Power Frequency and Radiofrequency Electromagnetic Fields

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Sources of Electromagnetic Fields

- **0 Hz**: Static (DC): natural background, VDUs, permanent magnets, MRI, transport
- **10 Hz**: Power frequency: electricity generation and supply, tape erasers, underfloor heating, motors, welding, transport, domestic/office appliances
- **1 kHz - 1 THz**: ITU band: ELF, VLF, VHF, UHF, SHF, EHF
- **1 kHz - 10 kHz**: RF welders, Cellphones, Cordless phones, RF fixed links
- **10 kHz - 100 kHz**: Radar, Radiolocation and radionavigation, Satellite uplinks
- **100 kHz - 1 MHz**: Electronic article surveillance and RF identification
- **1 MHz - 10 MHz**: Induction heating, Diathermy
- **10 MHz - 100 MHz**: Broadcast (AM, FM, TV), Ovens
- **100 MHz - 1 GHz**: Visual display units, WLAN
- **1 GHz - 10 GHz**: Ovens, RF welders, Cellphones, Cordless phones, RF fixed links
- **10 GHz - 100 GHz**: Radar, Radiolocation and radionavigation, Satellite uplinks
- **100 GHz - 1 THz**: Electronic article surveillance and RF identification

Infrared radiation

Visual display units
1) International EMF Exposure Guidelines

- Who publishes the guidelines?
- Where can they be found?
- Are they under review?
International Commission on Non-Ionizing Radiation Protection (ICNIRP)

- Independent international scientific organisation
- Officially recognised by WHO as its advisory body
- Members are elected - none from industry
- Publishes reviews, guidelines and statements

www.icnirp.org
Scope of Guidelines

- Cover exposure to EMFs from static E & H fields to lower boundary of infra-red, 300 GHz (1 mm wavelength)
- Relate to the exposure of people, not the emissions from sources
- Intended to apply to workers and members of the public
- Do not apply to patients exposed for medical diagnostic and treatment purposes
- Do not cover electrical interference with or heating of medical implants
- Set out a framework for protection based on basic restrictions and reference levels
UK Advice on EMF Guidelines

Latest formal advice was published in 2004

- EMF Advice Document: Docs NRPB 15(2)
- EMF Science Review: Docs NRPB 15(3)

“The review of current scientific knowledge, the adoption of a cautious approach to the interpretation of these data, and a recognition of the benefits of international harmonisation, combine in a recommendation to adopt the ICNIRP exposure guidelines for occupational and general public exposure to electromagnetic fields between 0 and 300 GHz.”

NRPB became HPA’s radiation protection division on 1 April 2005

see: www.hpa.org/radiation
Stochastic effects – Ionising radiation, but not EMFs

- Risk of an effect increases with increasing exposure, but a risk exists for all exposure levels
- Limits are set based on an acceptable level of risk

Deterministic effects – EMFs and ionising radiation

- Effects occur above a threshold exposure level, which may vary to some extent from person to person
- Limits are set at the lower end of the expected range of thresholds in order to prevent effects
2) Implementation of ICNIRP Exposure Guidelines

• UK Health and Safety Legislation
• EU Council Recommendation
• European Directive on Workers’ Exposure
There is presently no specific UK legislation setting exposure limits on EMFs

General UK safety legislation provides an enabling route for the guidelines
- Section 3 of the Health and Safety at Work etc. Act (risk assessment)
- Management of Health and Safety at Work Regulations 1999
- HSE refers to HPA advice on EMF exposure

ICNIRP guidelines have been widely adopted on a voluntary basis to aid risk assessments

http://www.hse.gov.uk/radiation/nonionising/index.htm
Published on 12 June 1999 and supported by the UK Government

Bears on governments in EU Member States

Framework for restricting EMF Exposure of the general public within Europe

Incorporates the ICNIRP numbers, but with provisos, e.g. “aim to achieve respect for”

Applies, in particular, to relevant areas where members of the public spend significant time


• Was agreed and published in 2004
• Would have applied to all workers from April 2008
• Postponed until 2012 and likely to be rewritten before then
• Restrictions are similar to ICNIRP occupational values
• The EU has mandated CENELEC (with CEN and ETSI) to develop exposure assessment standards (M351)
  • This work is not postponed
  • EN50499 is a useful document
• HSE is the lead Department in the UK

Also see Directive 2008/46/EC
3) Guidelines for Static Magnetic Fields
Geomagnetic Field

Magnetic Flux Density, $\mu$T

- 25
- 30
- 35
- 40
- 45
- 50
- 55
- 60
- 65
Electrochemical Industry
## Static Magnetic Fields in MRI

<table>
<thead>
<tr>
<th>Flux density (T)</th>
<th>Number of UK Scanners</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cylindrical bore</td>
<td>Open bore</td>
</tr>
<tr>
<td>≤0.35</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>0.5</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>0.6</td>
<td>58</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>345</td>
<td>2</td>
</tr>
<tr>
<td>1.5</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>&gt;3</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Published in August 2008

