8 HUMAN RESPONSES

8.1 Laboratory studies

Experimental studies using volunteers, including those exposed to EMFs, are restricted for ethical reasons to the investigation of transient physiological phenomena that can be determined to be harmless in the controlled conditions of a laboratory. The advantage of volunteer experiments is that they indicate the likely response of people exposed under similar conditions. Disadvantages of volunteer studies include the innocuous nature of the effects that can be investigated, the often short duration of exposure and investigation, the small number of subjects usually examined, and thus limited statistical power to detect an effect. In addition, it is difficult to create an identical physical environment for unexposed sessions for MRI studies, and the fields inside the magnet might interfere with measurements of the biological endpoints. Experiments on human subjects are naturally subject to stringent ethical constraints. The subjects are usually screened for medical fitness and, therefore, may not reflect the responses of potentially more susceptible members of society. Within this limited context, however, volunteer studies can give valuable insight into the physiological effects of exposure to an agent.

The majority of laboratory studies have examined static magnetic field effects, recently often in connection with MRI exposures. However, a few studies on the perceptual effects of surface charge generated by static electric fields have been carried out.

8.1.1 Static electric fields

Blondin et al. (1996) investigated human perception of electric fields and ion currents during conditions simulating those present in the vicinity of a high-voltage DC transmission line, with the purpose to establish the sensory thresholds for detection. Healthy volunteers were recruited through advertisements in local newspapers (23 men, 25 women). The electric fields and ion current generating system was located in the ceiling of the exposure chamber which could expose subjects to uniform DC fields of up to 50 kV m^{-1} and uniform ion current densities of up to 300 nA m^{-2}. Fields were presented either alone or in combination with some specified level of ions. Subjects were presented with continuous series of successive trials, each trial lasting about 25 seconds. Half of the trials were non-signal, 'blank' trials. The median detection thresholds were 45.1 kV m^{-1} in the non-ion condition, and 36.9 kV m^{-1} with a high ion-concentration condition. There was a large variation in individual thresholds; 33% had thresholds under 40 kV m^{-1} and 66% under 50 kV m^{-1}. Two subjects had thresholds under 20 kV m^{-1}. With a simultaneous high ion current density (120 nA m^{-2}), 33% of subjects detected fields < 20 kV m^{-1}, and 10% could detect a 10 kV m^{-1} field.

A study by Clairmont et al. (1989) investigated the effect of interactions between AC and DC fields when placing AC and DC high-voltage lines in the same power line corridor. A small part of the study was an experiment where human subjects described sensation levels at different exposure conditions. Observations were made under a hybrid (both AC and DC) test line. Each person rated various sensations at measurement locations along the lateral profile of the test line, while the DC field, AC field, and ion current density were simultaneously monitored at each of the locations. The authors concluded that the combination of AC and DC fields caused relatively large increases in sensation of the fields, compared to each field condition alone. However, there was no adequate description of how the experiments were conducted; i.e. the number of subjects, selection of subjects, and characteristics of subjects are all unknown, exposure conditions are poorly described, and subjects were not blinded to the exposure condition.

Table 36. Static electric fields

Authors	Endpoint	Exposure	Results	Comments
(Blondin et al., 1996)	Human perception of electric fields and ion currents	Electric field: 0 - 50 kV m^{-1} Ion current density: 0, 60 or 120 nA m^{-2}	Median detection threshold 45.1 kV m^{-1} in non-ion condition, 36.9 kV m^{-1} in high ion-concentration condition. 33% had thresholds < 40 kV m^{-1}, 66% < 50 kV m^{-1}. Two subjects had thresholds < 20 kV m^{-1}. With a ion current density of 120 nA m^{-2}, 33% detected fields < 20 kV m^{-1}, 10% detected a 10 kV m^{-1} field.	
(Clairmont et al., 1989)	Effects on human sensation by combination of DC and AC electric fields	DC field: 0 - 40 kV m^{-1} AC field: 0, 2, 5, 10, or 15 kV m^{-1}	Increased sensation in combined fields.	Experiment poorly described, not systematic, unknown number of subjects, not blinded.

