PREAMBLE

The WHO Environmental Health Criteria Programme

In 1973 the World Health Organization (WHO) Environmental Health Criteria Programme was initiated with the following objectives:

(i) to assess information on the relationship between exposure to environmental pollutants and human health, and to provide guidelines for setting exposure limits;

(ii) to identify new or potential pollutants;

(iii) to identify gaps in knowledge concerning the health effects of pollutants;

(iv) to promote the harmonization of toxicological and epidemiological methods in order to have internationally comparable results.

It should be noted in this context that WHO defines health as the state of complete physical, mental and social well being and not merely the absence of disease or infirmity (WHO, 1946).

The first Environmental Health Criteria (EHC) monograph, on mercury, was published in 1976 and since that time an ever-increasing number of assessments of chemical and of physical agents have been produced. In addition, many EHC monographs have been devoted to evaluating toxicological methodology, e.g., for genetic, neurotoxic, teratogenic and nephrotoxic agents. Other publications have been concerned with epidemiological guidelines, evaluation of short-term tests for carcinogens, biomarkers, effects on the elderly and so forth.

The original impetus for the Programme came from World Health Assembly resolutions and the recommendations of the 1972 UN Conference on the Human Environment. Subsequently the work became an integral part of the International Programme on Chemical Safety (IPCS), a cooperative programme of the United Nations Environment Programme (UNEP), the International Labour Office (ILO) and WHO. With the strong support of the new partners, the importance of occupational health and environmental effects was fully recognized. The EHC monographs have become widely established, used and recognized throughout the world.

Electromagnetic Fields

Three monographs on electromagnetic fields (EMF) address possible health effects from exposure to extremely low frequency (ELF) fields, static and ELF magnetic fields, and radiofrequency (RF) fields WHO, 1984; WHO, 1987; WHO, 1993. They were produced in collaboration with UNEP, ILO and the International Non-Ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA) and from 1992 the International Commission on Non-Ionizing Radiation Protection (ICNIRP).
EHC monographs are usually revised if new data are available that would substantially change the evaluation, if there is public concern for health or environmental effects of the agent because of greater exposure, or if an appreciable time period has elapsed since the last evaluation. The EHCs on EMF are being revised and will be published as a set of three monographs spanning the relevant EMF frequency range (0–300 GHz); static fields (0 Hz), ELF fields (up to 100 kHz, this volume) and RF fields (100 kHz – 300 GHz).

WHO's assessment of any health risks produced by non-ionizing radiation emitting technologies (in the frequency range 0–300 GHz) falls within the responsibilities of the International EMF Project. This Project was established by WHO in 1996 in response to public concern over health effects of EMF exposure, and is managed by the Radiation and Environmental Health Unit (RAD) which is coordinating the preparation of the EHC Monographs on EMF.

The WHO health risk assessment exercise includes the development of an extensive database that comprises relevant scientific publications. Interpretation of these studies can be controversial, as there exists a spectrum of opinion within the scientific community and elsewhere. In order to achieve as wide a degree of consensus as possible, the health risk assessment also draws on, and in some cases includes sections of, reviews already completed by other national and international expert review bodies, with particular reference to:

- the International Agency for Research on Cancer (IARC) Monograph on static and extremely low frequency (ELF) fields IARC, 2002. In June 2001 IARC formally evaluated the evidence for carcinogenesis from exposure to static and ELF fields. The review concluded that ELF magnetic fields are possibly carcinogenic to humans.
- Reviews on physics/engineering, biology and epidemiology commissioned by WHO to the International Commission on Non-Ionizing Radiation Protection (ICNIRP), a non-governmental organization in formal relations with WHO (ICNIRP, 2003).
- Reviews by the Advisory Group on Non-Ionising Radiation (AGNIR) of the Health Protection Agency (HPA), United Kingdom (AGNIR, 2001a; 2001b; 2004; 2006).

**Scope**

The EHC monographs are intended to provide critical reviews on the effect on human health and the environment of chemicals, physical and biological agents. As such, they include and review studies that are of direct relevance for the evaluation. However, they do not describe *every* study carried out. Worldwide data are used and are quoted from original studies, not from abstracts or reviews. Both published and unpublished reports are considered but preference is always given to published data. Unpublished data
are only used when relevant published data are absent or when they are pivotal to the risk assessment. A detailed policy statement is available that describes the procedures used for unpublished proprietary data so that this information can be used in the evaluation without compromising its confidential nature WHO, 1990.

In the evaluation of human health risks, sound human data, whenever available, are generally more informative than animal data. Animal and in vitro studies provide support and are used mainly to supply evidence missing from human studies. It is mandatory that research on human subjects is conducted in full accord with ethical principles, including the provisions of the Helsinki Declaration (WMO, 2004).