## AGNIR 2008 Review of Static Magnetic Fields

<table>
<thead>
<tr>
<th>Biological effect</th>
<th>Approximate Threshold B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alteration of effects on cells due to other agents</td>
<td>0.2 T</td>
</tr>
<tr>
<td>Orientation responses in cells and macromolecules</td>
<td>0.5 T</td>
</tr>
<tr>
<td>Vertigo and a metallic taste in humans</td>
<td>2 T</td>
</tr>
<tr>
<td>Aversive responses in animals</td>
<td>4 T</td>
</tr>
<tr>
<td>Cardiac effects increasingly likely</td>
<td>8 T</td>
</tr>
</tbody>
</table>

A hierarchy of biological responses with their likelihood and severity increasing with flux density

See report RCE-6 on HPA website:  
Basis of 2009 Guidelines for Static Magnetic Fields

Transient sensory effects:
- Vertigo
- Nausea
- Phosphenes

Some workers might voluntarily and knowingly experience these effects

Adverse health effects:
- Peripheral nerve stimulation
- Cardiovascular effects

8T is regarded as the limit of current knowledge
Basic Restrictions on Static Magnetic Flux Density

For specific work applications, exposure up to 8 T can be justified, if the environment is controlled and appropriate work practices are implemented to control movement-induced effects.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Magnetic flux density (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICNIRP occupational</td>
</tr>
<tr>
<td>Maximum in head, neck and trunk</td>
<td>2‡</td>
</tr>
<tr>
<td>Maximum in limbs</td>
<td>8</td>
</tr>
<tr>
<td>Maximum in any part of the body</td>
<td>-</td>
</tr>
</tbody>
</table>

*Dangers from flying objects can lead to much lower restriction levels in practice, such as 0.5 mT*
4) Guidelines for Low Frequency Fields
Low Frequency Sources
Induction Furnace
Current Density Induced by Electric Field

Vertical electric field in grounded person at 50 Hz

The colour map is a standard rainbow spectrum going from red for the highest current density to violet for the lowest.
Time-varying Fields 
($f < 10$ MHz)

- Electric currents and fields induced in tissue affect functions of the central nervous system (CNS)
  - Control of movement and posture
  - Memory and reasoning
  - Visual processes, magnetophosphenes
- Threshold electric field strengths in tissue
  - Magnetophosphenes: $\sim 10$-60 mV/m in retina (at 20 Hz)
  - Direct stimulation of nerves and muscles: $\sim$ few V/m
- Basic restrictions are presently set on induced current density in CNS tissues
Basic Restrictions on Induced Current Density

- Basic restrictions follow frequency dependence of biological responses
- Effects are instantaneous therefore time averaging is not permitted
5) Guidelines for Radiofrequency Fields
Radio Wave Sources in the Environment
Radio Wave Sources in the Environment
Induction Heating
Short Wave Diathermy

- Heating of body tissues: typically 27 MHz, up to around 400 W
- Factors in assessing exposures of operators
  - Time averaging and spatial variation in field strength
- Protection of operators usually through administrative controls
Variation in Absorbed Energy Distribution with Frequency

100 MHz  200 MHz  400 MHz  2450 MHz
Time-varying Fields
(100 kHz < f < 10 GHz)

- **Adverse effects due to energy absorption**
  - Heat stress (~38°C)
    - Headaches, dizziness, thirst
  - Decreased sperm count
  - Developmental defects
  - Reduced cognitive performance
  - Heat stroke (~41°C)
    - Convulsions, unconsciousness, organ damage, death

- **Basic restrictions are set on specific absorption rate (SAR) of energy in the body tissues**
  - Unit is the watt per kilogram (W kg⁻¹)
Rationale for Basic Restrictions on SAR

- Restrict whole-body SAR to avoid heat stress and heat stroke due to generalised heating
  - $1^\circ\text{C}$ rise in core temperature results from a whole-body averaged SAR of $4 \text{ W kg}^{-1}$
- Restrict localised SAR to avoid tissue damage
  - Eye damage, fetal abnormalities, etc
- Average exposures over a period of time
  - Increase in temperature due to energy absorption is not instantaneous
Basic Restrictions on Whole-body SAR

ICNIRP occupational
• 0.4 W kg\(^{-1}\) – Reduction factor of 10

ICNIRP general public
• 0.08 W kg\(^{-1}\) – Reduction factor of 50

The distribution of SAR in the body is to be averaged,
1) over the entire mass of the body, and
2) as the maximum occurring over any 6-minute period before comparison with these values.
6) Power Frequency Magnetic Fields and Cancer

The case for further precaution in the absence of accepted causality
• Pooled analyses of case control studies have shown a doubling of the (relative) risk of childhood leukaemia in association with prolonged exposure to power frequency fields above about 0.4 μT
  • Childhood leukaemia is rare (annual risk 1:20000)
  • Exposure above 0.4 μT is rare (0.5 % of UK population)
• If causal
  • The risk up to age 15 for the 500 children in the UK exposed above 0.4 μT would be doubled from 1:1400 to 1:700
  • Exposure would account for around 2-5 cases per year in the UK

In 2002, the International Agency for Research on Cancer (IARC) classified power frequency magnetic fields as a possible human carcinogen (*Group 2B*).

