

45092

This report contains the collective views of an international group of experts and does not necessarily represent the decisions or the stated policy of the United Nations Environment Programme, the International Radiation Protection Association, or the World Health Organization.

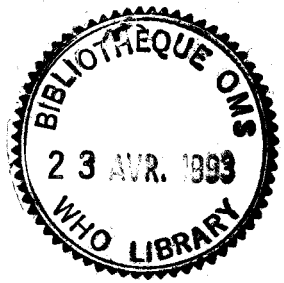
Environmental Health Criteria 137

ELECTROMAGNETIC FIELDS (300 Hz to 300 GHz)

Published under the joint sponsorship of
the United Nations Environment Programme,
the International Radiation Protection Association,
and the World Health Organization



World Health Organization
Geneva, 1993



WHO Library Cataloguing in Publication Data

Electromagnetic fields (300 Hz to 300 GHz)

(Environmental health criteria ; 137)

1. Electromagnetic fields - adverse effects 2. Environmental exposure I. Series

ISBN 92 4 157137 3 (NLM Classification: QT 34)
ISSN 0250-863X

The World Health Organization welcomes requests for permission to reproduce or translate its publications, in part or in full. Applications and enquiries should be addressed to the Office of Publications, World Health Organization, Geneva, Switzerland, which will be glad to provide the latest information on any changes made to the text, plans for new editions, and reprints and translations already available.

©World Health Organization 1993

Publications of the World Health Organization enjoy copyright protection in accordance with the provisions of Protocol 2 of the Universal Copyright Convention. All rights reserved.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the World Health Organization in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

CONTENTS

PREFACE	11
1. SUMMARY AND RECOMMENDATIONS FOR FURTHER STUDIES	15
1.1 Summary	15
1.1.1 Physical characteristics in relation to biological effects	15
1.1.2 Sources and exposure	16
1.1.2.1 Community	16
1.1.2.2 Home	16
1.1.2.3 Workplace	16
1.1.3 Biological effects	17
1.1.4 Laboratory studies	18
1.1.5 Human studies	20
1.1.6 Health hazard assessment	21
1.1.6.1 Thermal effects	21
1.1.6.2 Pulsed fields	22
1.1.6.3 Amplitude-modulated RF fields	22
1.1.6.4 RF field effects on tumour induction and promotion	22
1.1.6.5 RF-induced current densities	22
1.1.6.6 RF contact shocks and burns	22
1.1.7 Exposure standards	23
1.1.7.1 Basic exposure limits	23
1.1.7.2 Occupational exposure limits	24
1.1.7.3 Exposure limits for the general population	25
1.1.7.4 Implementation of standards	25
1.1.8 Protective measures	25
1.2 Recommendations for further studies	26
1.2.1 Introduction	26
1.2.2 Pulsed fields	26
1.2.3 Cancer, reproduction, and nervous system studies	27
1.2.4 Weak-field interactions	27
1.2.5 Epidemiology	28
2. PHYSICAL CHARACTERISTICS	29
2.1 Introduction	29

2.2	Electric field	29
2.3	Magnetic field	31
2.4	Waves and radiation	32
3.	NATURAL BACKGROUND AND HUMAN-MADE SOURCES	36
3.1	General	36
3.2	Natural background	37
3.2.1	Atmospheric fields	37
3.2.2	Terrestrial emissions	38
3.2.3	Extraterrestrial fields	38
3.3	Human-made sources	39
3.3.1	General	39
3.3.2	Environment, home, and public premises	43
3.3.3	Workplace	45
3.3.4	Medical practice	48
4.	EXPOSURE EVALUATION - CALCULATION AND MEASUREMENT	51
4.1	Introduction	51
4.2	Theoretical estimation	51
4.3	Measurements	56
4.3.1	Preliminary considerations	56
4.3.2	Near-field versus far-field	57
4.3.3	Instrumentation	57
4.3.4	Measurement procedures	58
5.	DOSIMETRY	61
5.1	General	61
5.2	Low frequency range	62
5.2.1	Magnetic fields	62
5.2.2	Electric fields	65
5.3	High-frequency range	72
5.4	Derivation of exposure limits from basic quantities	78
6.	INTERACTION MECHANISMS	80
6.1	General	80
6.2	Electrical properties of cells and tissues	81
6.2.1	Permittivity	81
6.2.2	Non-linear effects	84
6.2.3	Induced fields at the cellular level	85

