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**SCIENTIFIC COMMITTEE ON TOXICITY, ECOTOXICITY AND  
THE ENVIRONMENT (CSTEE)**

**Opinion on**

**Possible effects of Electromagnetic Fields (EMF), Radio Frequency Fields (RF)  
and Microwave Radiation on human health**

**Expressed at the 27th CSTEE plenary meeting**

**Brussels, 30 October 2001**

## Background

The Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE) was requested to prepare an update of the opinion (1) of the Scientific Steering Committee (SSC) on health effects of electromagnetic fields (EMF) dated 25-26 June 1998, which endorsed the guidelines published by the ICNIRP (International Commission on Non Ionising Radiation Protection) and served as a basis for the Council Recommendation of July 5, 1999, which limited the exposure of the general public to EMF.

The request derived from the increasing exposure to EMF consequent to the further growth in the use of electricity from the continuous development of the telecommunications industry and to a rapid increase in the installation of transmitter masts used as radiotelephone base stations. These transmitters are frequently sited close to houses, business premises and schools, and therefore an increasing proportion of the public is chronically exposed to ELF fields and RF. Moreover, the visibility of such masts has heightened the public concern about the risks from electromagnetic radiation. This is a complex field from a research viewpoint.

EMF cover a wide range of frequencies (0 Hz – 300 GHz) (Annex 1). In a discussion of their sources of exposure, and of their potential harmful effects, it is customary to distinguish between extremely low frequency electromagnetic fields (ELF) and radiofrequencies and microwaves. The present report deals with ELF (1 Hz – 1 kHz), RF (1 MHz – 1 GHz) and microwaves (1 GHz – 300 GHz). In addition to domestic, industrial and medical electrical appliances and devices, the high-voltage overhead transmission lines (and to a lesser extent underground cables) are a major source of exposure to ELF in the environment. The ELF frequency band is limited to 50 Hz in Europe and to 60 Hz in North America. The RF and lower microwave frequencies are of particular interest for broadcasting, mobile telephony. The 2.45 GHz frequency is mainly used in domestic and industrial microwave ovens.

The CSTEE was asked

*“... to provide, in the light of new knowledge and developments in technology and applications of sources and practices giving the exposure to electromagnetic fields, an update of the opinion delivered in June 1998 on:*

*A. Non thermal, long term health effects of exposure to EMFs in particular addressing epidemiological evidence and also biophysical and biological evidence on genetic and carcinogenic effects, effects on the immune and circulatory system and effects on the nervous system affecting or local part of the body or general behaviour of people exposed. The opinion should indicate whether any new recommendations for exposure limits can be made.*

*B. Whether for thermal and non thermal effects, the technical annex for the Council Recommendation<sup>1</sup> setting up basic restrictions and reference levels limiting the exposure to non-ionising radiation and based on the guidelines published by the International Commission on Non-Ionising Radiation Protection is still the appropriate scientific basis for a system of health protection against risks from non-ionising radiation”.*

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<sup>1</sup> OJ N° L 199/59 dated 30.07.1999

In order to reply to these questions, the CSTEE appointed a Working Group that included members of the CSTEE<sup>2</sup> as well as external experts<sup>3</sup> and Members of other scientific committees of the Commission<sup>4</sup>. The Working Group met on June 13, September 10 and October 18, 2001. It was decided to first address question A, *i.e.* to evaluate whether scientific findings, resulting from new investigations on non thermal effects of electromagnetic fields should lead to changes of the scientific evaluation underlying the June 1998 SSC opinion. Given the availability of a number of excellent scientific reviews of previous studies, the WG used these as a principal literature source upon which to elaborate its own conclusions.

Since the present report aims at giving a basis for an update of the 1998 Opinion of the Scientific Steering Committee, emphasis is given to issues for which there is new information. Thus, acute thermal health effects – which have been well established for the high frequency class of EMF – are not dealt with in the present report.

Expert Reviews (3-9), were utilised along with the scientific literature on specific subjects (*e.g.* neurobehavioral changes). Given the questions that have been posed to the CSTEE, the focus was on any finding with the potential to induce a reconsideration of the exposure limits recommended in 1999. Epidemiological studies aimed at identifying associations with cancer risks were discussed in depth. In interpreting epidemiological findings, reference was made to the classical criteria suggested almost 40 years ago by Austin Bradford Hill (see below).

