Powerfrequency EMFs and Health Risks

This article is separated into 11 sections, each of which can be individually downloaded. It is a 'work in progress' incorporating new information whenever time permits.

Section 2

Occupational exposure

11. References – 861 references

Occupational exposure

Probable occupational exposure has often relied on job title. This may be an adequate surrogate for exposure, but it also may be flawed and may also be responsible for some of the inconsistency of research findings. Mee (2009) looked at the way that magnetic field exposure has been documented and found, in a relatively small sample of people, including some of those taking part in the UK Adult Brain Tumour Study (UKABTS), that assessments of exposure based on job codes should also include information about equipment, power cables or substations in the work environment, to improve accuracy. Kheifets (2009) also recommended the development of a more complete job-exposure matrix that combines job title, work environment and task, and an index of exposure to electric fields, magnetic fields, spark discharge, contact current and other chemical and physical agents.

Cells were exposed to extremely low frequency electromagnetic fields for 45 minutes and tests for DNA effects were made 48 hours later (Mihai 2014). The tests showed that extremely low frequency electromagnetic field of 100 Hz and 5.6 mT had a genotoxic impact on Vero cells. However, the strength of magnetic fields was such that it would rarely be found except in exceptional occupational situations.

Occupational research

We will now look at people who are occupationally exposed to EMFs. It is assumed by protective legislation, that workers are physically fit so the exposure levels are set higher than those for the general public which includes members of potentially vulnerable subgroups such as children, the elderly and the sick.

In a study looking at potentially highly exposed workers at switching and transforming stations, it was reported that the measured magnetic fields were below ICNIRP. However, the average levels were 3.6 kV and 28.6 µT, with maximums of 15.5 kV and 710 µT (Korpinen 2011a). Magnetic fields inside Ukrainian substations were found to be up to 420 µT (Okun 2012) and in Iranian substations the magnetic field levels varied between 0.02 µT and 49.90 µT (Hosseini 2015); the authors of the study concluded that the spaces around incoming panels, transformers, and cables were hazardous zones of indoor electric substations. This sort of measured variation may explain differences in study findings where estimated exposures due to a job description were used. In a study of gas-insulated substations in Finland (Korpinen & Pääkkönen 2014), magnetic field levels varied from 0.4 to 43.0 µT. As Korpinen says in a further study (2011b) *"generally, the workers' exposure to the electric fields, current densities, and total contact currents are obviously lower if we use the average values from a certain measured time period than in the case where exposure is defined with only the help of the maximum values."* In a previous study (2010), Korpinen & Pääkkönen had found the measured electric field exceeded 10 kV/m in 3 cases (maximum 16.6 kV/m), for workers on a service platform at 110 kV substations. In an uninterruptible power supply factory in Turkey electric and magnetic field levels experienced by the workers reached up to 992 V/m and 215.6 µT in the test areas; 26.7 V/m and 7.6 µT in the production lines and 165.5 V/m and 65 µT in the vicinity of the power substations (Tesneli & Tesneli 2014). Cholesterol levels were changed in workers at an electric power plant exposed to high EMF levels for some time (Z Wang 2016). The findings showed that chronic EMF exposure was associated with the change of serum lipid levels.

In the Regione Campania, occupational magnetic exposure was measured for 400 workers in 80 different areas over 2 working shifts for textiles, industrial graphics, wood, manufacturing and ceramics. 70% of the monitored jobs showed an exposure below 0.4 microtesla (d'Angelo 2007).

There is emerging evidence that night shift work may increase breast cancer (LA Tsc 2014), certain cardiovascular diseases (Hansen & Lassen 2014, SL Tsc 2014) and colorectal cancer (Papantoniou 2014). Night shift work involves exposure to light-at-night, which may reduce normal nocturnal melatonin production, create circadian rhythm disruption and sleep deprivation. There is strong experimental evidence that light-at-night and circadian disruption may increase the risk of cancer and coronary heart diseases.

Workers with cardiac pacemakers may be at increased risk (Tiikkaja 2012). Pacemaker malfunction occurred in 6 of 16 pacemakers. Interaction developed almost immediately after high-intensity magnetic field exposure started. Some frequencies using ramp or square waveforms interfered with pacemakers even at levels below public exposure limits. Medical electronic devices and metallic implants are found in an increasing number of workers. Industrial applications requiring intense EMFs are growing and the potential risk of injurious interactions arising from EMF affecting devices or implants needs to be managed (Hocking & Mild 2008, Napp 2014).