6.2.4	Body impedance	86
6.3	Direct interactions - strong fields	88
6.3.1	Interactions with excitable tissues	88
6.3.2	Thermal interactions	89
6.4	Direct interactions - weak fields	91
6.4.1	General	91
6.4.2	Microelectrophoretic motion	93
6.4.3	Ion-resonance conditions	93
6.4.4	Calcium ion exchange	94
6.5	Indirect interactions	96
7.	CELLULAR AND ANIMAL STUDIES	104
7.1	Introduction	104
7.2	Macromolecules and cell systems	104
7.2.1	Effects on cell membranes	105
7.2.2	Effects on haematopoietic tissue	107
7.2.3	Isolated cerebral tissue, peripheral nerve tissue, and heart preparations	110
7.2.4	Mutagenic effects	111
7.2.5	Cancer-related studies	112
7.2.6	Summary and conclusions: <i>in vitro</i> studies	114
7.3	Animal studies	114
7.3.1	Nervous system	115
7.3.2	Ocular effects	118
7.3.3	Auditory perception	123
7.3.4	Behaviour	124
7.3.4.1	Thermoregulation	124
7.3.4.2	Activity (spontaneous movement)	126
7.3.4.3	Learned behaviours	127
7.3.5	Endocrine system	130
7.3.6	Haematopoietic and immune systems	133
7.3.7	Cardiovascular system	139
7.3.8	Reproduction and development	141
7.3.8.1	kHz studies	141
7.3.8.2	MHz and GHz studies	142
7.3.9	Genetics and mutagenesis	146
7.3.10	Cancer-related studies	148
7.3.11	Summary and conclusions	152
8.	HUMAN RESPONSES	155
8.1	Laboratory studies	155
8.1.1	Cutaneous perception	155

8.1.2	Other perception thresholds	158
8.1.3	Auditory effects	158
8.1.4	Induced-current effects	158
8.1.5	Thermoregulation	159
8.1.6	Contact currents	164
8.2	Epidemiological and clinical comparative studies	164
8.2.1	Mortality and morbidity studies	164
8.2.2	Ocular effects	168
8.2.3	Effects on reproduction	168
8.2.4	VDU studies	171
8.2.5	Conclusions	173
8.3	Clinical case studies and accidental overexposures	173
9.	HEALTH HAZARD ASSESSMENT	175
9.1	Introduction	175
9.2	Thermal effects	176
9.3	RF contact shocks and burns	177
9.4	Induced current densities	178
9.5	Pulsed RF fields	179
9.6	RF fields amplitude modulated at ELF frequencies	179
9.7	RF effects on tumour induction and progression	180
10.	EXPOSURE STANDARDS	181
10.1	General considerations	181
10.2	Present trends	182
10.3	Recommendations by the IRPA	183
10.4	Concluding remarks	186
11.	PROTECTIVE MEASURES	187
11.1	Engineering measures	187
11.2	Administrative controls	190
11.3	Personal protection	191
11.4	Medical surveillance	191
11.5	Interference with medical devices and safety equipment	193
	GLOSSARY	194
	REFERENCES	206
	RESUME ET RECOMMANDATIONS EN VUE D'ETUDES FUTURES	259
	RESUMEN Y RECOMENDACIONES PARA ESTUDIOS ULTERIORES	276

WHO/IRPA TASK GROUP ON ELECTROMAGNETIC
FIELDS (300 Hz TO 300 GHz)

Members

Prof J. Bernhardt ^a	Federal Office of Radiological Protection, Institute for Radiation Hygiene, Munich-Neuherberg, Germany
Dr C. F. Blackman	US Environmental Protection Agency, Health Effects Research Laboratory, North Carolina, USA
Dr L.A. Court ^a	Département de Protection Sanitaire, Centre d'Etudes Nucléaires, Fontenay-aux-Roses, France
Mme A. Duchêne ^a	Scientific Secretary, International Non-ionizing Radiation Committee, Fontenay-aux-Roses, France
Prof M. Grandolfo ^a	Istituto Superiore di Sanità, Rome, Italy
Dr M.H. Repacholi ^a	Royal Adelaide Hospital, Adelaide, Australia (<i>Chairman</i>)
Dr R.D. Saunders	National Radiological Protection Board, Didcot, United Kingdom (<i>Co-Rapporteur</i>)
Prof M.G. Shandala ^a	AN Marzeev Research Institute of General and Communal Hygiene, Kiev, USSR
Dr J.A. Stolwijk ^a	Department of Epidemiology and Public Health, Yale University, New Haven, USA
Dr M.A. Stuchly ^a	Bureau of Radiation and Medical Devices, Ottawa, Canada

Dr M. Swicord Centre for Devices and Radiological
Health, Food and Drug
Administration, Rockville, USA
(*Co-Rapporteur*)

Dr L.D. Szabo^a National Research Institute for
Radiobiology and Radiation Hygiene,
Budapest, Hungary

Dr S. Szmigielski Centre for Radiobiology and
Radiation Safety, Warsaw, Poland
(*Vice-Chairman*)

Observer

Dr A. McKinlay^a National Radiological Protection
Board, Didcot, United Kingdom

^aFrom the International Non-Ionizing Radiation Committee of IRPA.

NOTE TO READERS OF THE CRITERIA MONOGRAPHS

Every effort has been made to present information in the criteria monographs as accurately as possible without unduly delaying their publication. In the interest of all users of the environmental health criteria monographs, readers are kindly requested to communicate any errors that may have occurred to the Director of the International Programme on Chemical Safety, World Health Organization, Geneva, Switzerland, in order that they may be included in corrigenda, which will appear in subsequent volumes.

