side effects”, specific tumors etc..)

# The hot issue in RF: mobile phones and human health

- General interest:
  - RF source next to the human head
    - first time in the human history
    - potential for RF interaction with brain tissue
    - maximum SAR may close to the guidelines
    - very rapid increase of users, *high penetration* in the population
    - wide range of affected population (children, elders etc..)
    - even *small adverse effects* on health could have *major public health* implication (WHO)
  - Proliferation of base station antennas
    - rise of ambient RF radiation levels
    - increasing GSM contribution
  - High *public concerns* relate to the emissions of RF
  - Strong *social* (even political) *impact* in the decision process

# Mobile phones and health: dosimetry

- Exposure the human head to RF, current concepts:
  - *non-uniform, highly localised* exposure to brain tissue
  - *no* significant differences in the SAR depending on the *size of head*
  - not enough supported argument that the phones produce higher SAR in the head of *children compared to adults* due to dielectric properties of the brain tissue.
  - May produce *adverse thermal effects* in the tissue. However recent thermal models have shown ~ 0.1 °C temperature rise in the brain tissue.
  - SAR averaging over *10 g is less protective* than over 1 g.
- Exposure the environment and populations from base station (BS):
  - exposure very low: *not considered a risk*
  - *working* during maintenance very proximate to the BS may have higher absorption in the body
- In general: long-term RF exposure at low levels

# Mobile phones and human health: Epidemiology

- Five main epidemiological studies have been published related to the *mobile (cellular) phone users*.
- WHO-IARC study is in progress.
- All published studies have shown: *no increase in brain tumor*, nor in case-control (Sweden, USA), nor in cohort studies (Denmark).
- No excess mortality rate in US cellular compared to car-phone users.
- References:
  - *K.Rothmann (USA, Epidemiology, 1996), Dreyer (USA, JAMA, 1999)*
  - *L.Hardell (Sweden, In.J.Onc. 1999) , J.Muscat (USA, JAMA, 2000)*
  - *PD.Inskip (USA, N.Engl.J.Med, 2001), C.Johansen (Denmark, J. of Natl. Cancer Inst. 2001)*

# RF exposure to human: Epidemiology

- **No** relevant epidemiological studies on **public exposure to RF**.
- However the findings **from occupational** studies suggest: no indication of any increase in either brain or lymphatic/haematopoietic cancer mortality,
- except the studies on Polish military personnel (*Szmigelski, S*) and the recent uveal-melanoma study in Germany (*Stang. et al*) which **confounded** by **various factors** and **bias**.
- References:
  - **Robinette et al** (1990, *Am.J.Epidemiol.* US Navy), **Szmigelski** (1996, *Sci.Total Environ.* Polish military personnel), **Milham** (1998, *Am.J.Epidemiol.*, radio-amateurs), **Morgan** (2000, *Epidemiology*, Motorola workers), **Grayson** (1996, *Am.J.Epidemiol.*, US Air Force), **A.Stang** (2001, *Epidemiology*, RF workers), **Rothman** (2000, *The Lancet*, 356:1834-40 ,Review)

# Mobile phones and human health: human studies

- Investigation on *short term cognitive* effects of RF exposure have shown that power levels within the guidelines may influence the human behaviour. (*Preece 1999, Koivisto 2000*)
- The mechanism is unclear, a *localised heating* effects have been proposed.
- The reported *cognitive effects* appear to be *too small* to have any real functional significance.

## Mobile phones and human health: human studies (*cont'd*)

- Other findings from *electrophysiological* studies suggest that the exposure to mobile phone may influence the *brain functions* (Mann, Röschke, Hietanen, Thuróczy, Krause).
- There is *no evidence* that the reported neurological and cognitive effects would cause *adverse health effects*.
- Other reported *subjective symptoms* such as headache, sensations of heat, fatigue (Mild, Frey, Hocking) have not confirmed by experimental findings recently (Koivisto, 2001).

## Reports issued by scientific societies, groups and organizations

–**WHO Fact Sheet No.193 (1998, revised version in June 2000):** “...the **levels of RF** energy inside or to the sides of the building are normally **very low**. In many urban areas television and radio broadcast antenna commonly transmit higher RF levels than do mobile base stations...None of recent reviews have concluded that exposure to the RF fields from mobile phones or their base stations causes **any adverse health** consequence.” ([www.who.int/emf](http://www.who.int/emf))

–**The Royal Society of Canada (1999):** “..Surveys conducted in proximity to base stations operating in Canada indicate that the **public is exposed to extremely low intensity RF** fields in the environment. The panel noted that epidemiological studies of populations living near base stations are also lacking, but considers such studies to be of lower priority because of the very low field strengths in the vicinity of base station transmitters.” ([www.rsc.ca](http://www.rsc.ca))

