

FEATURE ARTICLE

Medical aspects of overexposures to electromagnetic fields

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Abstract

Overexposures to electromagnetic fields are uncommon events but are distressing to patients and demanding of physicians when they occur. The paper outlines some of the biophysical considerations in relation to health effects, the settings in which overexposures may occur, the characterisation of the overexposure, the clinical approach to a patient, and concludes with comments on medico-legal issues and the reporting of such cases.*

Keywords: radiofrequency, extremely low frequency, health effects, medical management.

Introduction

An overexposure to an electromagnetic field (EMF) is of intense concern to workers or members of the public. A doctor's scientific and humane skills are fully required to manage these patients. This paper is intended to guide the management of these cases. It is based on previous papers and clinical experience by one of the authors as well as another review paper and case reports^{1-2,3}. The paper relates only to acute health effects and does not discuss cancer or other long-term effects, nor does it include "electrical hypersensitivity" which is associated with exposure to very low-level fields.

The paper begins by outlining some of the biophysical considerations of EMF in relation to health effects, then considers the settings in which overexposures may occur, the characterisation of the overexposure, the clinical approach to a patient, and concludes with comments on medico-legal issues and the reporting of such cases.

Biophysics of electromagnetic fields (EMF)

EMF refers to electromagnetic fields occurring in the frequency range 0–300 GHz of the electromagnetic spectrum. These frequencies are non-ionising, ie they do not have sufficient energy to disrupt atomic structure (ionisation) like x-rays. EMF includes

50/60 Hz fields associated with electricity supplies as well as radiofrequencies (3 kHz–300 GHz) extensively used in communications, navigation, etc. These frequencies are the commonest electromagnetic fields encountered in practice and are the main focus of this paper. The biophysics and health effects of these frequencies and the relevant standards have been reviewed elsewhere^{4,5,6,7,8} and are briefly discussed below.

50/60Hz Fields. The main acute health effects of 50/60 Hz electromagnetic fields are caused by the induction of voltage gradients which may elicit an action potential and cause excitation of nerve, muscle and cardiac tissue. There is a very wide range in excitability of tissue ranging from alteration of synapse activity in the brain (0.075V/m peak), simulation of a 20 μm diameter nerve (6.15 V/m peak) or a 10 μm diameter nerve (12.30 V/m peak) or cardiac muscle (12.0 V/m peak); a range of over 160 fold.^{8,9}

Standards are set to prevent these effects (see Figs 1–3). The 2009 ICNIRP standard limits the induced *in-situ* electric field to 0.1 V/m at 50 Hz termed the “basic restriction”, which corresponds to an exposed field of 1 kV/m rms termed the occupational “reference level”. To allow for a wide margin of safety, the public exposure limit is set at 1/5 of this, ie 200 V/m. The respective magnetic field values for occupational exposure is 1000 A/m (the basic restriction), which corresponds to an exposed field of 500 μT (the reference level). To allow for a wide margin of safety, the public exposure limit is set at 1/5 of this, ie 100 μT . The standard permits higher exposure to a limb than the head.

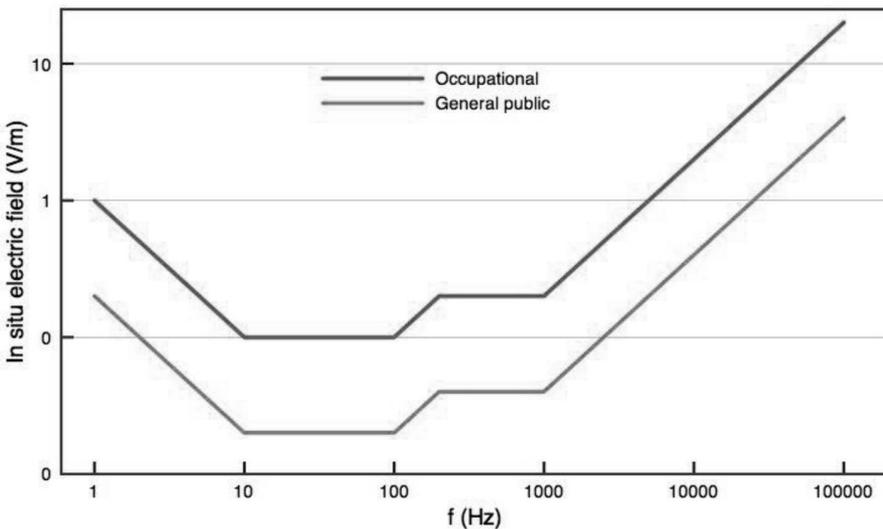


Fig 1. Basic restrictions; E-field. (ICNIRP 2009)

