Electromagnetic Fields from Therapeutic Diathermy Equipment:

A review of hazards and precautions

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Summary: Shortwave and microwave electromagnetic fields heat tissue through absorption of energy, and may lead to a danger of burns from current flow. The national and international bodies concerned with safe use of non-ionising radiations (NRPB and INIRC) have derived reference field strengths to provide guidance on limiting exposures to avoid these effects. The biological effects of exposure to electromagnetic fields and the power levels at which they occur are discussed. Measurements of field strengths close to diathermy equipment show that values above the reference levels extend to about 1 metre from electrodes and cables of continuous shortwave and microwave units, and about 0.5 m from pulsed shortwave units. Electric field strengths are greatest around the electrodes, while magnetic fields are highest near to the cables.

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Introduction

MODERN man is exposed to electromagnetic fields from many different sources, most of which have little effect on the body. However, some caution is required to ensure that people are not subjected to fields which might be harmful. Shortwave and microwave diathermy units heat tissue through absorption of energy from electromagnetic fields. The nature of these fields makes it impossible to concentrate all the energy in the tissue being treated, and anyone standing close to diathermy equipment, for example the operator, absorbs small amounts of electromagnetic energy.

During the 1980s all available evidence on the biological effects of electromagnetic fields has been collated (UNEP/WHO/IRPA 1981, 1987; NCRP, 1986). International guide lines have now been published on limiting exposure in the frequency range 100 kHz-300 GHz (IRPA/INIRC, 1988), and the National Radiological Protection Board (1989) has issued recommendations for the UK. The reference levels proposed in this report are not designed to act as limits, but are intended to indicate when guidance is required on working procedures. This paper describes some of the effects which can result from exposure to electromagnetic fields, reports measurements of fields around diathermy units, and discusses some implications of the new recommendations.

Review of Some Biological Effects of Electromagnetic Fields

Absorption of Energy

Absorption of energy in the body from electromagnetic fields is expressed in terms of the rate of absorption per unit mass of tissue. This is called the specific absorption rate (SAR), and is measured in units of watts per kilogram (W/kg). The IRPA/INIRC (1988) and NRPB (1989) have recommended that the whole-body SAR from electromagnetic fields should be limited to 0.4 W/kg. This is defined as the mean exposure for all tissues in the body averaged over a period of six minutes. The most sensitive indicator of stress from electromagnetic fields that has been found from studies of animals is the production of minor disturbances in patterns of learned behaviour. These disturbances occur at absorption rates which are a factor of ten greater than the whole-body SAR recommended by the NRPB (table 1).

Table 1: Rates of energy absorption and production in the human body

Activity	*Energy deposition rate (W/kg)*	*Reference*
Basal metabolic rate	1	
Energy generation during exercise	5-15	
Threshold for detectable effects (impairment of learned behaviour)	2-8	Blackwell and Saunders (1986)
Placing hands in lukewarm water	20-40	Sienkiewicz *et al* (1989)
Energy deposition from diathermy treatment	50-170	Guy *et al* (1974)
Reduction in transparency of lens of eye	130-600	NCRP (1986)
Recommended whole body SAR	0.4	IRPA/INIRC (1988), NRPB (1989)
Recommended SAR for any 100 g of internal organ or tissue	10	IRPA/INIRC (1988), NRPB (1989)
Recommended SAR for arms, legs, hands and feet	20	IRPA/INIRC (1988), NRPB (1989)

Electromagnetic fields do not heat the body uniformly, so in order to provide protection against localised hot spots, the IRPA/INIRC (1988) and NRPB (1989) recommend that the SAR should not exceed 10 W/kg in any 100 g of an internal organ or tissue, or 20 W/kg in the arms, legs, hands and feet. These levels are less stringent, because the thermoregulatory system has the capacity to maintain body temperature within well-defined limits through dilation of blood vessels, and can redistribute any energy absorbed locally to a wider volume. These SARs are compared to rates of energy production and absorption from some everyday human activities in table 1. They have been designed to provide protection against physical effects such as heating, but there is no evidence to suggest that the effects, if they were to occur, would lead to any long-term risk to health. The lack of blood supply to some ocular tissues makes them more susceptible to thermal damage. Reduction in transparency of the lens of the eye, leading to cataract formation, is a well-documented effect of microwave radiation (NRCP, 1986), but this has only been reported after prolonged exposure to SARs 10-100 times the recommended levels.