In Turkey, 75% of staff working in offices above or close to transformer stations and electric enclosures are exposed to magnetic field levels above 0.3 µT, the highest measuring 6.8 µT. Most of the staff are considered to be 'under risk' based on research linking increased risk of leukaemia and averaged fields above 0.2 µT (Cam 2011).

Many occupational studies have looked at potential risks to health from exposure to EMFs (especially magnetic field levels) during the day for electric utility workers. The studies have, by and large, focussed on cancer risk (Balamuralikrishnan 2012) though some have also looked at Parkinson's (Nichols & Sorahan 2005, Brouwer 2015), MND and Alzheimer's diseases (Noonan 2002, Qiu 2004 (in men, but not in women), Hug 2006, Sorahan & Kheifets 2007, Davanipour 2007), Vergara 2013). Feychting (1998) suggested that occupational magnetic field exposure might influence the *development* of dementia, as it seemed only to be important with respect to the last occupation. Corbacio (2011) found that occupational levels of EMF exposure, (3mT), affected short-term learning. Gobba (2009) suggested that magnetic-field-induce natural killer (NK) cell reduction could be involved in the development of neurodegenerative disorders and cancers (Gobba 2009). Zamanian (2010) found *"A significant number of staff which were exposed to electromagnetic fields and noise (78.2%) were suspected to have a kind of mental disorder."*

Sorahan found that UK electricity supply workers had a significant positive trend for acute lymphocytic leukaemia (ALL), but this was based, in the main, on unusually low risks in the lowest exposure category (Sorahan 2014a). In another study, there were no statistically significant dose-response effects shown for meningioma, but there was some evidence of elevated risks in the three highest exposure categories for exposures received more than 10 years ago (Sorahan 2014b). There was an increased risk of male skin cancer amongst workers employed in electricity generation and transmission jobs. Sorahan (2012) suggested this may be due to outdoor work.

Loomis (1997) found that PCBs cause cancer among electric utility workers, with malignant melanoma being of particular concern. This may have something to do with the work done by Fews (1999a, 1999b) whereby the strong electric fields associated with equipment producing high voltages can affect the charge on chemicals making them more likely to be absorbed by the body.

People with occupational exposure to EMFs from transformers and power cables had a significant increase in neurovegetative disorders (i.e., physical fatigue, psychical asthenia, lipothymia, decreased libido, melancholy, depressive tendency, and irritability), as well as changes in lymphocyte and NK cell levels (Bonhomme-Faivre 1998).

The individuals employed in the live-line procedures at 132 kV high-voltage substations. were found to be vulnerable for EM stress with altered epinephrine concentrations, DNA damage and increased oxidative stress (Tiwari 2015).

People with occupational exposure in the automotive industry were found to have significant effects on the nervous, cardiovascular, liver and haematology systems (Liu X 2013).

The development of new medical electronic devices and equipment, such as used in laparoscopic and robotic surgery, has increased the use of electrical apparatuses. J Park (2015) suggested that there may be effects of long-term ELF-MF exposure during many surgeries in the course of a surgeon's career.

The research has produced mixed results; some showing no effect (Sorahan 2001), and some an increased risk for all cancers, or brain cancer (Rodvall 1998), leukaemia and lung cancer, AML and follicular lymphoma in men (Koeman 2014) or myeloid leukaemia and Hodgkin's disease (Röösli 2007). Touitou (2012) found no long-term effect from working in power-frequency fields of 0.1 to 2.6 microtesla. There were 15 healthy male exposed workers in the study. Those who choose to work long-term in industry with high exposures may not represent the range of more vulnerable people in the residential public.

In a study of Norwegian female radio and telegraph operators between 1961 and 2002, Kliukiene (2003) found an increased risk of oestrogen receptor-positive breast cancer in the younger women, while the older age group had an elevated risk of oestrogen receptor-negative breast cancer.

Occupational exposure to low frequency electric and magnetic fields was found to increase the incidence of headache, insomnia and tinnitus, due to a localised impairment of outer hair cells (J Zhao 2013). The incidence of reduced semen quality was also found (Irgens 1999).