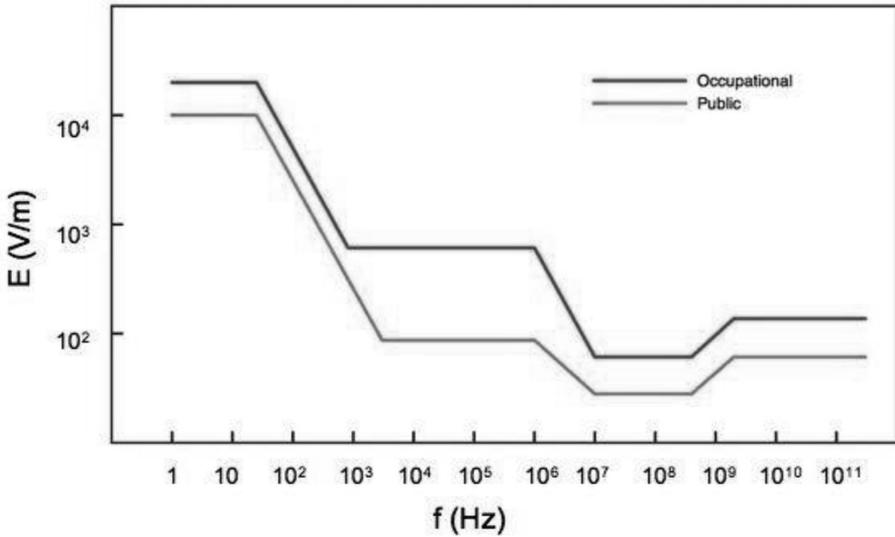


Fig 2. Reference level; E-field (ICNIRP 1996)

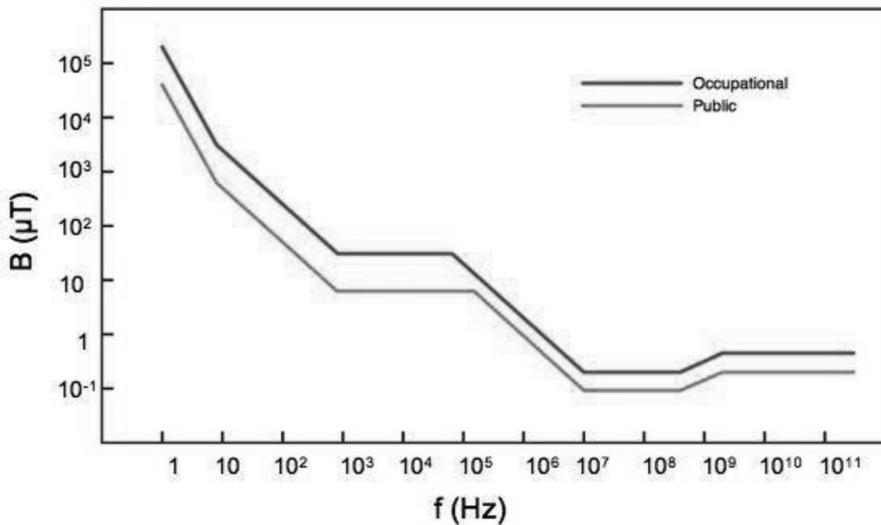


Fig 3. Reference level; B-field (ICNIRP 1996)

- The clinical effects are similar to an electric shock because the fields induce voltage and currents in the body and hence injury can occur in the same way if this is excessive.¹⁰
- Low-frequency (20 Hz) electric and magnetic fields are able to interact with synapses in the retina to cause a flickering light sensation called electrophosphenes or magnetophosphenes respectively. The threshold for this effect is between 10–100 mV/m. It is thought synapses in the brain may be similarly sensitive.