The amount of energy absorbed from an electromagnetic field is affected by the relative sizes of the wavelength of the radiation and the human body. A human being, lying in a favourable orientation, can act like a tuned antenna, absorbing energy from a field with maximum efficiency. The frequencies used for shortwave diathermy lie in the range where such resonances can occur. These effects have been taken into account in the derivation of reference power densities and field strengths which could give rise to an SAR of 0.4 W/kg for human beings. These reference levels are derived for the case of optimum coupling between a plane wave field and the human body at each frequency, and thus err on the side of safety. The values recommended by the NRPB (1989) for frequencies used for diathermy treatments are given in table 2. These levels apply to occupationally

Table 2: Derived exposure levels

Equipment	Frequency (MHz)	Wavelength (m)	Derived exposure levels: Magnetic field (A/m)	Electric field (V/m)	Power density (W/m^2)
Shortwave	27	11.1	0.18	61.4	10
Shortwave	434	1.45	0.17	64.0	10.8
Shortwave	915	3.0	0.25	92.6	22.8
Microwave	2,450	0.12	0.36	137	50

exposed workers and members of the general public, but not to patients undergoing diathermy treatment for whom the potential benefits should outweigh any possible hazard.

Effects from Flow of Induced Charge

Any person standing within an electric field can have small amounts of charge induced on the surface of his body. If he is in conductive contact with the ground, this charge will flow through his body to earth, producing an electric current which will heat the tissue. For a human being who is standing, the current will flow through the legs. The amount of heating depends on the current density, or the current flowing across unit area, and because the lower legs and ankles are thinner and thus have a smaller cross-sectional area for the current to flow through (fig 1a), they will be heated more than the rest of the body (Gandhi *et al*, 1985; Dimbylow, 1988). Electric field strengths recommended by NRPB and INIRC for 27 MHz have been set to avoid this hazard.

If a person in an electromagnetic field touches any metal object connected to earth, this may also provide a route to ground for charge induced in the body. Where charge flows through a small area of skin, the local current density will be much greater at the point of contact (fig 1b) and this leads

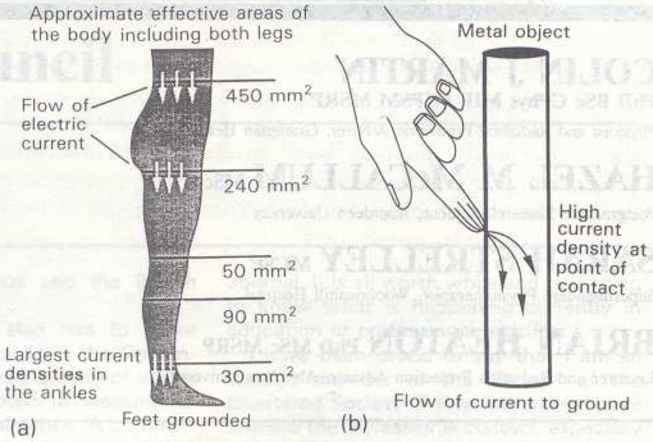

Fig 1: Origin of hazards from flow of electric charge in the body. (a) Energy absorption in legs: Reduction in cross-sectional area of the body, from the trunk downwards, will produce higher electric current densities in legs, where the area through which current flows is smallest. (b) Radiofrequency burn: If charge is induced in a body in an electromagnetic field, and the person touches a grounded metal object, current will flow through the point of contact. If area of contact is small this can lead to high current density which may produce a small burn. The same can occur if current flows from a metal object through a person to ground

to a risk of a radiofrequency burn for 27 MHz fields (Ghandi and Chatterjee, 1982). Burns can result from currents of 50 to 100 mA at the point of contact, although such burns are unlikely to be serious because of the small area of contact coupled with the reflex action of the body. NRPB (1989) recommends that conditions where currents over 100 mA can occur should be avoided. This is one reason why metal framed couches and chairs should not be used for treatments. Other items of equipment brought within the field of a diathermy unit, especially ones with associated cables which could act as receiving antennae, may also lead to this type of hazard, with charge induced in the object flowing to earth through any person touching them. Metal objects will also modify the field distribution from a diathermy unit.