All studies, with either positive or negative effects, need to be evaluated and judged on their own merit, and then all together in a weight of evidence approach. It is important to determine how much a set of evidence changes the probability that exposure causes an outcome. Generally, studies must be replicated or be in agreement with similar studies. The evidence for an effect is further strengthened if the results from different types of studies (epidemiology and laboratory) point to the same conclusion.

The EHC monographs are intended to assist national and international authorities in making risk assessments and subsequent risk management decisions. They represent an evaluation of risks as far as the data will allow and are not, in any sense, recommendations for regulation or standard setting. These latter are the exclusive purview of national and regional governments. However, the EMF EHCs do provide bodies such as ICNIRP with the scientific basis for reviewing their international exposure guidelines.

Procedures

The general procedures that result in the publication of this EHC monograph are discussed below.

A first draft, prepared by consultants or staff from a RAD Collaborating Centre, is based initially on data provided from reference databases such as Medline and PubMed and on IARC and ICNIRP reviews. The draft document, when received by RAD, may require an initial review by a small panel of experts to determine its scientific quality and objectivity. Once the document is acceptable as a first draft, it is distributed, in its unedited form, to well over 150 EHC contact points throughout the world who are asked to comment on its completeness and accuracy and, where necessary, provide additional material. The contact points, usually designated by governments, may be Collaborating Centres, or individual scientists known for their particular expertise. Generally some months are allowed before the comments are considered by the author(s). A second draft incorporating comments received and approved by the Coordinator (RAD), is then distributed to Task Group members, who carry out the peer review, at least six weeks before their meeting.
The Task Group members serve as individual scientists, not as representatives of their organization. Their function is to evaluate the accuracy, significance and relevance of the information in the document and to assess the health and environmental risks from exposure to the part of the electromagnetic spectrum being addressed. A summary and recommendations for further research and improved safety aspects are also required. The composition of the Task Group is dictated by the range of expertise required for the subject of the meeting (epidemiology, biological and physical sciences, medicine and public health) and by the need for a balance in the range of opinions on the science, gender and geographical distribution.

The membership of the WHO Task Groups is approved by the Assistant Director General of the Cluster on Sustainable Development and Health Environments. These Task Groups are the highest level committees within WHO for conducting health risk assessments.

Task Groups conduct a critical and thorough review of an advanced draft of the ELF EHC monograph and assess any risks to health from exposure to both electric and magnetic fields, reach agreements by consensus, and make final conclusions and recommendations that cannot be altered after the Task Group meeting.

The World Health Organization recognizes the important role played by non-governmental organizations (NGOs). Representatives from relevant national and international associations may be invited to join the Task Group as observers. While observers may provide a valuable contribution to the process, they can only speak at the invitation of the Chairperson. Observers do not participate in the final evaluation; this is the sole responsibility of the Task Group members. When the Task Group considers it to be appropriate, it may meet in camera.

All individuals who as authors, consultants or advisers participate in the preparation of the EHC monograph must, in addition to serving in their personal capacity as scientists, inform WHO if at any time a conflict of interest, whether actual or potential, could be perceived in their work. They are required to sign a conflict of interest statement. Such a procedure ensures the transparency and probity of the process.

When the Task Group has completed its review and the Coordinator (RAD) is satisfied as to the scientific consistency and completeness of the document, it then goes for language editing, reference checking, and preparation of camera-ready copy. After approval by the Director, Department of Protection of the Human Environment (PHE), the monograph is submitted to the WHO Office of Publications for printing. At this time a copy of the final draft is sent to the Chairperson and Rapporteur of the Task Group to check the proofs.

Extremely Low Frequency Environmental Health Criteria

This EHC addresses the possible health effects of exposure to extremely low frequency (>0 Hz – 100 kHz) electric and magnetic fields. By
far the majority of studies concern the health effects resulting from exposure to power frequency (50–60 Hz) magnetic fields; a few studies address the effects of exposure to power frequency electric fields. In addition, a number of studies have addressed the effects of exposure to the very low frequency (VLF, 3–30 kHz) switched gradient magnetic fields used in Magnetic Resonance Imaging, and, more commonly, the weaker VLF fields emitted by visual display units (VDU’s) and televisions.

The ELF EHC is organized by disease category; separate expert working groups met in order to develop drafts addressing neurodegenerative disorders (chapter 7), cardiovascular disorders (chapter 8), childhood leukaemia (Section 11.2.1) and protective measures (chapter 13). The membership of these expert working groups is given below. Drafts of the other chapters were prepared by consultants, staff from WHO collaborating centres and by RAD Unit staff. These included Prof. Paul Elliot, Imperial College of Science, Technology and Medicine, UK, Prof. Maria Stuchly, University of Victoria, Canada, and Dr Bernard Veyret, ENSCPB, France, in addition to individuals who were also members of one of the expert working groups and/or the Task Group (see below). The draft chapters were individually reviewed by external referees prior to their collation as a draft document.