Given the possibility of different mechanisms of action, separate consideration was given to two circumstances, *i.e.*:

- exposure to extremely low frequency electromagnetic fields – ELF, *i.e.* up to 50-60 Hz, emitted by overhead and underground power lines and cables and certain electrical domestic and industrial appliances, and
- exposure to intermediate, radiofrequency and microwave frequencies from 1 kHz up to 300 GHz, emitted by sources such as visual display units, television sets and induction heaters, RF heaters, mobile phones, radio and TV broadcast, microwave communication and domestic and industrial microwave ovens.

The ICNIRP guideline for 50/60 Hz electric and magnetic fields is based on a maximum current density in the body of 10 mA/m<sup>2</sup>. This results in the ICNIRP reference levels for the general public of 5 kV/m and 100 µT for the electric and magnetic field respectively.

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The following table roughly summarises the underlying effects of static, ELF, RF and microwaves which possibly could induce a biological change.

| Frequency                           | Mechanism                                             | Unit of deposition                               |
|-------------------------------------|-------------------------------------------------------|--------------------------------------------------|
| Static magnetic field<br>0 Hz       | Magnetic induction and magnetomechanical interactions |                                                  |
| ELF<br>30 Hz – 300 Hz<br>ELF        | Current induction in body                             | $A/m^2 = H_{A/m} \times f \times$<br>Body length |
| RF & microwaves<br>0,1 MHz – 10 GHz | Energy deposition                                     | SAR in W/kg                                      |
| 10 GHz – 300 GHz                    | Surface tissue heating                                | Power density W/m <sup>2</sup>                   |

SAR = Specific energy Absorption Rate

A = Area

H = field strength

### Interaction of electromagnetic fields with biological systems

A major determinant for the induction of current or heat (energy) in a biological or non-biological system is frequency. The unit of deposition is current density ( $A/m^2$ ) which depends on the field strength (H in A/m), the frequency and the body length. Exposure to ELF does not result in a deposition of energy in the body, whereas exposure to RF and microwaves, (such as 900 MHz and 1800 GSM-radiation etc.) does. The measure of the energy deposition or absorption in the body is the SAR. The energy of all electric, magnetic and electromagnetic fields is orders of magnitudes below that of ionising radiation.

Whereas ionising radiation produces biochemical effects such as breaking covalent chemical bonds, generation of ions and other reactive chemical species, the primary consequence of the interaction of electromagnetic fields with biological systems is likely to be the induction of currents. These may invoke the formation of electric dipoles and/or the reorientation of dipoles already present. With cellular and animal systems no consistent relationship has been found between effects and either time varying or varying field strength at frequencies below 100 kHz and current density at or below 10 mA/m<sup>2</sup>. At these levels of exposure, indeed, heat deriving from absorption of electromagnetic energy is well below that due to normal metabolic processes.

### Austin Bradford's Hill criteria for causal inference

Most epidemiological studies on the effects of EMF on humans are observational in nature, which renders problematic the assessment of causality. In a classic essay (2), Austin Bradford Hill laid down a series of criteria useful in drawing a conclusion as to whether a relationship between an alleged cause and an effect expresses causation or merely an association. With the exception of the first criterion, none of the others is a *sine qua non*. The hypothesis of causation become stronger as the number of fulfilled criteria increases. The criteria are:

- Strength of the association, commonly expressed in terms of relative risk, *i.e.* the factor by which the probability of developing the disease is increased in the exposed over the non exposed population groups. An indicator useful in public health is the attributable risk, *i.e.*

the proportion of cases caused by the exposure (either among the exposed or the general population).

- Consistency of results between independently performed studies.
- Specificity of the association (although it has become obvious that the rule “one cause – one effect” is hardly applicable for conditions with a multifactorial aetiology).
- Temporal relationship (exposure must precede the effect, taking into account the latent period of the condition).
- Biological gradient, *i.e.* a dose-response effect.
- Biological plausibility, *i.e.* whether it is reasonable to postulate that the cause acts through a mechanism which corresponds to biological knowledge of the adverse effects of the agent.
- Coherence of the cause-to-effect interpretation with generally known facts on the natural history and biology of the disease.
- Reproduction of the condition experimentally (either in animals or in man).