8.1.2 *Static magnetic fields*

8.1.2.1 Neurobehavioural studies

Possible effects on the nervous system can be studied at several different levels, from a simple level to the more complex. Effects on properties of the peripheral nervous system, such as conduction velocity, are readily investigated and may be relevant to effects seen at higher levels of organization. Measurement of evoked potentials recorded from the brain, usually in response to an auditory, visual or somatic signal, takes this process further and include measuring potential effects on signal transduction and central nervous system processing. Measurement of the electrical activity of the brain (EEG) reflects spontaneous activity, possibly in different mental states, but the results are notoriously difficult to interpret. Tests of cognition, mood and other behaviours assess the integrated output of the brain, and so are directly relevant to well being.

8.1.2.1.1 Human peripheral nerve function

Hong (1987) studied peripheral motor nerve conduction velocity and nerve excitability in 10 volunteers after short exposure (5, 10, 15 sec) to 1 T. No changes were found in nerve conduction velocity, whereas a transient increase in the nerve excitability index (measured as the ratio of the compound muscle action potential seen during or after exposure compared to that measured before exposure) was observed. This change was observed 5 sec or more after exposure, and disappeared within the following 3 min. The authors concluded that motor nerve excitability is increased during such exposure.

Vogl et al. (1991) studied nerve conduction velocity in 10 subjects before, during and after exposure to static magnetic fields of 1 T, and to combined MRI and RF fields. They found no effects of either static field exposure alone or from MRI imaging.

Table 37. Peripheral nerve conduction velocity

Authors	Endpoint	Exposure	Results	Comments
Static magnetic field studies				
(Hong, 1987)	Nerve function	1 T 5, 10, 15 sec	No effect on nerve conduction velocity; temporary increase of excitability index: effect not present 3 min after exposure.	

MRI or combined exposure studies				
(Vogl et al., 1991)	Peripheral nerve conduction velocities	1 T 1 h	Evoked potentials, as measured here, are not affected by MRI exposure.	

8.1.2.1.2 Evoked and spontaneous brain activity

Electrical responses (potentials) evoked in the brain by exposure of a subject to a sensory stimulus such as an auditory noise or visual signal can be used as a diagnostic tool to indicate conduction problems in a nerve pathway, including nerves and synapses within the central nervous system. Hong and Shellock (1990) measured latencies of somatosensory evoked potentials in 11 normal subjects exposed to a static field of 1.5 T without detecting any differences in the latency or amplitude of evoked waveform when comparing measurements before and during exposure.

Dobson, Fuller and collaborators studied spontaneously occurring activity as measured in epileptic patients by EEG after exposure to fields in the mT range. Using the technique of comparing to individual baselines, they reported increased epileptiform activity in six out of nine presurgical epileptic patients. No effect was seen in one other patient and the results in the last two could not be interpreted. One non-epileptic volunteer was also included in the study (Fuller et al., 1995). In a study of 10 mesial temporal lobe epilepsy patients, Dobson et al. (2000a), making the critical assumption that epileptiform activity is a time-invariant Poisson process, found an alteration in epileptiform activity in five out of 10 patients, although the stimulation protocol resulting in these alterations differing between patients. A very complex field protocol makes the evaluation of the exposure difficult. Dobson et al. (2000b) also studied three patients with mesial temporal lobe epilepsy. Significant alterations in epileptiform activity were observed in 2 of the three subjects, while magnetic stimulation resulted in cessation of interictal spike/wave trains in the third.

Müller and Hotz (1990) measured possible delays in brainstem auditory evoked potentials after exposure to up to 2 T MRI imaging without finding any significant difference in a sample of 11 patients when comparing to measurements made before the exposure. In addition, one healthy volunteer was exposed during three hours of increasing exposure from 0 to 2 T MRI (Hotz et al., 1992). No effect was found on brainstem response in this person.

Vogl et al. (1991) recorded auditory (N=6), visual (N=20) and somatosensory evoked potentials (N=20) before, during and after exposure to static magnetic fields of 1 T and to combined MRI and RF fields without seeing any effect on latency and waveform for any of the exposure conditions.

Metabolic activity is another way of assessing neural activity in the brain. Volkow et al. (2000) measured brain metabolic activity in 12 healthy volunteers during MRI exposure, simulated MRI exposure (using a PET scanner modified to look like an MRI unit), and during a regular PET scan. The real and simulated MRI exposures were associated with lower metabolic activity compared to the regular PET scan. The authors suggest that this was due to differences in the visual field of the MRI and PET scanner, and that it also indicated that the subjects had habituated to the pulsed gradient field noise of the MRI scan.