## Reports... (cont'd)

### –Independent Expert Group on Mobile Phones (IEGMP, UK, 2000) :

- Exposure to radiofrequency radiation below guideline levels **does not cause adverse health effects** to the general population
- There **may be biological effects** occurring exposures below these guidelines. This does not necessarily mean that these effects lead to disease or injury but this is important information
- It is not possible at present say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects , and that the gaps in knowledge are sufficient to justify a **precautionary approach** ([www.iegmp.org.uk](http://www.iegmp.org.uk))

### –French expert group on mobile (2001) :

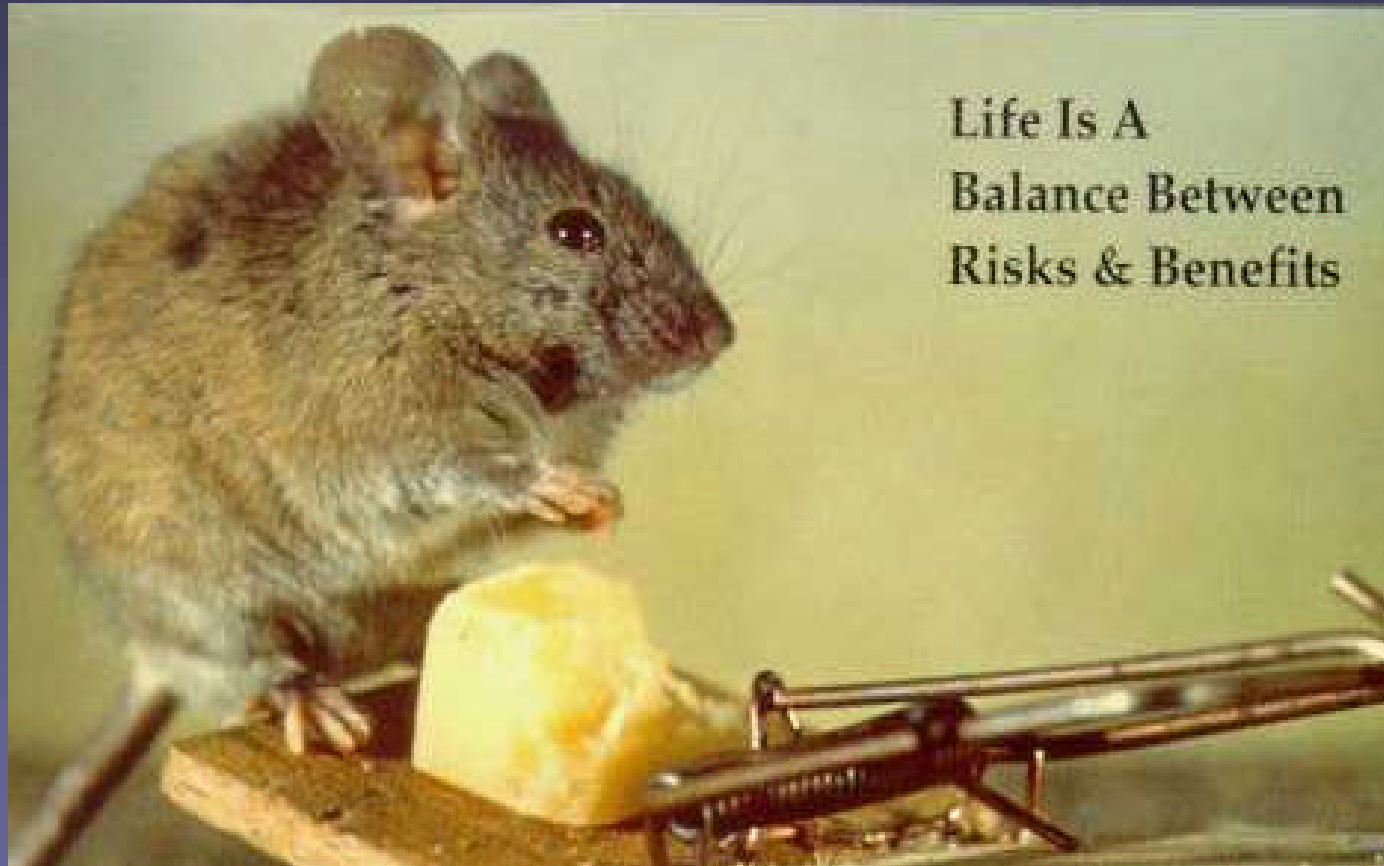
- Scientific data indicate, with relative certainty, that, during exposure to RF from a mobile phone, a **variety of biological effects** occur (eg.electroencephalogram profile, reaction time, etc.) at energy levels that do **not cause any local increase in temperature**. However, in the current state of knowledge of these non-thermal effects, it is **not yet** possible to determine whether they **represent a health hazard**. ([www.sante.gouv.fr](http://www.sante.gouv.fr))

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- and many others...

**Thanks for your attention!**



Life Is A  
Balance Between  
Risks & Benefits

*by John Paling, USA*