The draft EHC was subsequently distributed for external review. Editorial changes and minor scientific points were addressed by a WHO Editorial Group and the final draft was distributed to Task Group members prior to the Task Group meeting.

The Task Group met from October 3–7, 2005 at WHO headquarters in Geneva. The text of the EHC was subsequently edited for clarity and consistency by an Editorial Group consisting of Prof. Emilie van Deventer and Prof. Chiyoji Ohkubo, both from WHO, Geneva, Switzerland, Dr Rick Saunders, Health Protection Agency, Chilton, UK, Dr Eric van Rongen, Health Council of the Netherlands, Prof. Leeka Kheifets, UCLA School of Public Health, Los Angeles, CA, USA and Dr Chris Portier, NIEHS, Research Triangle Park, NC, USA. Following a final review by the Task Group and scientific and text editing, the EHC was published on the International EMF Projects website on 18 June 2007.

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ACKNOWLEDGEMENTS

This monograph represents the most thorough health risk assessment currently available on extremely low frequency electric and magnetic fields. WHO acknowledges and thanks all contributors to this important publication.

In particular, thanks go to the experts that drafted the initial version of the various chapters, including Prof. Paul Elliot, Prof. Maria Stuchly, and Prof. Bernard Veyret, the members of the Working Groups and the members of the Task Group.

Special thanks go to Dr Eric van Rongen, from the Health Council of the Netherlands, and Dr Rick Saunders, from the Health Protection Agency, United Kingdom, for their continuing work throughout the development of this monograph, and to Prof. Leeka Kheifets, who continued her involvement in the development of the document long after she left WHO.

WHO also acknowledges the generous support of the Health Council of the Netherlands for providing the scientific and language editing, and for performing the final layout of the document.