Evidence for Non-thermal Effects of Electromagnetic Fields

There is also a possibility that there are non-thermal effects of electromagnetic fields. Laboratory experiments on animals and cell cultures have provided some evidence that electromagnetic fields, especially low-frequency fields (10 to 100 Hz), may produce changes below the levels at which any significant heating would occur (NRCP, 1986). Some epidemiological studies have suggested that there may be a slight increase in the incidence of leukaemia in subjects living near to power lines, due to exposure to 50 to 60 Hz fields. However, because of the sizes of the populations studied, the evidence is inconclusive. The times for which physiotherapists are exposed to low-frequency fields from pulsed units are a hundred thousand times shorter than the exposure periods in the epidemiological studies, so even if further evidence of such effects were found, there is no reason to suspect any long-term health risk to physiotherapists working with diathermy equipment.

Experimental Measures of Stray Fields Around Diathermy Equipment

Electromagnetic radiation from diathermy equipment has both electric and magnetic components. Electric and magnetic fields have been recorded during patient and phantom treatments in physiotherapy departments in a number of hospitals and health clinics in the Grampian Region (Martin *et al*, 1990). Electric field strengths were measured with a Raham model 4 meter (General Microwave Corporation, USA) and magnetic field strengths with a probe constructed in the biomedical physics and bio-engineering department at Aberdeen (Martin *et al*, 1990). Phantoms were made from plastic modules filled with saline of conductivity 600 mS/m. The modules were eight 5-litre containers, a 65 mm diameter tube and a glove. These were positioned side by side, or fixed together, to simulate human bodies undergoing treatments of different areas. Figures 2, 3 and 4 show contour maps of stray electric fields around an Ultratherm 608S 27 MHz unit, with three different treatment configurations, but similar power settings. Electric fields are

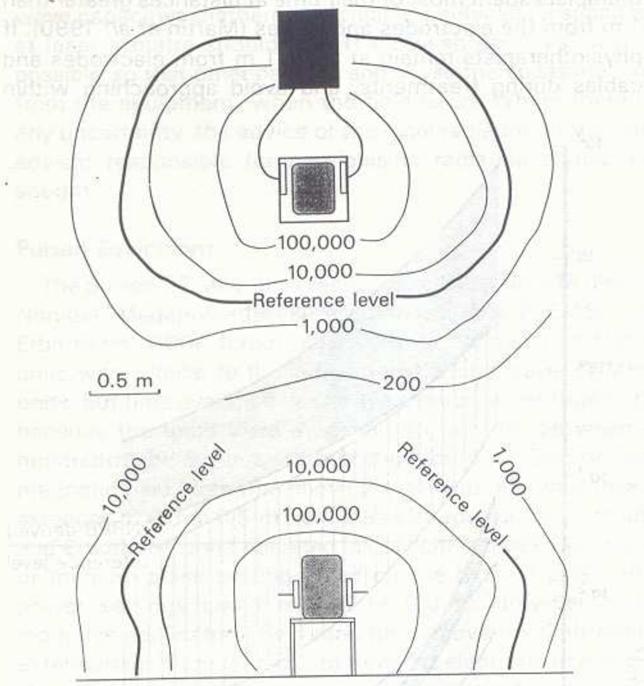

Fig 2: Contour maps showing distribution of square of electric field strength in $(V/m)^2$ around a contraplanar treatment of a phantom. Plots are made in horizontal and vertical planes through electrodes of Ultratherm 608S (Siemens) (power setting 3). A contour is included at 3770 $(V/m)^2$, NRPB reference level (61.4 V/m)^2

measured in units of volts per metre (V/m), and magnetic fields in amperes per metre (A/m). The amount of heating produced is related to the squares of the electric and magnetic field strengths, and so the squares of the field strengths are shown in the plots.