## Radiofrequencies and microwaves (RF)

As stated above these are emitted from sources such as visual display units, television sets, AM radio, induction heaters, mobile phones, etc. The primary literature reviews of effects used for the preparation of the present report were the “Stewart Report” (3) published in 2000 and Elwood’s review (4) of the epidemiological studies, which was published in 1999 and later extended to early 2001 in order to identify an exposure standard for Australia (5). To the knowledge of the CSTEE, no additional relevant findings have been reported subsequently. The CSTEE did not identify any major reason for dissent from these reviews with regard to either exhaustiveness of reported scientific observations or the interpretation of scientific findings.

Particular attention was given to the sections regarding the biological end points specifically mentioned in the questions asked to the CSTEE, *i.e.* effects on the immune and circulatory system, on the nervous system, on the general behaviour of exposed people as well as experimental and epidemiological studies investigating carcinogenic risks. Conclusions reached by the CSTEE on each of these areas are summarised below:

**1. Immune system:** thermal levels of RF exposure elicit both stimulatory and inhibitory responses in components of the immune system. These effects were generally found to be transitory, returning to normal levels following termination of exposure. No consistent effects of low level RF exposure have been reported on blood forming and circulating blood cells or on immune responses.

**2. Heart and blood pressure:** With the exception of a well designed but small study (which therefore requires confirmation in larger and independent investigations) reporting early effects on blood pressure in volunteers exposed to a conventional GSM digital mobile phone position close to the head, available findings provide no consistent evidence of an effect of mobile phones on the heart and circulation.

**3. Nervous system:** In the absence of heating, evidence for changes in neuronal excitability, neurotransmitter function and innate and learned behaviour, and for changes in the blood-brain barrier has been inconsistent and unconvincing. Extrapolation from laboratory studies in rats to humans is problematic because of the differences in the pattern of RF energy deposition between rodents and humans. Furthermore, in contrast to humans, rats have the capacity to perceive RF as sounds, which is likely to influence their reactivity. Some studies have suggested an effect on membrane proteins, and on the flux of calcium and other ions across the membrane of neurons and EEG rhythms but these are not reproducible.

**4. Neurobehavioral effects and effects on driving:** Relevance of experimental studies to man is uncertain because of interspecies differences in the perception of intense pulsed RF fields. Studies on the acute effects of mobile phones on human volunteers have shown some neurobehavioral changes (such so-called neurobehavioral effects are mostly reporting of subjective malaise), the mechanism of which might include a localised heating effect. The interaction between electromagnetic fields and drugs has not been adequately investigated. The main effects of the use of mobile phones on driving are attributable to diversion of the attention.

**5. Ocular effects:** The eye is a potential target organ of RF and microwave energy because it is not protected by the bone. Electric activity is part of the retina function and therefore objects placed in front of the eye may act as “heat sink” for thermal effects, In addition, the fibres that make up the bulk of the lens have a limited capacity for repair following insult.

The literature on the ocular effects of microwaves in laboratory animals (including monkeys and rabbits) is extensive, but experimental designs are difficult to reproduce and results are still controversial. Marked interspecies differences have been noticed. Lens cataracts has been produced after exposure to very high frequencies, but it is not clear whether or not the effect is due to thermal changes. Thus, the relevance of current knowledge to human risk, in the absence of thermal effect, is very limited.

**6. Observations in humans regarding health outcomes other than cancer:** No consistent evidence of effects on humans has yet been derived from formal epidemiological studies. This cannot be taken to mean that RF and microwaves do not pose any hazard to human health. Most formal epidemiological studies have focussed on the occurrence of cancer.

Among people exposed to radiowaves or otherwise exposed to electromagnetic fields, there have been case reports or reports of small series of cases of subjective symptoms (fatigue, stress, sleep disturbances, depression, burning sensations, rashes, muscular pain, ear, nose, and throat problems, as well as digestive disorders etc.) in individuals that have been characterised as “hypersensitive”. The symptoms described seem to affect a limited number of persons but as yet there are no reliable estimates of the frequency of its occurrence. Almost nothing is known on the role of conditions of exposure (frequency, concentration, duration etc.). Limited studies on volunteers found no connection between reported symptoms and exposure to electromagnetic fields. It is therefore very difficult to ascertain whether these are true effects.