Table 38. Evoked and spontaneous brain activity

Authors	Endpoint	Exposure	Results	Comments
Static magnetic field studies				
(Hong & Shellock, 1990)	Somato-sensory evoked potentials (SEP). Difference in latency of N20 and P25.	1.5 T duration not specified	No effects on short-latency of SEP.	Applied t-statistic does not look sound.
(Fuller et al., 1995)	EEG of epileptic patients	0.1, 0.9, 1.3, 1.8 mT 20 sec	Generation of epileptiform activity in the range of 0.9 - 1.8 mT in 6 of 7 exposed patients.	Dosimetry at the target (hippocampus) is questionable. Protocol is based on the assumption that there is no time trend in the epileptiform activity.
(Dobson et al., 2000a)	EEG of epileptic patients. Interictal spike counts	1 - 4 mT repeatedly for 5, 20 sec	No overall effect attributable to SMF exposure. Claim that 50% of subjects had significant alteration in at least one protocol (5/30 significant protocols).	Experimental protocol complex and difficult to interpret. Baseline before sub-protocols not consistent. Overall evaluation questionable. No sham exposures. Possible time trends.

(Dobson et al., 2000b)	EEG of epileptic patients. Interictal spike counts	0.9, 1.3, 1.8 mT repeatedly for 2, 5,10, 20 sec	Generation of epileptiform activity at 1.8 mT in two of three patients.	Experimental protocol complex and difficult to interpret. Insufficient data to draw conclusions. Very inhomogeneous results, even within the three subjects.
MRI or combined exposure studies				
(Müller & Hotz, 1990; Hotz et al., 1992)	Brainstem auditory evoked potentials (BAEP)	1.5 T 14 - 67 min	No change in relative BAEP inter-peak latency after exposure to MRI.	
(Hotz et al., 1992)	Brainstem auditory evoked potentials (BAEP)	0, 0.5, 1, 1.5, 2 T 3 h	No change.	N=1.
(Vogl et al., 1991)	Somato-sensory, visual, and auditory evoked potentials and peripheral nerve conduction velocities	1 T 1 h	Evoked potentials, as measured here, are not affected by MRI exposure.	
(Volkow et al., 2000)	Brain glucose metabolism	4 T 35 min	Metabolism lowered in real and simulated MRI environment: no effect of SMF (but effect of visual stimulation).	Possibility that sound stimulus is responsible for differences between MRI and PET. Small gradient fields present with SMF.
Studies considered to be uninformative				
(von Klitzing, 1989) (von Klitzing & Tessmann, 1989) (von Klitzing, 1987)				

8.1.2.1.3 Sensory perception

Schenck et al. (1992) reported 'dose-dependent' sensations of vertigo, nausea and a metallic taste in the mouth in 11 volunteers exposed to static magnetic fields of 1.5 and 4 T, and another group of 24 subjects with 1.5 T exposure, in an MRI system. Similar sensations have been anecdotally noted by other groups during volunteer and patient exposures (Kangarlu et al., 1999; Chakeres et al., 2003b; Crozier & Liu, 2005). These sensations occurred during movement of the head through a gradient field. In addition, magnetic phosphenes could sometimes be seen during eye movement in a field of at least 2 T. These effects may well be attributable to the weak electric fields induced by movement within the gradient field. The vertigo however, may be specifically attributable to magnetohydrodynamic forces acting on the endolymph of the semi-circular canals (Schenck, 2000).

In a study of auditory function, Winther (1999) found no effect on hearing and balance in 11 healthy male subjects following their exposure to a static magnetic field of 2 - 7 mT for 9 h. The subjects slept near the magnet during one night. Hearing and balance were measured in the evening before, and in the morning after the exposure.

Table 39. Sensory perception

Authors	**Endpoint**	**Exposure**	**Results**	**Comments**
Static magnetic field studies				
(Schenck et al., 1992)	Sensory experiences during motion in the field	1.5, 4 T total exposure, 1 - 35 h over one year	At 4 T more vertigo, nausea, metallic taste, magneto-phosphenes.	Results consistent with induced electric fields and/or with direct effect on vestibular organ.
(Winther et al., 1999)	Inner ear function	2 - 7 mT 9 h	No effect on any parameter.	