The highest electric field strengths occur near to the electrodes, while magnetic fields are greatest around the cables. The fields associated with capacitive treatments are generally higher than those with inductive applicators. Large variations in field strength result from differences in the electrode arrangement and positioning of the cables and console. The magnitudes of stray electric fields were affected by factors such as distance of the electrodes from the body surface, the electrode diameter, and the volume of the section of the body treated. For example with a contraplanar treatment of a flat wrist where the two electrodes are

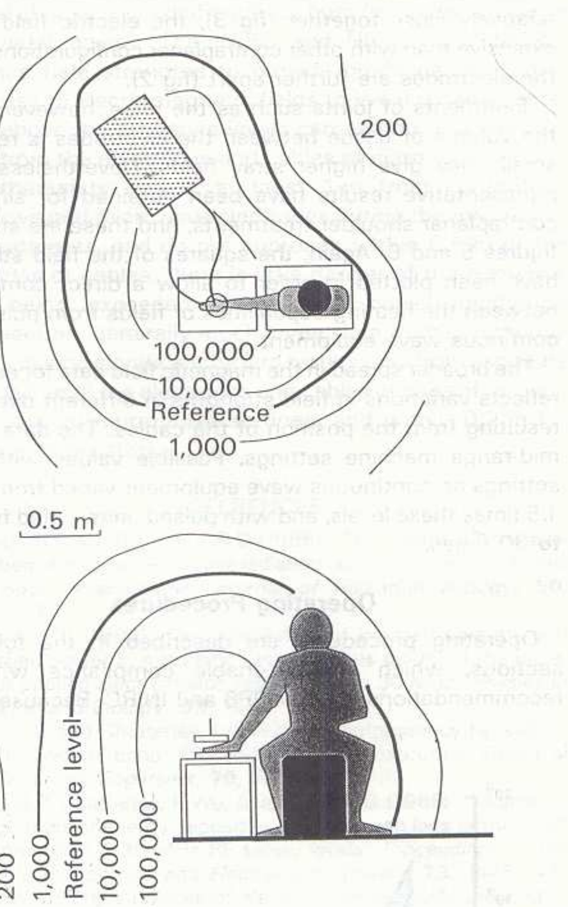

Fig 3: Maps of distribution of electric field strength in $(V/m)^2$ for a contraplanar wrist treatment using one rigid and one malleable electrode, with an Ultratherm 608S (power setting 3)

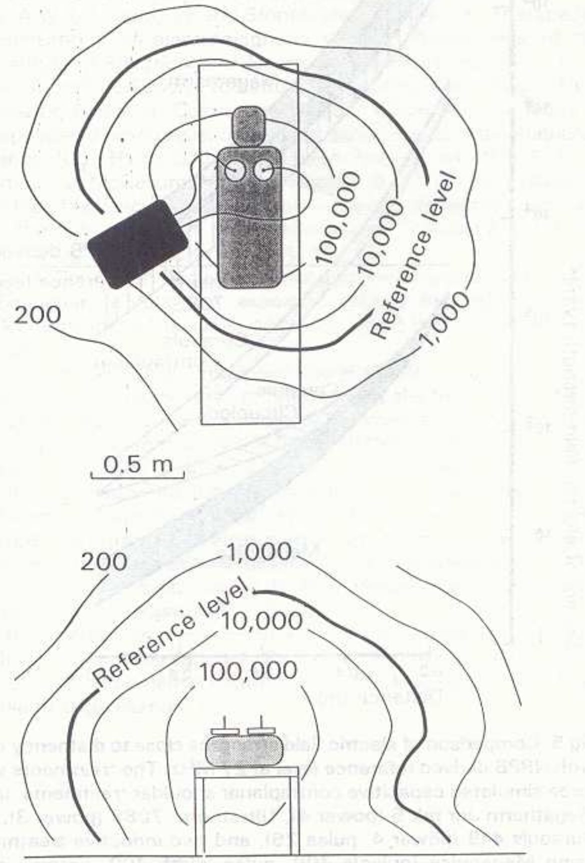

Fig 4: Maps of distribution of electric field strength in $(V/m)^2$ around a co-planar back treatment, with an Ultratherm 608S (power setting 3)

relatively close together (fig 3), the electric field is less extensive than with other contraplanar configurations where the electrodes are further apart (fig 2).

Treatments of joints such as the knee, however, where the volume of tissue between the electrodes is relatively small, may give higher stray fields. Nevertheless, some representative results have been obtained for simulated contraplanar shoulder treatments, and these are shown in figures 5 and 6. Again, the squares of the field strengths have been plotted in order to allow a direct comparison between the heating capabilities of fields from pulsed and continous wave equipment.