**7. Genotoxicity:** An overview of *in vitro* genotoxicity data, subjected to a weight-of-evidence evaluation (6) concluded that there are no strong indications that electromagnetic fields between 30 MHz and 300 GHz cause DNA damage. Where effects were found, they were attributable to hyperthermia. Despite minor inconsistencies in the literature, it is concluded that, *in vivo* and *in vitro* experiments on the induction of *micronuclei*, SCE or chromosomal aberrations did not detect any effect. Cell transformation assays of radiofrequency field exposure are difficult to interpret because of technical difficulties. There have been reports of DNA fragmentation and on effects on nucleic acid synthesis, which could be relevant to malignancy, but these have not been confirmed independently and are subject to much controversy. The possible interaction between electromagnetic fields and physical or chemical mutagenic or carcinogenic agents represents an interesting hypothesis, which has not been yet sufficiently investigated.

**8. Experimental carcinogenesis:** The possible carcinogenicity of RF has been investigated in a number of experimental systems. Results have been essentially negative. Original observations of a possible promoting effect on mammary carcinogenesis in mice were not confirmed in subsequent studies. An interesting observation is that of Repacholi *et al* (7), who induced a two-fold increase in lymphoma incidence in a strain of lymphoma-prone transgenic mice (E mu-Pim1) following exposure (1 hour daily for up to 18 months) to plane-wave fields of 900 MHz with a pulse repetition frequency of 217 Hz and a pulse width of 0.6 ms (7). As yet, the open literature has not reported any replication of this finding. It is therefore concluded that it provides inadequate evidence of experimental carcinogenicity.

**9. Effects on melatonin production:** Recent studies on human volunteers and well-designed studies in mice have not provided any evidence of an effect of EMF on this endpoint. There is no support to the hypothesis that a decreased production of melatonin might interfere with mammary carcinogenesis either in women or in animals. Thus, relevance to long-term effects seems negligible.

### **10. Epidemiological studies on the association between RF magnetic fields and human cancer:**

A number of studies which address three circumstances of exposure: the workplace, the residence close to RF emitters and the use of mobile phones have been published. These have been reviewed in the “Stewart’s report” (3), by Elwood (5) and by a Working Group assembled by the Canadian Royal Society (8).

Overall, the epidemiological evidence of RF and microwaves does not suggest consistent cancer excesses. Some studies were very large (*e.g.* the “Motorola study” included 200.000 subjects followed up for a total of approximately 2 million person year-risk).

Thus, for the time being, epidemiological studies on the association between cancer and RF do not indicate any need for reconsidering the exposure limits that have been set a few years ago. This is consistent with the lack of evidence of genotoxic effects believed to be associated to the process of carcinogenesis.

Nevertheless, the need for additional epidemiological surveillance is suggested by some limitations of the studies that are currently available: **i.** the relatively short period of observation compared to the potential latent period of long-term effects; **ii.** the use of proxies (*e.g.* distance from putative sources, extent of use of cellular phone, etc) in order to estimate individual exposure which may be unreliable and could artificially lower risk estimates and **iii.** low statistical power of analyses indicating lack of association.

## **Extremely low frequency fields (ELF)**

The major concern regarding ELF derives from recent reports raising the question as to whether 50/60 Hz magnetic fields might induce cancer in man. A comprehensive review of the available literature has been the so-called “Doll’s Report”(9) published early in 2001. This has been a major source of information for the CSTEE. In addition, the CSTEE considered in detail the results of two meta-analyses of previous epidemiological investigations designed as case-control studies which were reported in 2000 (10, 11). A “meta-analysis” is an epidemiological tool that contributes to the assessment of overall evidence of a cause-to-effect relationship, utilising investigations from separate studies. It consists in the creation of a single database through the pooling of the original data of the individual studies. An obvious pre-requisite is that individual studies being meta-analysed must be comparable, both in the design and in the assessment of exposure.