8.1.2.1.4 Cognitive studies

With regard to cognitive studies, two studies using a battery of cognitive test have been recently carried out during exposure to fields of 1.5 and 8 T (see Chakeres & de Vocht, 2005 for a review). Chakeres et al. (2003a) studied the effect of an 8 T static field exposure on the cognitive function of 25 healthy volunteers aged between 20 and 51 years. Cognitive function was assessed using seven standard neuropsychological tests of short-term memory, working memory, attention, and auditory reaction time. The tests were conducted inside and outside of the magnet, and the order of exposure condition was randomized. No effects were found, except for a small decline in the performance of a short-term memory task.

De Vocht et al. (2003) examined the effect of exposure to a 1.5 T static magnetic field on 6 standard measures of sensory function, cognitive function and motor co-ordination in 17 healthy volunteers. The head of the exposed subjects was in a field of 700 mT. The subjects did all tests at a session before the start of the experiment, to minimize the learning effect. Four different exposure conditions were used; 1st week unexposed with no movements, 2nd week unexposed with movements, 3rd week exposed with movements, and 4th week exposed with no movements. The authors found significant declines in the performance of a hand-eye coordination task (4%) and a near visual contrast sensitivity task (16%) when subjects were exposed to static and gradient fields.

Preece et al. (1998) also examined static field effects on cognitive function in 16 subjects during exposure to a static magnetic field of 0.5 mT (or to a 50 Hz, 0.5 mT magnetic field) in a randomized three-way cross over study. No effects were found during static field exposure, although exposure to the 50 Hz field resulted in a decline in numeric working memory sensitivity and word recognition sensitivity.

Other studies have generally reported a lack of effect on cognitive function following static magnetic fields or MRI exposure. In a study of 10 subjects, Kangarlu et al. (1999) found no effects on executive, cognitive, language and motor functions tested immediately after a one hour exposure to an 8 T pure static field when compared to tests performed shortly before the exposure session. The study design did not take possible learning effects into account.

Brockway and Bream (1992) included a total of 421 patients and volunteers in four experiments on the effect of MRI exposure on memory. In the first two experiments, 100 subjects were tested before and after MRI exposure. The last two experiments included exposed subjects and an unexposed control group. In experiment one, a reduced face and name identification ability was found, which the authors attributed to the order in which the tests were performed. A similar effect was found in experiment four, but this was seen in both the exposed and unexposed groups.

Besson et al. (1984) compared scores from 7 subjects on 7 psychometric tests performed before exposure to a NMR brain imaging procedure and respective test scores 1-5 days after the exposure. Exposure duration was 10 minutes, and the corresponding static field was 0.04 T; RF fields were also present. An improvement in two tests was found. However, this may be due to a learning effect.

Sweetland et al. (1987) assigned 150 volunteers either to an MRI imaging procedure (0.15 T static field and RF), a sham condition without any field, or a control condition outside the MRI unit. Exposure duration was 47 minutes. A battery of psychometric tests was performed before exposure, immediately after exposure, and three months later. Analyses of differences in the test scores did not indicate an exposure effect. Given the large number of tests that were analysed, a few statistically significant results were probably due to chance.

These data did not show effects of exposure on neurophysiological responses and cognitive functions in stationary volunteers during exposure to static magnetic fields of up to 8 T, nor can they rule out such effects. However, a dose dependent induction of vertigo and nausea was found in workers and volunteers during movement in static fields greater than 2 - 3 T. The possibility that eye-hand coordination and near visual contrast sensitivity are reduced in fields adjacent to a 1.5 T MRI unit should be further investigated. The presence of a magnetic field gradient was more commonly associated with these types of neurophysiological responses. All available studies are based on small numbers with limited power to detect modest effects, and have methodological limitations.

Table 40. Cognitive functions

Authors	Endpoint	Exposure	Results	Comments
Static magnetic field studies				
(Chakeres et al., 2003a)	11 different standardised neuro-cognitive tests, and an auditory motor reaction time test	0.05, 8 T ~ 1 h	No effect, except for small negative effect on short-term memory.	
(de Vocht et al., 2003)	Evaluation of cognitive-motor, cognitive and sensory function	0, 1.5 T 1 h	No effect, except for 4% reduction in performance of eye-hand coordination tests and 16% reduction in near visual contrast.	
(Preece et al., 1998)	Cognitive function	0.6 mT ~ 1 h	No effect.	Exposure duration not given. Presumed to be throughout the behavioural test.
(Kangarlu et al., 1999)	Cognitive, language and motor function	8 T 1 h	No effects. Some reports of vertigo and metallic taste in the mouth during movement.	The study design did not take into account possible learning effects.