- Other health effects may arise from stimulatory effects on peripheral and central neurons and on neural networks. Myelinated nerves are thicker and more sensitive to EMF than unmyelinated nerves as in the grey matter of the central nervous system (CNS). It has been suggested on general principles that persons with epilepsy may be more sensitive to 50/60Hz EMF than others.
- Cardiac tissue is excitable at relatively high exposure levels (12.0 V/m peak) as discussed above. It may be stimulated to cause arrhythmias which may be life-threatening. This requires emergency medical treatment.
- Burns may occur with very high levels of exposure. They may be superficial or deep.
- Psychological effects such as post-traumatic stress disorder (PTSD) may also occur, and be difficult to distinguish from direct effects on the CNS.
- Electromagnetic interference of medical devices may occur. 50/60 Hz EMF overexposure may cause interference with medical devices which are often designed to be immune (protected) from normal EMF exposures. These devices may include cardiac pacemakers, insulin pumps, hearing devices, etc.

Radio frequency fields. The main acute health effects of radio frequency fields (3 kHz–300 GHz) are caused by heating of tissue due to the rapidly alternating fields exciting dipole molecules such as water or due to resistive heating of tissues. The standards have been set to minimise excess heating on the assumption of normal thermoregulation and good vascularity of tissue. These standards are “frequency dependent” because the extent of coupling of the body to fields (absorption) varies with frequency. It is lowest with the low frequencies (kHz), greatest with the frequencies at body resonance (2–5m wavelength in the low MHz region) and less again with the high frequencies (GHz) which mainly have surface absorption. This frequency-dependent absorption by the body results in a “U”-shaped safety curve (see Figs 1–3). The basic restrictions are expressed as a specific absorption rate (SAR) of energy into tissue (W/kg) and the corresponding reference levels are usually expressed as a power density (W/m²) rather than in terms of the individual electric or magnetic fields. The occupational standards are five times greater than the public exposure limits.

The following health effects may occur:

- **Sensation of warmth.** Radiofrequency fields act by causing heating. This may cause a sensation of warmth in an affected area, although this is not inevitable with only modest fields and deep penetration.
- **Compartment syndrome.** Radio frequencies may penetrate deeply and cause heating of muscle or other tissues without obvious superficial burns. This heating may cause injury and inflammation of muscle tissue and/or thrombosis of blood vessels leading to impaired circulation and ischaemia (compartment syndrome)¹¹. This requires emergency medical attention.

- **Ocular effects.** Radiofrequency may cause keratitis and iritis resulting in pain and a small pupil. Cataracts may be induced in animals exposed to intense radiofrequency (RF) fields. Cataracts take weeks to months to mature, which gives a window of opportunity to examine the lens immediately after an accident to assess its “pre-injury” status and then to examine it again a few months later to observe if injury has occurred.
- **Nervous system.** Effects on the CNS may include headaches and lethargy and cognitive effects such as decreased concentration. These may warrant more detailed assessment by investigations such as MRI or by neuropsychological testing. There is debate in the literature regarding other effects of RF fields on the CNS. Reeves reviewed the case reports of 34 cases of overexposure in the US air force¹². He found neuropsychological symptoms were common but assigned the 66% of cases to pre-existing psychiatric morbidity. This prevalence of psychological morbidity is improbable for a random event given that the community prevalence is only 15%. The case reports apparently did not recognise PTSD nor were nerve conduction tests or full neuropsychological assessment tests conducted on all cases. Comprehensive assessment of these symptoms is warranted before assigning them to “pre-existing morbidity”.

Effects on the peripheral nervous system include dysaesthesiae (pins and needles). Marchiori et al¹¹ reported a case in which a cook put her hand in a microwave oven with a faulty switch and suffered prolonged dysaesthesiae of the hand and face. The autonomic nervous system may be affected; Foreman reported raised blood pressure in their patients five months after an overexposure¹³.

- Psychological effects such as PTSD may also occur, and be difficult to distinguish from direct effects on the CNS.
- **Reproductive effects.** Both male and female reproduction may be affected by overexposure to RF fields. Heating of the testis in animals reduces the sperm count which usually returns to normal after heating ceases; however, the long-term effects on fertility are not known. Male workers may be intensely concerned regarding effects of an overexposure on virility, sterility and the possibility of malformed babies. This needs to be sympathetically discussed and sperm tests offered as appropriate.

The foetus in the pregnant female may be exposed to frequencies (eg MHz) which can penetrate deeply early in the pregnancy or to shorter wavelengths (eg GHz) later in the pregnancy. Overexposure early in pregnancy may be associated with miscarriage (abortion). The effects of overexposure later in pregnancy are not known. Because of the association of EMF with cancer, overexposure is likely to be of intense concern to the mother.