Results of one of the two “meta-analyses”, which have been presented to the CSTEE, included 9 studies published between 1993 and 1999 in which 50-60 Hz magnetic fields had been measured in the children’s houses during the previous 24-48 h or had been evaluated through theoretical calculations. Total numbers of cases and controls were respectively 3247 and 10400. Sensitivity analyses (estimation of relative risks following exclusion of studies carried out in some countries, notably US and Canada) and analyses limited to subgroups of studies carried out in Scandinavian countries) did not materially change the estimates.



**The following conclusions were reached with regard to the two meta-analyses:**

- Both meta-analyses estimated a twofold excess risk for leukaemia for children living in households where exposures to ELF were estimated to be higher than 0.4  $\mu\text{T}$  (0.3  $\mu\text{T}$  according to Greenland's meta-analysis);
- In some studies, selection bias may have occurred, leading to an over-representation of children of higher socio-economic status among cases, but there are no reasons to believe that this was a phenomenon common to all studies taken in consideration;
- The exposure category for which such excess risk has been estimated is open-ended. No analyses have been performed using other cut-off points (also because the number of children exposed to more than 0.4  $\mu\text{T}$  is very small). In other words, the shape of the dose-response relationship above 0.4  $\mu\text{T}$  is not known.
- Relative risk estimates for exposures, intermediate between those showing a statistically significant excess and the reference group, were just above 1.
- In most studies included in the meta-analyses carried out in European countries, children *with leukaemia* exposed to extremely low frequency EMF at levels of 0.4  $\mu\text{T}$  and above did not exceed 1% of the population group which was studied. Thus the percentage attributable risk in the population is likely to be less than 1% of the leukaemia cases.

Other potential end-points of ELF-related effects have received less attention, both in humans and in experimental systems. Recent reports conclude respectively that there is no consistent evidence of genotoxicity (8) or DNA damage (WHO Fact sheet no 263). Also the evidence of effects on the immune system is extremely limited.

In the case of ELF, reports [CSTEE/2000/26-Add.35 -“Electromagnetic hypersensitivity: an environmental illness” - draft WHO Fact Sheet (document has been reviewed and final version will be released shortly)] on possibly hypersensitive individuals require confirmation and do not provide a basis for changes in exposure limits.

## Opinion/Conclusions

### Answer to question A:

- The additional information which has become available on carcinogenic and other non-thermal effects of radiofrequency and microwave radiation frequencies in the last years does not justify a revision of exposure limits set by the Commission on the basis of the conclusions of the 1998 opinion of the Steering Scientific Committee. In particular, in humans, no evidence of carcinogenicity in either children or adults has resulted from epidemiological studies (the size of some of which was very large, although the period of observation was not long enough for a definitive statement). A relatively large series of laboratory studies has not provided evidence of genotoxicity. Subjective symptoms affecting some individuals possibly exists, but not enough information is available on: the levels of exposure producing such effect, on the features underlying individual susceptibility, on the possible biological mechanisms *or* the prevalence of susceptible individuals in different populations. Thus, current knowledge is insufficient for the implementation of measures aimed at the identification and protection of a highly sensitive sub-group of the population.

With regard to extremely low frequency electromagnetic fields, the CSTEE reached the following conclusions:

- Combined analyses of the epidemiological studies on the association between exposure to ELF and childhood leukaemia have strengthened the evidence of an association. However, given some inconsistencies in exposure measurements and the absence of other criteria commonly used in assessing causality (particularly a plausible explanation of underlying biological mechanisms, see above), the association does not meet adequate criteria for being considered causal. Thus the overall evidence for 50/60 Hz magnetic fields to produce childhood leukaemia must be regarded as being limited\* (\*).
- The effect, if any, seems to be limited to exposures above 0.4 µT. In European countries, the proportion of children exposed to such levels is less than 1%. Assuming that the risk is doubled among the exposed, in the general population this would roughly correspond to an excess incidence of less than 1% childhood leukaemia. To put this in context, in European countries, the incidence of leukaemia is around 45 per million children (age 0-14) per year.
- Whether changes of recommended exposure limits to 50/60 Hz magnetic fields (12) ought to be recommended on this basis is a problem for risk managers, falling beyond the remit of the CSTEE.
- There is no convincing suggestion of any other carcinogenic effect of ELF on either children or adults. Current information on this respect does not provide clues for reconsidering exposure limits.
- Reports on possibly hypersensitive individuals require confirmation and do not provide a basis for proposing changes in the exposure limits.