Seidler (2007) found a link between the late development of dementia and blue-collar work, specifically electrical and electronics workers, metal workers, construction workers, food and beverage processors and labourers, but not with magnetic field exposure *per se*. it may be that some of these occupations had magnetic field exposure late in their occupation supporting Feychting's 1998 study.

A review of the early work was done in 1999 by Kheifets, and another occupational meta-analysis in 2008, covering publications between 1993 and 2007 showed small increases in leukaemia and brain cancer risk. Occupational ELF exposure in the recent past was linked to an increased risk of glioma (Turner 2014), suggesting that ELF exposure may play a role in the later stages (promotion and progression) of brain tumour growth. A small study in turkey by Celikler (2009) found that people with occupational exposure to electromagnetic fields had significant damage to lymphocytes which has been associated with subsequent cancer development.

A study by Mortazavi (2012) may offer a suggestion as to why there are mixed results. They looked at the effect on serum cortisol level of dentists working with magnetorestrictive cavirtons. In the EMF-exposed group, cortisol level decreased significantly from start of work until noon, when work stopped. The authors commented *"As cortisol plays an important role in blood pressure regulation, cardiovascular, and immune system dysfunction, a low cortisol level may threaten health."* If it were to do so, the effects may differ from person to person.

A further review by Kheifets in 2010 has been criticised as being industry-biased, trying to shut down the debate, whilst ignoring most of the available evidence, (a review by Miller & Green 2010) and Villeneuve (2000a, 2000b), all from the Canadian-French project on electric utility workers, which found increases in leukaemia, lymphoma and brain cancer, sometimes more than 10 times the expected rate. Karipidis (2007) found an increased risk of Non-Hodgkin's lymphoma associated with occupational exposure to EMFs. Kaufman (2009) found that working with or near powerlines increased the risk of myeloid leukaemia by more than 4 times.

They wanted to stop the work on electric fields as a result of a Swiss study of railway workers by Röösli (2008), (though Swiss railways operate at 16.7 Hz, a different frequency to the supply used in the electricity industry studies, making the exposures not comparable), and another study by Kheifets (1997) of 6 workers, none of whom were employed as powerline workers who have the highest exposures. This reason for stopping work on the effects of electric fields, seems inadequate.

Minder & Pfluger (2001) found links between heavy exposure to ELF magnetic fields and leukaemia in Swiss railway employees and shunting yard engineers were 5 times more likely to die of a brain tumour.

No increase in risk was found for acoustic neuroma by Forssén (2006). Pearce (2007) in a large study looking at paternal occupational EMF exposure, found a significantly increased risk of leukaemia, and some other types of cancer, in the children of the exposed fathers, especially boys aged less than 6. Paternal exposure to battery-powered forklifts was positively associated with neuroblastoma (De Roos 2001). Paternal average extremely low frequency magnetic field exposure >0.4 microTesla was weakly associated with neuroblastoma whereas maternal exposure was not.

Behrens (2004) provides a hypothesis that may explain some of the differential results. They suggest that factored in to occupational studies should be non-occupational household exposures. They looked at long term cumulative exposures to EMFs and found that power-line workers would be exposed to 6,250 µT hours for 10 years of employment compared to 21,608 µT hours for 10 years of exposure from sleeping beside an electric clock. Gobba (2011) also pointed out the problems of misclassification of exposure if job exposure matrices and time weighted averages only were taken into account. Only 60% of the 24 hour exposures were accounted for occupationally in this study.

Women exposed to electrical transmission installations, especially those with dark-coloured irises were at particular risk for uveal melanoma (Behrens 2010).

Physiotherapy personnel who are exposed to EMFs in the course of their work, reported parodontosis (a disease of the teeth of primary degenerative nature) 42%; cardiovascular disorders 41.6%; allergic conditions with skin or systemic manifestation 40.8%; photosensibilization 34.1%; skin diseases 31.5%; musculoskeletal disorders 30% and neoplasm disorders 7.5% (Vesselinova 2013). Menstrual disturbances were observed in 20% of female physiotherapist personnel.

Davanipour (2014) found that working in an occupation with medium or high exposure to ELF magnetic fields could increase the risk of severe cognitive dysfunction, especially if the person smoked. Busljeta (2000) and Davanipour & Sobel (2009) reviewed the research into EMF and the risks of Alzheimer's disease and breast cancer. They concluded that long-term significant occupational exposure increased the risk of both. They recommended that mitigation of exposure through equipment design changes and environmental placement of electrical equipment should be instituted.