MRI or combined exposure studies				
(Brockway & Bream, Jr., 1992)	Memory loss: specifically recall tests for faces, common objects, lexical items and digit span	0, 1.5 T duration unspecified	Some decline in memory performance in patients compared to controls, but not attributed to exposure, since effects were independent of body location (e.g. head or foot) being imaged.	RF (and presumably switched gradient fields) also present. Effect cannot be ascribed to SMF alone.
(Sweetland et al., 1987)	Six standardised tests of cognitive function	0.15 T ~ 1 h	No apparent effect on human cognition. However, anxiety scores increased and digit span scores decreased following MRI exposure. Interpretation of effects difficult: no difference between exposed and control groups.	Switched gradient and RF fields also present.
(Besson et al., 1984)	Four standardised tests of cognitive function	0.04 T 10 min	Increase in verbal and full scale IQ following exposure.	Switched gradient fields and RF fields also present

8.1.2.2 Circulatory system

It is known that flow potentials, which can be easily recorded on ECGs (see chapter 5), are induced around the major blood vessels and hearts of exposed patients during MRI. In addition, calculations suggest that magnetohydrodynamic forces will impede the flow of blood in major vessels at very high flux densities (~ 5% at 10 T; see section 5.1.3). The possible consequences of these effects have been explored in studies of high-intensity static magnetic field with intensities between 1 and 8 T associated with MRI-investigations. Other studies focused on the physiotherapeutic devices already in clinical use with intensities < 100 mT. Exposure durations have varied from 10 min up to 1 h.

8.1.2.2.1 Cardiac function, blood flow and blood pressure in volunteers

A number of volunteer studies have recently been carried out to test these calculations. Kangarlu et al. (1999) found that 10 volunteers exposed to an 8 T field for 1 hour showed no change in heart rate, or diastolic or systolic blood pressure, measured after exposure, compared to measurements taken before the exposure. The ECG recorded during exposure was regarded as uninterpretable due to the superposition of the potential generated by aortic blood flow and smaller potentials generated by blood flow in other vessels, but no change was observed when comparing ECG measurements taken before and after the exposure. More detailed studies by the same group have recently been published. One of these involved a study of 25 subjects and reported a lack of clinically significant effects of exposure to fields of up to 8 T on heart rate, respiratory rate, systolic and diastolic blood pressure, finger pulse oxygenation levels and core body temperature (Chakeres et al., 2003b). There was a statistically significant trend for systolic pressure to increase with flux density. At 8 T this was about 4 mm Hg, which is consistent with a haemodynamic compensation for a magnetohydrodynamic reduction in blood flow (Chakeres & de Vocht, 2005), but was also approximately one half of the difference seen when the subjects moved from a supine to a sitting body position. Blood pressure returned to normal after cessation of exposure. It is not clear whether the change in blood pressure was caused by the static field exposure or to other circumstances during the experiment, as no sham exposed group was included. No ectopic beats or cardiac arrhythmias were reported in either study.

Hinman (2002) reported the effects of exposure on heart rate and blood pressure associated with short-term exposure to 100 mT static magnetic fields. The exposure was local; the subjects laid down on 42 small permanent magnets. Seventy-five healthy adults were assigned to one of three treatment groups (positive versus negative polarity and control) in a double blind, randomized controlled trial. Heart rate and blood pressure were monitored prior to exposure, at 1 min, 5 min, 10 min and 15 min intervals during exposure, and again 5 min after exposure. Slight, non-significant decreases in heart rate and blood pressure were observed. An earlier study (Jehenson et al., 1988), conducted at a flux density of 2 T, investigated cardiac rhythm changes in 12 healthy volunteers for 1 hour before exposure, 1 hour during exposure, and 22 hours after exposure. In addition, four subjects were exposed to 1 T, and nine control subjects were exposed to 0 T. A significant 17% increase in cardiac cycle length was observed after 10 minutes of exposure at 2 T and during the reminder of the exposure period. The cardiac cycle was back to pre-exposure values 10 minutes after exposure. No significant effects were observed at 1 or 0 T.

No effects on blood flow were seen in a number of other studies (Stick et al., 1991; Mayrovitz et al., 2001; Martel et al., 2002). All of these studies used small, locally placed, permanent magnets, e.g. on the forearm or on the hand.