The broader spread in the magnetic field data for each unit reflects variations in field strengths in different directions, resulting from the position of the cables. The data are for mid-range machine settings. Possible values with other settings on continuous wave equipment varied from 0.5 to 1.5 times these levels, and with pulsed units varied from 0.1 to 30 times.

Operating Procedures

Operating procedures are described in the following sections, which should enable compliance with the recommendations of the NRPB and INIRC. Because of the wide range of power and pulse settings for pulsed equipment, distances have been proposed for units operated at low and medium levels. However, equipment is operated infrequently at both high pulse and power settings, and the recommendations made were appropriate for all treatments performed in Grampian Region during a period of one week, when a survey of diathermy use was carried out.

Continuous Wave Equipment

The units tested were Ultratherm 608 and 708S (Siemens), and Megatherm Jnr mk 5 (EMS), which were all 27 MHz; and a 434 MHz Sieretherm 609S (Siemens). Field strengths above the recommended whole-body levels for shortwave equipment extended 0.5 to 1.0 m from the electrodes and cables (figs 5, 6). Fields above the level for 2,450 MHz radiation extend for 0.1 to 0.5 m from the applicators of the Microtron 200 (EMS), although because of standing waves, localised hot spots could occur at distances up to 1.0 m.

Observations of working practices showed that physiotherapists spent most of their time at distances greater than 1 m from the electrodes and cables (Martin *et al*, 1990). If physiotherapists remain at least 1 m from electrodes and cables during treatments, and avoid approaching within

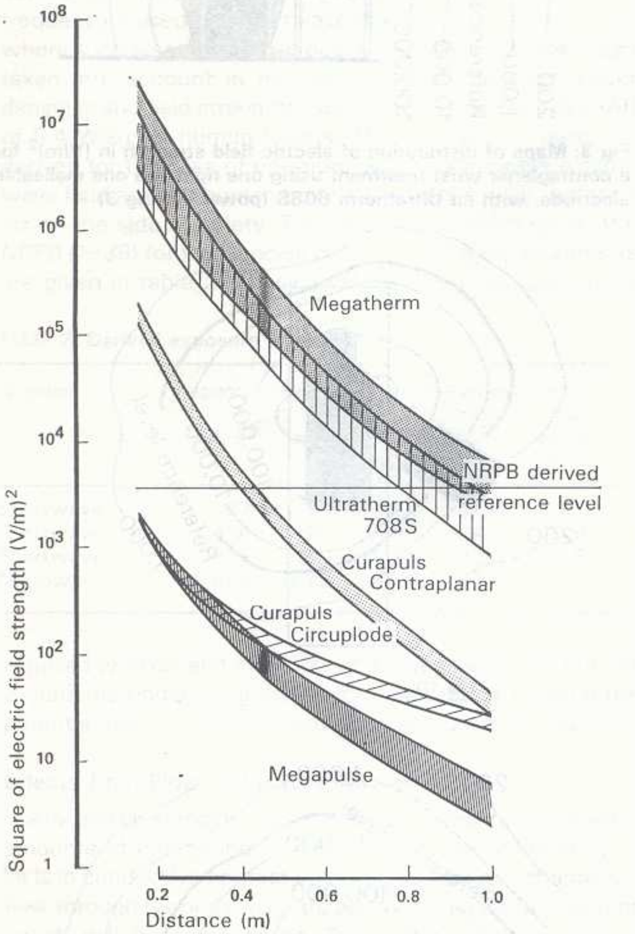

Fig 5: Comparison of electric field strengths close to diathermy units with NRPB derived reference level at 27 MHz. The treatments were three simulated capacitive contraplanar shoulder treatments, using Megatherm Jnr mk 5 (power 4), Ultratherm 708S (power 3), and Curapuls 419 (power 4, pulse 26), and two inductive treatments using Megapulse (pulse/s 400, pulse width 100, norm), and a Curapuls Circuplode (power 4, pulse 26). Graphs show fall in time-averaged value of square of electric field strength with distance from electrodes