Grundy (2016) found that occupational exposure to magnetic fields in man increased the risk of breast cancer; exposure of 0.3 μT or more carried an increased risk, exposure of 0.6 μT or more nearly doubled the risk compared to exposures of less than 0.3 μT. Those exposed to occupational MF fields for at least 30 years had a nearly threefold increase in risk of breast cancer when compared to those with background levels of exposure. Peplonska (2007) and McElroy (2007) also found an increased risk of breast cancer with occupations that had potential exposure to EMFs, among postmenopausal women (Labrèche 2003).

Forssén (2000) evaluated the effect of occupational magnetic field exposure on breast cancer in females and combined residential and occupational magnetic field exposure to reduce misclassification. Women below age 50 who were occupationally exposed to magnetic fields had one and a half times the risk breast cancer. For women below 50 years of age who had oestrogen receptor-positive breast cancer, the risk was tripled. The results for residential and occupational exposures combined showed similar results.

Bethwaite (2001) found a significantly elevated risk of acute leukaemia for electrical workers overall, and for the specific occupational categories of welders/flame cutters and telephone line workers. A dose-response effect was also found, indicating that acute leukaemia risk was related to historical and current magnetic field exposures in an occupational context.

ALS (Amyotrophic Lateral Sclerosis, or Lou Gehrig's disease - a form of motor neurone disease) was linked to powerfrequency magnetic fields in the California report (see below). ALS, and to a lesser extent Alzheimer's Disease, have been consistently linked with occupational exposure to EMFs (Johansen 2000, 2004, Ahlbom 2001, Johansen 2001, Harmanci 2003, Håkansson 2003, Feychting 2003, Park 2005, Zhou 2012), and in a review of 10 studies by CY Li & Sung 2003). A study by Poulletier de Gannes (2008) found no association between ALS and occupational exposure of between 100 and 1000 microtesla. These are far higher field levels than most research study has looked at, and they may exceed the 'window of effect'. A meta-analysis of 14 epidemiological studies by García (2008) concluded that there was a link between occupational ELF EMFs and Alzheimer's disease, though they felt it was important to have "*more information on relevant duration and time windows of exposure, on biological mechanisms for this potential association and on interactions between electromagnetic fields exposure and established risk factors for AD*." Vergara (2015) found that electric occupations were associated with ALS, but not electric shocks or magnetic fields.

An association between occupational exposure to EMFs and suicide between the ages of 20 and 35 was found by van Wijngaarden (2000 and 2003). The exposure level was based on job title on the death certificate, rather than measured field levels, and he recommended further investigation, using more accurate measures. The results of a study by van Wijngaarden (2001) indicate excess risk of total mortality, cardiovascular disease, and some cancers, particularly lung cancer, among electric utility workers, which could be related to both occupational and non-occupational risk factors.

A study by Di Giampaolo (2006) found that high magnetic field levels in a museum workplace affected the immune systems of those working there; the women more than the men. Johansson (2009) reviewed papers on the effects of EMFs on the immune system and concluded that immune system disturbance increased the risk for various diseases, including cancer, Gobba (2009) suggesting this may be a result of the reduction of NK cells in the presence of elevated magnetic fields.

Bonhomme-Faivre (2003) found that chronic occupational exposure to magnetic fields between 0.2 and 6.6 microtesla had an effect on lymphocyte levels and other immunological parameters, suggesting a general diminution of immune system function. The levels increased when exposure stopped, suggesting a direct causal relationship. Any changes in immune system function, such as that found in electric utility workers (Ichinose 2004), may lead to a variety of health effects. Being exposed to EMFs at work significantly increased the risk of leukaemia in their children (Keegan 2012).

Electronic equipment repairers exposed to low-frequency EMFs are at risk of oxidative stress and sleep insufficiency (El-Helaly 2010). It was suggested that taking antioxidant supplements, such as melatonin, would ameliorate the oxidative effect of EMFs. Liu H (2014) found that daily occupational EMF exposure was associated with poor sleep quality.

28% of those exposed to ELF EMFs in substation units suffered from poor health status and 61% were diagnosed with a sleep disorder (Monazzam 2014).