Shellock and Crues (1987) included 50 patients for clinical MRI imaging that were evaluated for heart rate and blood pressure. The study was done with a 1.5 T system, and the RF component gave whole body average SAR of 0.4 - 1.2 W/kg. There was no change in average heart rate or blood pressure immediately before and after MRI exposure. The authors concluded that whole body MRI exposure at 1.5 T is not associated with significant changes in heart rate or blood pressure.

Table 41. Cardiac function, blood flow and blood pressure

Authors	Endpoint	Exposure	Results	Comments
Static magnetic field studies				
(Kangarlu et al., 1999)	Body temperature, heart rate, respiratory rate, blood pressure, cognitive changes and ECG	8 T 1 h	No effect; although ECG changes were noted within normal range.	ECG's obtained during exposure could not be interpreted.
(Chakeres et al., 2003b)	ECG, heart rate, respiratory rate, systolic and diastolic blood pressures, finger pulse oxygenation levels, core body temperature	1.5 - 8 T 5 min	No clinically significant changes in vital signs. Systolic blood pressure increased with 8 T exposure. ECG rhythm strip analysis showed no significant post-exposure changes.	
(Hinman, 2002)	Heart rate and blood pressure	< 100 mT 15 min	No effect.	
(Jehenson et al., 1988)	Cardiac rhythm	1 - 2 T 1 h	Temporary increase in cardiac cycle length: 17% at 2 T, 10% at 1 T, and 0% at 0 T.	Harmless for healthy subjects, possible safety problem in dysrhythmic patients.
(Stick et al., 1991)	Blood flow in single thumb or forearm	0.4 - 0.5, 0.9 - 1 T 10 min	No blood flow change in the skin of the thumb and at the forearm.	No statistics.

(Mayrovitz et al., 2001)	Laser Doppler flowmetry (LDF) or laser Doppler imaging (LDI) perfusion in single hand	0.1 T 36 min	No detectable effect on skin blood perfusion in healthy subjects.	
(Martel et al., 2002)	Resting forearm blood flow and vascular resistance	30 min	No effect.	
(Weikl et al., 1989)	ECG	0.5 - 4 T 10 or 30 min	No arrhythmias, no changes in heart rate. Small reversible changes in ECG due to Hall effect.	
MRI or combined exposure studies				
(Shellock & Crues, 1987)	Heart rate and blood pressure	1.5 T 15 min	Whole body average SAR > 0.4 W/kg. Heart rate and average mean blood pressure not altered.	MRI exposure conditions.
Studies considered to be uninformative				
(Barker & Cain, 1985) (Sud & Sekhon, 1989) (Sakhnini & Khuzaie, 2001)				

8.1.2.2.2 Serum proteins and hormone levels

Male volunteers (N=35), 25 to 49 years old, were exposed to a static magnetic field of 9.6 mT during 40 minutes (Schmidt et al., 1999). A set of Helmholtz coils was used to produce the static field, which also created a ripple of time-varying magnetic fields 0.2 - 0.6% of the static field (19 - 57 μT). The subjects also spent a 40 min control period inside the coils without exposure, with one week between the two sessions. Urine and blood samples were taken before and after exposure and control sessions. An increase in serum and urinary creatinine was found after exposure. No change in calcium levels was observed. However, it is not possible to separate effects of the static magnetic field from the time varying field.

Healthy male volunteers (N=11), 23 - 43 years old, were exposed during the night to a static magnetic field from a 0.5 T interventional MRI unit (Haugsdal et al., 2001). Three beds were set up in the vicinity of the super-conducting coil, and exposure ranged from 1.2 - 13.7 mT at different locations in the beds. Total daily urine production was collected in four time intervals during the exposure day, the day after exposure and the control day 7 days after the exposure day. No effect on the excretion of 6-sulfatoxymelatonin was found. However, the number of subjects was too small to detect modest effects on melatonin production. The exposure situation did not resemble ordinary working conditions around an MRI system in terms of movements in varying static magnetic fields.

Table 42. Serum hormones and proteins

Authors	Endpoint	Exposure	Results	Comments
Static magnetic field studies				
(Schmidt et al., 1999)	Creatinine, calcium	9.6 mT 40 min	Increase in serum and urinary creatinine. No change in calcium levels.	Paper in Norwegian. Exposure to SMF + time varying field.
(Haugsdal et al., 2001)	Melatonin	1.2 - 13.7 mT 9 h	No effect on the excretion of 6-sulfatoxymelatonin.	Number of subjects too small to detect modest effects on melatonin levels. Nocturnal situation is not equal to normal work environments (e.g. movement while working, time varying fields).