- **Metallic implants.** Medical implants such as orthopaedic rods may act as an antenna to concentrate an RF field. Some costume jewellery may act similarly. The associated heating may result in injury to local tissue and low frequencies (<100 kHz) may stimulate nerve or muscle.

- **Shock and burn.** Radiofrequency EMF may cause superficial or deep burns.¹⁴ Deep burns may be associated with the compartment syndrome discussed above.
- Electromagnetic interference of medical devices may occur with moderate levels of exposure. Radiofrequency EMF overexposure may cause interference with medical devices which are often designed to be immune (protected) from normal exposures.¹⁵

Settings of overexposures to EMF

The definition of an overexposure is problematic. Technically, any exposure above the appropriate limit is an overexposure. However, standards are set with a wide margin of safety and it is most unlikely that a single, brief (sec–min) exposure just above the limits will result in health effects. On the other hand, the person, for example a pregnant woman, may be understandably concerned and warrants proper medical management. In some cases, the basic restrictions need to be calculated from the measured exposure to determine if an overexposure has actually occurred; this may be important for medico-legal purposes. Standards vary between authorities such as ICNIRP and IEEE^{4,8} which indicates some uncertainty in the setting of the standards, particularly for extremely low frequencies.

Overexposures may occur in a wide variety of settings, including the following:

- **EMF workers.** Many workers are employed in industries which either intentionally use electromagnetic fields or they are exposed to fields as a byproduct of a process. For example, RF fields are intentionally generated for broadcasting, telecommunications, RF sealing, etc, whereas 50/60 Hz fields are generated as a byproduct in electricity generation, transmission and distribution. An EMF worker is supposed to be informed and knowledgeable about EMF and work in a “controlled environment” and hence is permitted to work at higher exposure limits than the public. An overexposure may occur as a result of faulty equipment, poor work practices, etc.
- **Other workers exposed to EMF.** Many other workers are employed where exposure to electromagnetic fields may occur directly as part of working with equipment or inadvertently. Overexposure may occur as a result of faulty equipment or poor work practices. For example, tradesmen, such as air-conditioning mechanics working on rooftops, may be inadvertently overexposed to RF fields from antennae on the rooftop.
- **Trespassers on EMF facilities.** Youths may trespass on EMF facilities without an awareness of the hazards they may be exposed to and have inadvertent overexposures to EMF.
- **Criminal.** There have been case reports of child abuse in which a baby has been placed in a microwave oven causing overexposure to RF fields.¹⁶

- **Medical misadventure.** Radiofrequency fields are sometimes used in medical therapy. While most standards exempt proper medical usage of intense RF fields from limits because the therapeutic benefit outweighs likely harm, excessive exposure may be a cause of injury.
- **Military usage.** Recently, intense beams of radiofrequency (60 GHz) which cause heating and pain have been developed as a means of crowd control. It is claimed that these fields are without adverse effects.¹⁷

Characterisation of the overexposure

When an overexposure is alleged to have occurred, the following parameters (ideally) should be collected to enable proper characterisation of the exposure as a basis for understanding the potential biophysics and hence, health effects on the person. Information may be available from the patient and/or from the site owner and/or from an equipment manufacturer. Sometimes, occupational hygiene expertise may be required to measure field strengths, particularly if there are multiple sources.