DEDICATION

This monograph is dedicated to:

Professor Przemyslaw A. Czerski, a charter member of International Non-ionizing Radiation Committee, who died on 15 April 1990 in Silver Spring, MD (USA). He was a pioneer investigator into the effects of non-ionizing radiation on biosystems and the assessment of the potential hazards associated with such exposure. As a fervent promoter of international cooperation, Professor Czerski played an active part in the establishment of the International Non-Ionizing Radiation Committee and in the development of its activities. His broad scientific knowledge and his tireless energy made him a major contributor to the present publication.

PREFACE

The International Radiation Protection Association (IRPA) initiated activities concerned with non-ionizing radiation by forming a Working Group on Non-Ionizing Radiation in 1974. This Working Group later became the International Non-Ionizing Radiation Committee (IRPA/INIRC), at the IRPA meeting held in Paris in 1977. The IRPA/INIRC reviews the scientific literature on non-ionizing radiation and makes assessments of the health risks of human exposure to such radiation. On the basis of Environmental Health Criteria monographs, developed in conjunction with the World Health Organization, Division of Environmental Health, the IRPA/INIRC recommends guidelines on exposure limits, drafts codes of safe practice, and works in conjunction with other international organizations to promote safety and standardization in the non-ionizing radiation field.

A WHO/IRPA Task Group to review the final draft of the Environmental Health Criteria on Electromagnetic Fields (300 Hz-300 GHz) met at the WHO Collaborating Centre for NIR in Ottawa, Canada, from 22 to 26 October 1990. Dr A.J. Liston, Assistant Deputy Minister, Health Protection Branch, opened the meeting on behalf of the Minister for Health and Welfare Canada. Mr J.R. Hickman, Director General, Environmental Health Directorate, welcomed the participants. The support of Health and Welfare Canada and the local organization by the Environmental Health Directorate are gratefully acknowledged.

The first draft of this publication was compiled by Professor J. Bernhardt, Professor P. Czerski, Professor M. Grandolfo, Dr A. McKinlay, Dr M. Repacholi, Dr R. Saunders, Professor J. Stolwijk, and Dr M. Stuchly. An editorial group comprising Professor J. Bernhardt, Professor P. Czerski, Professor M. Grandolfo, Mr C. Hicks, Dr A. McKinlay, Dr R. Saunders, Mr D. Sliney, Professor J. Stolwijk, and Dr M. Swicord met at the US Army Environmental Hygiene Agency, Edgewood, MD, in February 1990 to revise the draft. A second editorial group comprising Professor J. Bernhardt, Mme A. Duchêne, Dr A. McKinlay (Chairman), Professor B. Knave, Dr R. Saunders, and Dr M. Stuchly met at the National Radiological Protection Board, Didcot, United Kingdom, in May 1990 to collate and incorporate the comments received by IPCS Focal

Points, IRPA Associate Societies, and individual experts. Dr M. Repacholi was responsible for the scientific editing of the text and Mrs M.O. Head of Oxford for the language editing.

This publication comprises a review of the data on the effects of electromagnetic field exposure on biological systems pertinent to the evaluation of human health risks. The purpose of the document is to provide an overview of the known biological effects of electromagnetic fields in the frequency range 300 Hz to 300 GHz, to identify gaps in this knowledge so that direction for further research can be given, and to provide information for health authorities, regulatory, and similar agencies on the possible effects of electromagnetic field exposure on human health, so that guidance can be given on the assessment of risks from occupational and general population exposure.

Most radiofrequency (RF) field standards are based on the premise that there exists a threshold specific absorption rate (SAR) of RF energy (for frequencies above about 1 MHz) of 1-4 W/kg, above which there is increasing likelihood of adverse health effects. Below about 1 MHz, standards are based on induced currents in the body, causing shocks and burns. The purpose of updating the original Environmental Health Criteria monograph on radio frequency (WHO, 1981) is not only to provide a description of more completely developed RF dosimetry in humans, but to critically review more recent scientific literature, to determine if the threshold SAR on which standards are based is still valid. With the frequency range covered by the document extended down to 300 Hz, more emphasis is placed on induced currents and other possible mechanisms of interaction.

In conducting the literature review, earlier reports are not necessarily included, since these were reviewed in UNEP/WHO/IRPA (1981). Every effort has been made to distinguish clearly between biological effects that have been established and those that have been reported as preliminary or isolated results, or as hypotheses proposed to explain observed results. The conclusions of this document are based on peer reviewed and established knowledge of interactions of electromagnetic fields with biological systems.

Subjects reviewed include: the physical characteristics of electromagnetic fields; measurement techniques; applications of electromagnetic fields and sources of exposure; mechanisms of interaction; biological effects; and guidance on the development of protective measures, such as regulations or safe-use guidelines.

Health agencies and regulatory authorities are encouraged to set up and develop programmes that ensure that the maximum benefit occurs with the lowest exposure. It is hoped that this criteria document will provide useful information for the development of national protection measures against electromagnetic fields, as well as serving as a reliable basis for such reports as environmental impact statements necessary for proposed electromagnetic field emission facilities.

The WHO Regional Office for Europe has published a second edition of the book entitled *Nonionizing radiation protection*, which includes a chapter on radiofrequency radiation (Suess & Benwell-Morison, 1989).