8.1.2.3 Body and skin temperature

The effect of exposure to 1.5 T pure static magnetic fields for 20 min or 60 min on human body and skin temperature was investigated in three experiments performed by Shellock et al. (1986; 1989). The group size varied from 6 to 11 healthy volunteers for different experiments. Skin temperature was measured on the following sites: abdomen, forehead, upper arm, forearm, chest, thigh, calf and sublingual area. Body temperature was measured via an oesophageal tube. No significant temperature changes were found.

Chakeres et al. (2003b) studied 25 healthy volunteers, aged 24 - 53 years, exposed to static magnetic field strengths of 1.5, 3, 4.5, 6, and 8 T. Core body temperature was measured before, during, and after exposure. No change in core body temperature was found.

Shellock and Crues (1987) included 50 patients for clinical MRI imaging that were evaluated for core and skin temperatures. The study was done with a 1.5 T system, and the RF component gave a whole body average SAR of 0.4 - 1.2 W kg^{-1}. There was an average increase of core body temperature of 0.2 °C, but there was no correlation between change in body temperature and SAR.

The influence on deep body core and superficial body temperature of humans as the result of exposure to 0.35 T and 1.5 T pure static and RF fields was investigated in a total of 20 subjects in several experiments (Vogl et al., 1988). Outcomes were measured before, during and after exposure. No influence on the central body temperature (oesophagus and rectum), or on the superficial temperature (venous intravascular), was seen.

Table 43. Body and skin temperature				
Authors	**Endpoint**	**Exposure**	**Results**	**Comments**
Static magnetic field studies				
(Shellock et al., 1986)	Body temperature	1.5 T 20, 60 min	No changes in core body temperature.	
(Shellock et al., 1989)	Body and skin temperatures	1.5 T 20 min	No significant changes of surface temperature at abdomen, forehead, upper arm, forearm, chest, thigh, calf and sublingual.	
(Chakeres et al., 2003b)	Core body temperature	1.5 - 8 T 5 min	No effect on core temperature.	
MRI or combined exposure studies				
(Shellock & Crues, 1987)	Temperature	1.5 T 15 min	Whole body average SAR > 0.4 W/kg. Core body temperature increased on average 0.2 °C.	MRI exposure conditions.
(Vogl et al., 1986) (Vogl et al., 1988)	Deep and superficial body temperatures	0.35 or 1.5 T exposure to SMF followed by imaging sequences	No temperature change due to MRI procedure, no change of core temperature (oesophagus, rectum) nor of the superficial temperature (venous intravascular).	No conclusion for skin and subcutaneous temperatures.

8.1.2.4 Dental exposure

Orthodontic magnets and implants are tools sometimes used nowadays in dental and oral medicine. Questions have been asked about the potential adverse health effects of static fields from these implants.

Bondemark et al. (1995; 1998) examined the effects of orthodontic magnets on the oral mucosa, the dental pulp and the gingival in a total of 15 patients (two studies, N_1=7, N_2=8 patients). The endpoints of those examinations were morphological and histological alterations of the surrounding tissue. The magnet and the demagnetised control magnet were bonded on molars on either side of the mouth. The static magnetic fields from the implants varied between 10 and 140 mT. The maximum observation period was 9 months. Some inflammations were detected in tissue close to both the magnet and demagnetised magnet, but not in other sites. Those were attributed to contact irritation rather than to the static magnetic field.

Table 44. Dental exposure

Authors	**Endpoint**	**Exposure**	**Conclusions**	**Comments**
Static magnetic field studies				
(Bondemark et al., 1995)	Tissue changes	10 - 90 mT 8 wk	No histologically detectable changes in human dental pulp or gingival tissues.	
(Bondemark et al., 1998)	Morphological, histological and immunohisto-chemical changes	80 - 140 mT 9 months	No difference found between control and test tissues. Observed minor tissue reactions were attributed to contact irritation with the magnet body.	

8.1.2.5 Therapeutic treatment

The impact of magnetism on human tissues and human health and its use in the therapeutic treatment is an ancient and contentious subject (Schenck, 2005) that remains so to the present (Whitaker & Adderly, 1998; Park, 2000). The studies are listed in Table 45.