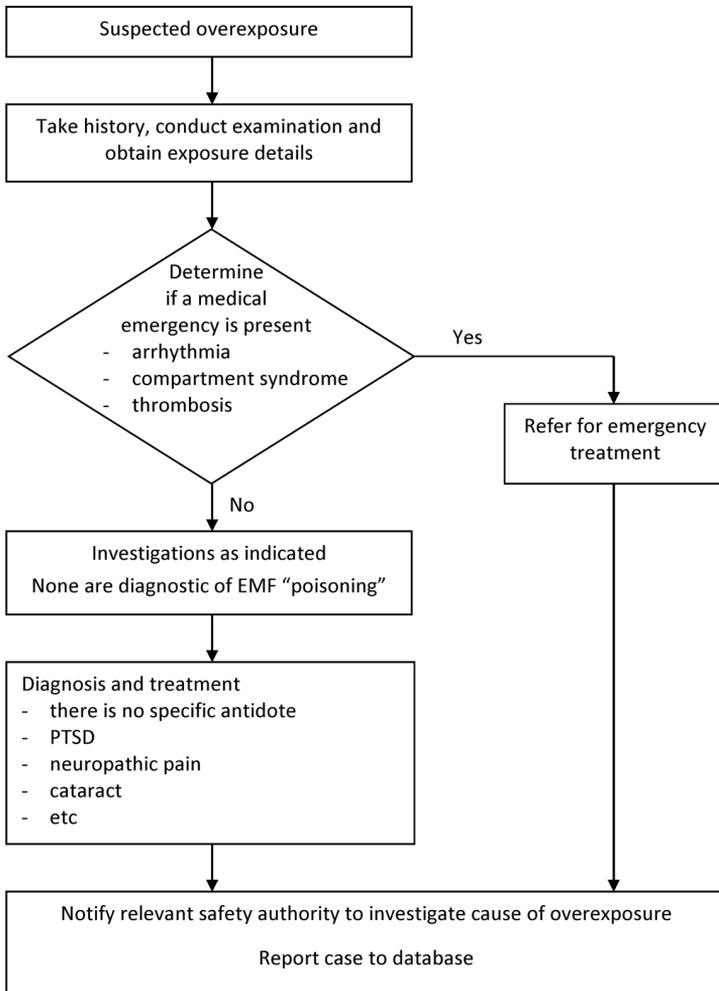
- **Frequency.** The overexposure EMF frequency needs to be determined as it is fundamental to the biophysics and pathology. Electric power frequencies (50/60 Hz) are usually obvious from the source. Information about the RF involved is important because wavelength determines coupling and depth of penetration into the body and hence possible effects.
- **Intensity.** The intensity of exposure from the EMF should be determined, partly for biological purposes and partly for medico-legal ones. This information may be estimated from first principles such as closeness to a powerful source or be known to an employer or site owner or may require the services of an occupational hygienist to measure it. Once the intensity of exposure is known, it may be further calculated in terms of the basic restrictions. As discussed above, the excitability of various tissues varies widely with 50/60 Hz EMF exposure and hence information about intensity of exposure provides some guide to potential health effects.
- **Duration of exposure.** This information is often available from the person. It may be in terms of days — months — years. While the energy from EMF is not cumulative in the body (unlike a toxin such as lead), it is likely that the more prolonged or recurrent an overexposure, the more likely there are to be health effects.
- Where possible, the site of the exposure should be visited with the worker and photographed so the position of the worker in relation to the source is clearly documented. Where a site visit is not possible, information such as site plans or photographs can be sent by email or mobile phone.

Clinical approach to the patient

When taking the history from an overexposed person, the physician needs to gain the confidence of the patient by showing an understanding of EMF. This is particularly important with regard to EMF workers. When the physician is not confident in understanding EMF, referral to a specialist in occupational medicine with experience

in EMF is recommended, for example, by a three-way telephone conversation between the patient, treating doctor and the specialist. (The authors are available for emergency professional assistance — see author details for contact.) The flowchart shows the steps in management and the proforma helps guide collection of information (see Diagram and Table).

Flowchart of Management of EMF Overexposure



- sperm count (helpful for reassurance)
 - ultrasound, etc of foetus, if needed (helpful for reassurance)
 - other tests as required by symptoms and the site of exposure
 - a panel of tests as a baseline and to screen for coincidental illness-causing symptoms eg FBE, C-reactive protein, electrolytes, etc.
- **Treatment.** Treatment is based on the symptoms and the findings on examination; there is no “antidote” for “EMF poisoning”. If there has been no overexposure, the patient can be reassured but may need assessment for PTSD. If there has been an overexposure, this needs to be discussed with the patient and their concerns explored. Persistent headaches and dysaesthesiae may be treated with tricyclic antidepressants, gabapentin or congeners. Specific pathologies such as arrhythmias, compartment syndrome, cataract, PTSD, etc will need to be treated in the usual manner.

Success will be determined by the confidence the patient has in the doctor, which is determined by the doctor's showing an understanding about EMF.

Medico-legal aspects

Overexposure incidents may become subject to legal proceedings such as workers compensation or other litigation. Therefore, medical records need to be fully documented and maintained.

Where appropriate, the doctor may refer the case to relevant authorities to properly investigate the cause of the overexposure with a view to prevention of recurrence.