As a generality, occupational magnetic field exposure is likely to be higher than that experienced by the general public normally. It has been suggested that only certain 'windows' of exposure may be responsible for health effects, or the timing of exposure may be important (Röösli 2007). The research often assumes that the higher the exposure the greater the effect (Swanson & Kheifets 2006). This is not true for many biological responses and may explain the variability in results. Hakansson (2002) found for the highest exposure group an increased risk of developing cancer of the liver, kidney, and pituitary gland among male welders. Highly exposed women welders were more likely to develop brain tumours and leukaemia, menstrual disorders and neurovegetative symptoms (Y Xu 2016). The hypothesis of a biological mechanism involving the endocrine system was partly supported. For example, a study by Man & Shahidan (2008) looked at exposure to magnetic fields among welders. They concluded "*The mere assessing of the MF exposure levels through spot measurements does not give an overall picture of the total amount of exposure received by the welders as some of these workers performed the welding task throughout the day, whereas others performed this as a part of their job. The exposure to various chemicals in the fume may complicate the interpretation of the elevated health risk among the welders.*" Sharifian (2009) in a study looking at EMF exposure to spot welders, said that ELF-MF could influence the red blood cell antioxidant activity and might act as an oxidative stressor. Kula (1999) found that chronic occupational exposure of steelworkers to a 50 Hz magnetic field could influence some blood serum parameters. The most distinct changes were found in workers who had been occupationally exposed for more than 10 years.

Another study of welders (Dominici 2011) reported that the hypothesis of a correlation between genotoxic assays and ELF-MF exposure value was partially supported, especially as regards micronuclei frequency assay.

Magnetic flux densities in excess of the action levels for peripheral nerve stimulation are reported for workers involved in welding, induction heating, transcranial magnetic stimulation, and magnetic resonance imaging (MRI). The corresponding health effects exposure limit values for the electric fields in the worker's body can be exceeded for welding and MRI, but calculations for induction heating and transcranial magnetic stimulation are lacking. Since the revised European Directive conditionally exempts MRI-related activities from the exposure limits, measures to reduce exposure may be necessary for welding, induction heating, and transcranial nerve stimulation. Since such measures can be complicated, there is a clear need for exposure databases for different workplace scenarios with significant EMF exposure and guidance on good practices (Stam 2014).

Nurses involved in administering contrast agents (see above) into a patient during the examination are exposed to static magnetic fields (SMF) from the permanently active magnets of MRI scanners. In the course of a patient's routine examination the nurses are present between 0.4 and 2.9 minutes in SMFs of 0.5 mT, only sometimes exceeding 75mT. When patients need more attention because of their health status/condition, the nurses' exposure may be significantly longer – it may even exceed 10 minutes and be over 500mT (Karpowicz & Gryz 2013). An Italian study (Moro 2013) measured, using a personal dosimeter, that radiologists spent 162 seconds (mean) injecting contrast medium (a time fraction of 7%) up to 409 mT, and radiographers spent 347 seconds (mean) and a time fraction of 31% in fields of up to 1550 mT.

9% of radiographers are estimated to be exposed to EMFs in the course of their work (Schaap 2013). This was especially true of people scanning animals.

Bradley (2007), Riches (2007), Crozier (2007, 2007) and Wilén (2010) found that staff, especially when moving quickly, were exposed to time-varying magnetic field exposures which exceeded the limits stated in the published guidance. Riches concluded that the Directive will have a major impact on the current use and future development of MRI due to limitations on exposure to time-varying gradient fields and movement within the spatially-varying static field. The team believes that it will make interventional work impossible and routine MRI use impracticable in Europe.

A review of current research on staff exposure to static magnetic fields and health effects was undertaken by Franco (2008). The effects listed were vertigo, nausea and a metallic taste in the mouth (also Schaap 2014), changes in blood pressure and heart rate, induction of ectopic heart beats and increased likelihood of reversible arrhythmia and a decrease of working memory and eye-hand co-ordination. It was felt that these effects may result in a possible negative influence on the performance of workers during critical procedures. Sait (1999) suggested that short exposures to magnetic fields at occupational levels may influence heart rate control mechanisms.

Adverse effects of static magnetic fields from MRIs on the bone health, both bone mineral content and bone mineral density of MRI workers (Güngör 2014).