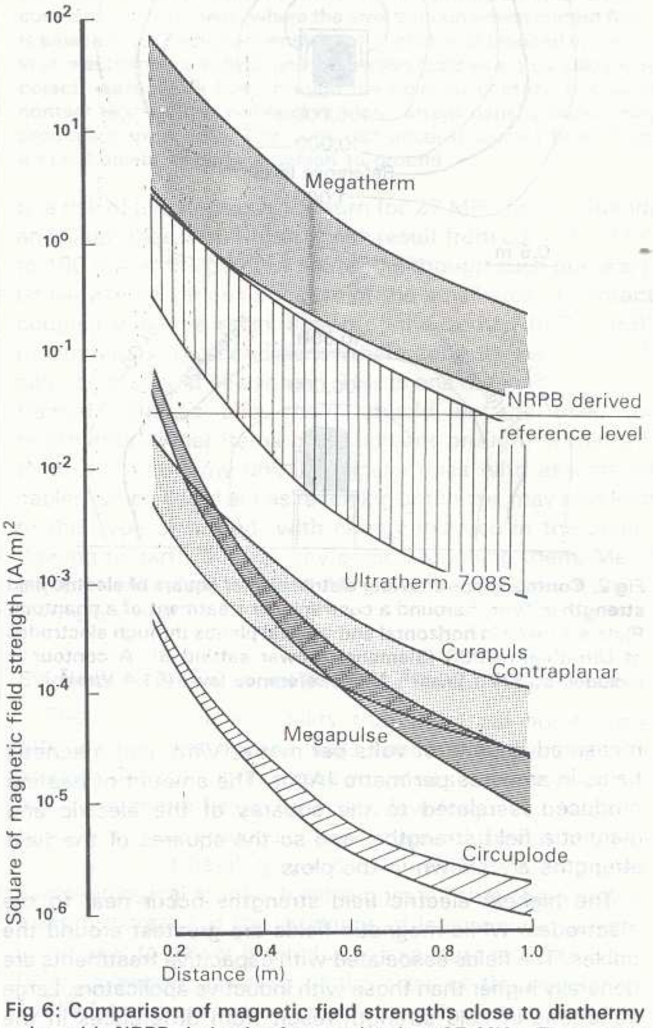

Fig 6: Comparison of magnetic field strengths close to diathermy units with NRPB derived reference level at 27 MHz. Treatments monitored and the equipment settings were the same as those used for figure 5. Variation in the time-averaged value of square of magnetic field strength with distance from electrodes is shown

0.5 m even for short periods when the field is switched on, there is little danger of exposures exceeding the reference levels, but particular care should be taken when higher power settings are used. Positioning of the equipment so that the operator does not have to walk past the electrodes in order to reach the control panel can assist in reducing this exposure.

The level of exposure of physiotherapists' eyes is small (Martin *et al*, 1990), but care should be taken to ensure that patient's eyes are not closer to the electrodes and cables than necessary during treatment. Fields within 0.2 m of electrodes could potentially produce SARs similar to those at which ocular effects have occurred with microwaves, although no such effects have been reported with shortwave fields. A distance of at least 0.2 and preferably 0.3 m should therefore be maintained between the patient's eyes and the treatment electrodes. Appropriate positioning of the head may reduce the exposure, by increasing the distance of the eyes from the electrodes and shielding them to some extent with intervening tissue.

In departments where patients are treated with continuous wave capacitive diathermy in adjacent cubicles, a space of at least a metre should be left between couches, where possible, so that other patients and physiotherapists are 1 m from the equipment, when the field is on. Where there is any uncertainty, the advice of the local radiation protection adviser responsible for non-ionising radiation should be sought.

Pulsed Equipment

The pulsed 27 MHz units tested were Curapuls 419 (Enraf-Nonius), Megapulse (EMS), Megatherm Plus 7 (EMS) and Erbotherm 1100P (Erbe). Peak field strengths from these units were similar to those from continuous wave 27 MHz units, but time averaged values were much lower (figs 5, 6) because the units were switched on only for between a hundredth and a thousandth of the total time. Electric and magnetic field strengths above the derived reference levels extended to 0.3 to 0.5 m from the electrodes of the Curapuls and Erbotherm units operated in capacitive modes with low or medium pulse settings, and on the highest pulse and power settings could extend to 0.8 m. However, with inductive applicators, field strengths above the limit rarely extended for more than 0.2 m from the electrode or cables. Operators are therefore advised to stand at a distance of at least 0.5 m from the electrodes and cables when the units are used in capacitive modes at low and medium power settings and 0.2 m away when single inductive electrodes are used. All the units can be operated in continuous wave mode, and under these circumstances precautions should be taken similar to those for other continuous shortwave equipment.