Database of overexposures

We consider it would be helpful if a database were formed for reporting of overexposure incidents. Overexposures are rare events and pooling of reports would enable better analysis of this data. For example, it would improve documentation of health effects (or their absence) after exposure to levels above the occupational exposure limits. This may provide insight into biological mechanisms and pathologies at levels of exposure which are ethically not acceptable in human studies. It could help resolve the question of whether EMF causes direct effects on the CNS as compared to indirect psychological ones. In addition, if a pattern of overexposure incidents emerges, then preventive action may be taken. For example, after several reports of exposure to tradesmen on rooftops to RF sources, an alert notice was issued by health and safety authorities to site owners and workers in Victoria, Australia.¹⁸

Such a database would be comparable to the other databases developed for recording occupational diseases such as respiratory disease. The database could cover a region, such as a country or the EU, or be international. It could be managed in conjunction with the social partners of industry and unions and government. The proforma which is provided to help guide clinical assessment (Table above) could be modified so as to protect privacy and then be used for reporting incidents in a standardised fashion.

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- 1 Hocking B and Joyner K. Health aspects of radio frequency radiation accidents. Part 2: a proposed protocol for assessment of health effects. *Journal of Microwave Power and Electromagnetic Energy*. 1988; 23(2) 75–80.
 - 2 Hocking B. Management of RFR Overexposures. *Australian Family Physician*. 2001; 30(4) 339–342. (http://www.arpana.gov.au/pubs/rps/rps3_manage.pdf)
 - 3 COMAR. (IEEE Committee on Man and Radiation) Medical Aspects of RFR Overexposure. *Health Phys*. 2002; 82(3); 387–91
 - 4 International Commission on Non-Ionizing Radiation Protection. GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC, AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz) 1998: 74, (4) 494–521.
 - 5 International Commission on Non-Ionizing Radiation Protection. Statement on the Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and EMF up to 300GHz. *Health Physics*. 2009: 97 (3); 257–258.
 - 6 Environmental Health Criteria 238 (2007): Extremely Low Frequency (ELF) Fields WHO, Geneva, Switzerland, ISBN 978-92-4-157238-5
 - 7 Environmental Health Criteria 137 (1993): Electromagnetic Fields (300 Hz–300 GHz) WHO, Geneva, Switzerland, ISBN 92-4-157137-3
 - 8 IEEE (2002) IEEE standard for safety levels with respect to human exposure to electromagnetic fields, 0–3 kHz. IEEE Standard C95.6-2002, Institute of Electrical and Electronics Engineers, New York.
 - 9 Reilly JP. *Applied Bioelectricity*, Springer, 1998.
 - 10 Lee R. Injury by electrical forces. *Current Problems in Surgery*. 1997; 34 (9), 677–765.
 - 11 Marchioi P, Silva H, Hiralal M et al. "Acute multiple mononeuropathy after accidental exposure to oven microwave." *Occup Med*. 1995; 45; 276–277.
 - 12 Reeves G. "Review of Extensive workups of 34 USAF Patients Overexposed to RF." *Aviat Aero Environ Med* 2000; 71(3); 206–215) and Hocking B (corres) 2001; 72(6); 590-1.
 - 13 Foreman S, Holmes C, McManamon, Wedding W. Psychological symptoms and intermittent hypertension following microwave exposure. *J Occupational Medicine*. 1982; 24; 932–34.
 - 14 Hocking B, Joyner K, Newman H and Aldred R. Radiofrequency electric shock and burn. *Med J Aust*. 1994: 161; 683–685.
 - 15 International Electrotechnical Commission (IEC). Electromagnetic compatibility requirements and tests for medical electrical equipment (Standard No. IEC 60601-1-2: 2001). Geneva, Switzerland: IEC; 2001.
 - 16 Alexander R, Surrel J, Cohle S. "Microwave burns to children: an unusual manifestation of child abuse. *Paediatrics*. 1987. 79. 255–260.
 - 17 Hamdling D. Microwave weapon will rain pain from the sky. *New Scientist*. 23 July 2009.
 - 18 WorkSafe Victoria. Radiofrequency (RF) radiation — Dangers of exposure.[http://www.worksafe.vic.gov.au/wps/wcm/connect/WorkSafe/Home/Forms+and+Publications/Alerts/import_Radio+frequency+\(RF\)+radiation+-+Dangers+of+exposure](http://www.worksafe.vic.gov.au/wps/wcm/connect/WorkSafe/Home/Forms+and+Publications/Alerts/import_Radio+frequency+(RF)+radiation+-+Dangers+of+exposure)
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