**EVALUATION**

- There is *limited evidence* in humans for carcinogenicity of extremely low frequency magnetic fields in relation to childhood leukaemia.
- There is *inadequate evidence* in humans for the carcinogenicity of extremely low frequency magnetic fields in relation to all other cancers.
- There is *inadequate evidence* in experimental animals for the carcinogenicity of extremely low frequency magnetic fields.

Adopt ICNIRP guidelines and

- The government should consider the need for further precautionary measures in respect of exposure of children to power frequency magnetic fields
- In doing so it should note that the overall evidence for adverse effects at exposure levels normally experienced by the public is weak
- The least weak evidence is for the exposure of children to power frequency magnetic fields and childhood leukaemia
Stakeholders Advisory Group on ELF EMF (SAGE)

Set up in 2004 to identify and explore implications for a precautionary approach in response to concerns about the possibility of health effects at field levels below those defined in the ICNIRP exposure guidelines

Main recommendations

- Better information for the public
- Optimal phasing of 132 kV overhead lines
- Corridor option also identified - a moratorium on new homes and schools built in the vicinity of existing power lines, and vice versa

http://www.rkpartnership.co.uk/sage/
Support for

- Investigating modifications to house wiring to reduce fields
- Optimal phasing of power lines
- Testing market for low field appliances
- Public information with proportionate health messages

Agreed with SAGE there are no viable precautionary options for existing dwellings near high voltage power lines

No support for corridor option for new buildings near high voltage power lines or *vice versa*

Government response to SAGE Report

To take forward the measures proposed by SAGE on:

- Optimal phasing of high voltage overhead power lines
- Electrical appliances in homes
- Household wiring practices
- The provision of advice to the public on ELF EMF.

Corridor option: no new lines near homes and schools and vice versa

“SAGE’s cost benefit analysis does not support this option. The Government therefore consider this option to be disproportionate given the evidence base on the potential health risks arising from exposure to ELF EMF and has no plans to take it forward.”

Written Ministerial Statement 16th October 2009
http://www.publications.parliament.uk/pa/cm200809/cmhansrd/cm091016/wmstext/91016m0001.htm
7) Mobile Phones

Precautionary approach

- Adopt international guidelines
- Set up a research programme
- Measures to address concern
- Audit of base stations
- Provision of information

www.iegmp.org.uk
Computational Dosimetry for Mobile Phones

SAR

Temperature rise
Mobile phones were recognised as a new situation
  • Large numbers of people using a device held to their head producing localised exposures up to around 50% of ICNIRP guidelines

Individual studies were identified reporting biological effects at levels comparable with guideline values

Group’s concern led to advice that the non-essential use of phones by children should be discouraged

Advice accepted by CMO and HPA
Interphone

- Large multinational case-control study of mobile phone users
- Co-ordinated by IARC
  - 14 studies (13 countries)
  - Ages 30-59
- End-points
  - Glioma & meningioma (6000 cases)
  - Parotid gland tumour (600 cases)
  - Acoustic neurinoma (1000 cases)
- Several individual and pooled datasets have already been published
  - Full analysis is still awaited

http://www.iarc.fr/en/research-groups/RAD/current-topics.php
In the last few years, epidemiologic evidence on mobile phone use and the risk of brain and other tumors of the head in adults has grown in volume, geographic diversity of study settings, and the amount of data on longer-term users.

Some key methodologic problems remain, particularly with regard to selective nonresponse and inaccuracy and bias in recall of phone use.

Overall the studies published to date do not demonstrate an increased risk within approximately 10 years of use for any tumor of the brain or any other head tumor.

Despite the methodologic shortcomings and the limited data on long latency and long-term use, the available data do not suggest a causal association between mobile phone use and fast-growing tumors such as malignant glioma in adults (at least for tumors with short induction periods).

For slow-growing tumors such as meningioma and acoustic neuroma, as well as for glioma among long-term users, the absence of association reported thus far is less conclusive because the observation period has been too short.

_Epidemiology, September 2009 - Volume 20 - Issue 5 - pp 639-652_
8) Summary
Future Guidelines for Static and Low Frequency Fields

ICNIRP Guidelines for Static Fields
2009

ICNIRP Guidelines for Low Frequency Fields
2010?
Summary of EMF Exposure Guidelines

- Derived from comprehensive reviews of the science
- Apply to public and workers
- Contain restrictions on exposure
  - Used within risk assessments
  - Incorporated in EU Directives
  - Incorporated into technical standards
- Identify areas of scientific uncertainty
  - Make research recommendations
  - Indicate situations that may merit consideration of further precautions
Thank You

Any questions............

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