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\* (\*) This term is used according to the definition given by the International Agency for Research on cancer, i.e. “A positive association has been observed between exposure to the agent ... for which a causal interpretation is considered ... to be credible, but chance, bias or confounding could not be ruled out with reasonable confidence”. Indeed the CSTEE is aware that on this basis, IARC has recently evaluated that extremely low frequency magnetic fields are possibly carcinogenic to humans (group 2B) based on the association of higher level residential ELF magnetic fields and increased risk for childhood leukaemia.

**Answer to question B:**

- On the basis of the information available to the CSTEE at the time of responding to this opinion request, the committee has insufficient scientific evidence, as to thermal and non thermal effects, to propose alternatives to the technical annex for the Council Recommendation setting up basic restrictions and reference levels limiting the exposure to non-ionising radiation, based on the guidelines published by the International Commission on Non-Ionising Radiation Protection.

**Note**

The CSTEE will provide subsequently recommendations for research priorities needed in order to fill the critical gaps in present knowledge which stem from the summary review presented here.

## References

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5. ARPANSA Australian Radiation Protection and Nuclear Safety Agency (in press) Maximum Exposure Levels to Radiofrequency Fields – 3 kHz to 300 GHz, Annex 3 : Epidemiological studies of exposure to radiofrequencies and human health, Sydney.
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**Annex 1**

|                            |                        |                      |                         |                 |                     |
|----------------------------|------------------------|----------------------|-------------------------|-----------------|---------------------|
| Hz<br>3 x 10 <sup>15</sup> | IONISING RADIATION     |                      |                         |                 |                     |
| 3 x 10 <sup>14</sup>       | NON-IONISING RADIATION | UV                   |                         | STERILIZATION   |                     |
|                            |                        | VISIBLE              |                         | LASER           |                     |
|                            |                        | INFRA-RED            |                         | LAMPS           |                     |
|                            |                        |                      |                         | THERMAL SOURCES |                     |
|                            |                        |                      |                         | REMOTE CONTROL  |                     |
|                            |                        | 3 x 10 <sup>11</sup> | RADIO FREQUENCY         | MICROWAVE       | RADARS              |
|                            |                        |                      |                         |                 | MICROWAVE DIATHERMY |
|                            |                        |                      |                         |                 | CELL PHONE          |
|                            |                        |                      |                         |                 | MICROWAVE OVEN      |
|                            |                        |                      |                         |                 | RADIO LINKS         |
| 3 x 10 <sup>8</sup>        | RADIO FREQUENCY        | MICROWAVE            | TV AND RADIO BROADCASTS |                 |                     |
|                            |                        |                      | RADIOFREQUENCY THERAPY  |                 |                     |
|                            |                        |                      | AMATEUR RADIO           |                 |                     |
|                            |                        |                      | RADIOFREQUENCY WELDING  |                 |                     |
|                            |                        |                      | INDUCTION HEATING       |                 |                     |
| 3 x 10 <sup>4</sup>        | LOW FREQUENCY          |                      | METAL DETECTOR          |                 |                     |
|                            |                        |                      | VIDEO DISPLAY UNITS     |                 |                     |
|                            |                        |                      | MAGNETOTHERAPY          |                 |                     |
|                            |                        |                      | DOMESTIC APPLIANCE      |                 |                     |
|                            |                        |                      | POWER LINES             |                 |                     |
| 3 x 10 <sup>1</sup>        | LOW FREQUENCY          |                      | TELEPHONE LINES         |                 |                     |
|                            |                        |                      |                         |                 |                     |
|                            |                        |                      |                         |                 |                     |
|                            |                        |                      |                         |                 |                     |
|                            |                        |                      |                         |                 |                     |
| 0                          | STATIC FIELDS          |                      | MAGNETIC RESONANCE      |                 |                     |
|                            |                        |                      | ELECTROLYSIS            |                 |                     |