Conclusion

Electromagnetic fields can produce a variety of physical effects. Those of most relevance at the frequencies used for diathermy treatment are heating of tissue, either through direct absorption of electromagnetic energy or flow of induced charge, and radiofrequency burn from flow of charge to a metal object. The INIRC and NRPB have derived reference field strengths to provide guidance on limited exposures to electromagnetic fields to avoid these effects. Fields above the reference levels can extend to about one metre from the electrodes and cables of diathermy units. If physiotherapists remain at least 1 m from continuous shortwave and microwave electrodes during the majority of any treatments, and do not approach within 0.5 m of the electrodes or cables, there is little danger of the reference levels being exceeded. Fields from pulsed diathermy equipment are generally much lower than from continuous wave units and significant hazard results only from exposure within 0.5 m of the electrodes and cables of capacitive units at low and medium pulse settings, and within 0.2 m for inductive applicators.

REFERENCES

Blackwell, R P and Saunders, R D (1986). 'The effects of low-level radiofrequency and microwave radiation on brain tissue and animal behaviour', *International Journal of Radiation Biology*, **50**, 761–787.

Dimbylow, P J (1988). 'The calculation of induced currents and absorbed power in a realistic hetrogeneous model of the lower leg for applied electric fields from 60 Hz to 30 MHz', *Physics in Medicine and Biology*, **33**, 1453.

Ghandi, O P and Chatterjee, I (1982). 'Radiofrequency hazards in the VLF and MF band', *Proceedings of the Institute of Electrical and Electronic Engineers*, **70**, 1462–64.

Ghandi, O P, Chatterjee, I, Wu, D and Gu, Y-G (1985). 'Likelihood of high rates of energy deposition in the human legs at the ANSI recommended 3-30 MHz RF safety levels', *Proceedings of the Institute of Electrical and Electronic Engineers*, **73**, 1445–47.

Guy, A W (1971). 'Analyses of electromagnetic fields induced in biological tissues by thermographic studies on equivalent phantom models', *Institute of Electrical and Electronic Engineers Transactions on Microwave Theory and Technology* (Special Issue on Biological Effects of Microwaves), **MTT-19**, 214–223.

Guy, A W, Lehmann, J F and Stonebridge, J B (1974). 'Therapeutic applications of electromagnetic power', *Proceedings of the Institute of Electrical and Electronic Engineers*, **62**, 55–75.

International Radiation Protection Association/International Non-ionizing Radiation Committee (1988). 'Guide lines on limits of exposure to radiofrequency electromagnetic fields in the frequency range 100 kHz to 300 GHz', *Health Physics*, **54**, 115–123.

Martin, C J, McCallum, H M and Heaton, B (1990). 'An evaluation of radiofrequency exposure from therapeutic diathermy equipment in the light of current recommendations', *Clinical Physics and Physiological Measurement*, **11**, 53–63.

National Council on Radiation Protection and Measurement (1986). 'Biological effects and exposure criteria for radiofrequency electromagnetic fields', Report no 86, NCRP, Bethesda, Maryland, USA.

National Radiological Protection Board (1989). 'Guidance as to restrictions on exposures to time varying electromagnetic fields and the 1988 recommendations of the International Non-ionizing Radiation Committee', NRPB-GS11, HMSO, London.

Sienkiewicz, Z J, O'Hagan, J B, Muirhead, C R and Pearson, A J (1989). 'Relationship between local temperature and heat transfer through the hand and wrist', *Bioelectromagnetics*, **10**, 77–84.

United Nations Environment Program/World Health Organisation/International Radiation Protection Association (1981). *Envrionmental Health Criteria 16: Radiofrequency and microwaves*, World Health Organisation, Geneva.

United Nations Environment Program/World Health Organisation/International Radiation Protection Association (1987). *Environmental Health Criteria 69: Magnetic fields*, World Health Organisation, Geneva.