Dr. Emilie van Deventer
Acting Coordinator, Radiation and Environmental Health
World Health Organization
1 June 2007
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AC</td>
<td>alternating current</td>
</tr>
<tr>
<td>ACTH</td>
<td>adrenocorticotropic hormone</td>
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<tr>
<td>AD</td>
<td>Alzheimer’s disease</td>
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<tr>
<td>AF</td>
<td>attributable fraction</td>
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<tr>
<td>AGNIR</td>
<td>Advisory Group on Non-Ionising Radiation</td>
</tr>
<tr>
<td>ALL</td>
<td>acute lymphocytic leukaemia</td>
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<tr>
<td>ALS</td>
<td>amyotrophic lateral sclerosis</td>
</tr>
<tr>
<td>AMI</td>
<td>acute myocardial infarction</td>
</tr>
<tr>
<td>AML</td>
<td>acute myeloid leukaemia</td>
</tr>
<tr>
<td>aMT6s</td>
<td>6-sulphatoxymelatonin</td>
</tr>
<tr>
<td>AN</td>
<td>attributable number</td>
</tr>
<tr>
<td>BP</td>
<td>benzo(a)pyrene</td>
</tr>
<tr>
<td>CA</td>
<td>chromosomal aberrations</td>
</tr>
<tr>
<td>CAM</td>
<td>cell adhesion molecule</td>
</tr>
<tr>
<td>CBPI</td>
<td>cytokinesis-blocked proliferation index</td>
</tr>
<tr>
<td>CI</td>
<td>confidence interval</td>
</tr>
<tr>
<td>CNS</td>
<td>central nervous system</td>
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<tr>
<td>Con-A</td>
<td>concanavalin-A</td>
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<td>Cx</td>
<td>connexin</td>
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<td>DC</td>
<td>direct current</td>
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<td>DENA</td>
<td>diethylnitrosamine</td>
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<tr>
<td>DMBA</td>
<td>7,12-dimethylbenz(a)anthracene</td>
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<tr>
<td>DNA</td>
<td>deoxyribonucleic acid</td>
</tr>
<tr>
<td>EAS</td>
<td>electronic access and security system</td>
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<tr>
<td>EBCLIS</td>
<td>electric blanket cancer Long Island study</td>
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<tr>
<td>ECG</td>
<td>electrocardiogram</td>
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<tr>
<td>EEG</td>
<td>electroencephalograms</td>
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<tr>
<td>EHC</td>
<td>Environmental Health Criteria</td>
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<tr>
<td>ELF</td>
<td>extremely low frequency</td>
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<tr>
<td>EM</td>
<td>electromagnetic</td>
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<tr>
<td>EMF</td>
<td>electromagnetic fields</td>
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<tr>
<td>ENU</td>
<td>N-ethyl-N-nitrosourea</td>
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<tr>
<td>ER</td>
<td>estrogen receptor</td>
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<tr>
<td>ERP</td>
<td>evoked or event-related potentials</td>
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<tr>
<td>ES</td>
<td>embryonic stem cells</td>
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<tr>
<td>FDTD</td>
<td>finite-difference time-domain</td>
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<td>FFT</td>
<td>fast Fourier transformation</td>
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<tr>
<td>FSH</td>
<td>follicle stimulating hormone</td>
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<td>GABA</td>
<td>gamma-aminobutyric acid</td>
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<td>GCS</td>
<td>ceramide glucosyltransferase</td>
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<tr>
<td>GH</td>
<td>growth hormone</td>
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<tr>
<td>GJIC</td>
<td>gap junction intercellular communication</td>
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<tr>
<td>H2O2</td>
<td>hydrogen peroxide</td>
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<td>HIOMT</td>
<td>hydroxyindole-O-methyltransferase</td>
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<tr>
<td>HRV</td>
<td>heart rate variability</td>
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HSF  heat shock factor
hsp  heat shock protein
IARC  International Agency for Research on Cancer
ICNIRP  International Commission on Non-Ionizing Radiation Protection
IEEE  Institute of Electrical and Electronic Engineers
IEI  idiopathic environmental intolerance
IFN  interferon
lg  immunoglobulin
IL  interleukin
JEM  job-exposure matrix
LAK  lymphokine activated killer
LH  luteinising hormone
LIBCSP  Long Island breast cancer study project
LPS  lipopolysaccharide
LTP  long-term potentiation
MBM  mouse bone marrow
MN  micronucleus
MRI  magnetic resonance imaging
mRNA  messenger ribonucleic acid
MS  multiple sclerosis
NA  noradrenaline
NADH  nicotinamide adenine dinucleotide
NADPH  nicotinamide adenine dinucleotide phosphate
NAT  N-acetyl-transferase enzyme
NDI  nuclear division index
NGF  nerve growth factor
NHL  non-Hodgkin lymphoma
NIEHS  National Institute for Environmental Health Sciences
NIOHS  National Institute for Occupational Safety and Health
NK  natural killer
NMU  N-methylnitrosourea
NO  nitric oxide
NRPB  National Radiological Protection Board
ODC  ornithine decarboxylase
OHCC  ordinary high current configuration
8-OhdG  8-hydroxydeoxyguanine
OLCC  ordinary low current configuration
OR  odds ratio
PAGE  poly-acrylamide gel electrophoresis
PARP  poly-ADP ribose polymerase
PBMC  peripheral blood mononuclear cells
PHA  phytohemagglutinin
PKC  protein kinase C
RAD  Radiation and Environmental Health Unit
RF  radiofrequency
RFID  radiofrequency identification
RNS  reactive nitrogen species
ROS reactive oxygen species
RR relative risk
SCE sister chromatid exchange
SD standard deviation
SES socioeconomic status
SMR standardized mortality ratio
SIR standardized incidence ratio
SPFD scalar potential finite difference
SRR standardized relative mortality risk ratio
TGFR transforming growth factor receptor
TMS transcranial magnetic stimulation
TNF tumour necrosis factor
TNFR tumour necrosis factor receptor
TPA 12-0-tetradecanoylphorbol-13-acetate
TSH thyroid-stimulating hormone
TWA time-weighted average
UG underground
UKCCSI United Kingdom childhood cancer study investigators
ULF ultra low frequency
UV ultraviolet
VDU visual display unit
VHCC very high current configuration
VLCC very low current configuration
VLF very low frequency
WBC white blood cell
WHO World Health Organization

Units

A ampere
kA kiloampere, 10^3 ampere
eV electronvolt
F farad
µF microfarad, 10^-6 farad
Hz hertz
kHz kilohertz, 10^3 hertz
MHz megahertz, 10^6 hertz
J joule
kJ kilojoule, 10^3 joule
M molar
nM nanomolar, 10^-9 molar
N newton
pN piconewton, 10^-12 newton
V volt
kV kilovolt, 10^3 volt
mV millivolt, 10^-3 volt
µV microvolt, 10^-6 volt
<table>
<thead>
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<tr>
<td>T</td>
<td>tesla</td>
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<tr>
<td>kT</td>
<td>kilotesla, $10^3$ tesla</td>
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<td>mT</td>
<td>millitesla, $10^{-3}$ tesla</td>
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<tr>
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<td>microtesla, $10^{-6}$ tesla</td>
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<td>watt</td>
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<tr>
<td>kW</td>
<td>kilowatt, $10^3$ watt</td>
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<tr>
<td>Ω</td>
<td>ohm</td>
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<tr>
<td>kΩ</td>
<td>kilohm, $10^3$ ohm</td>
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