Many of the studies on therapeutic effects share a number of methodological limitations, the most important being potential placebo effects due to lack of blinding and the fact that the field strengths were not adequately characterized.

Table 45. Therapeutic treatment
Authors
Studies considered to be uninformative
(Hong et al., 1982) (Lin et al., 1985) (Ivanov et al., 1990) (Lud & Demeckiy, 1990) (Caselli et al., 1997) (Dexter, Jr., 1997) (Vallbona et al., 1997) (Bernhold & Bondemark, 1998) (Man et al., 1999) (Collacott et al., 2000) (Holcomb et al., 2000) (Alfano et al., 2001) (Segal et al., 2001) (Thomas et al., 2001) (Suomi & Koceja, 2001) (Carter et al., 2002) (Hinman et al., 2002) (Weintraub et al., 2003)

8.1.2.6 Conclusions

There are only very limited data available from human experimental studies on the potential effects of exposure to static electric fields. The results of the one small study that has investigated detection thresholds for static electric fields indicated that the perception threshold in people depends on various factors and ranges between 10 and 45 kV m^{-1}. Thresholds for annoyance from such sensations are probably equally variable, but have not been systematically studied. The study of combined electric fields from DC and AC high voltage power lines indicated the possibility of increased sensations of the combined exposure, but limitations of the experimental design, and lack of confirmative data, prevent any conclusions.

The available data do not indicate that there are effects of static magnetic field exposure on neurophysiological responses and cognitive functions in stationary volunteers, nor can they rule out such effects (since most of the performed studies are small and have several methodological limitations). A dose-dependent induction of vertigo and nausea was found in workers, patients and volunteers during movement in static fields greater than about 2 T. One study suggested that eye-hand coordination and near visual contrast sensitivity are reduced in fields adjacent to a 1.5 T MRI unit. The occurrence of all of these effects is likely to be dependent on the gradient of the field and the movement of the subject.

Flow potentials are induced in the major blood vessels and in the heart by the flow of blood with a static magnetic field. These electrical potentials are largest in the aorta, and occur during the T-wave of the cardiac cycle. In addition, the flow of blood in a vessel will experience a force opposing its motion. It has been estimated that the flow potentials will generate currents at the sino-atrial node of about 110 - 120 mA m^{-2} at 5 T, and about 200 mA m^{-2} at 10 T. It was predicted that the magnetohydrodynamic effect could lead to a reduction in blood flow in the aorta estimated to about 1% and 5%, respectively. A small change in blood pressure and heart rate was observed in some studies, but these were in the range of normal physiological variability.

There is no evidence of effects of static magnetic fields on other aspects of cardiovascular physiology, or on serum proteins and hormones. Exposure to static magnetic fields of up to 8 T does not appear to induce temperature changes in humans. However, most of the studies were very small, based on convenience samples, and often included non-comparable groups. Thus, it is not possible to draw any conclusions regarding the wide variety of end-points examined in this report.

Because of methodological limitations in available studies, it is not possible to draw any conclusions regarding the wide variety of reported therapeutic end-points.

8.2 Epidemiological studies

Epidemiological studies can provide direct information on the health of people exposed to static fields, and are therefore given the greatest weight in health risk assessment by WHO and IARC (Repacholi & Cardis, 1997). However, their observational nature makes it difficult to infer causal relationships, except when the evidence is strong or when findings are supported by experimental data. This is because they may be subject to bias (such as when the quality of information on EMF exposures obtained directly from diseased people differs from that obtained from people without the disease) and confounding factors. The latter may occur, for example, when workers exposed to EMFs are also exposed to other agents in the workplace that are strongly correlated to static fields and could affect disease risk.

Studies have been carried out almost exclusively on workers exposed to static magnetic fields generated by equipment using large DC currents (see chapter 3). Most workers were exposed to moderate static magnetic fields of up to several 10’s mT either as welders, aluminium smelters, or workers in various industrial plants using large electrolytic cells in chemical separation processes. However, such work is also likely to have involved exposure to a variety of potentially hazardous fumes and aerosols, confounding interpretation. Health endpoints studied in these workers have included cancer incidence, haematological changes and related outcomes, chromosome aberration frequency, reproductive outcomes and musculoskeletal disorders. In addition, one study examined fertility and pregnancy outcome in female MRI operators, where the potential to have been exposed to relatively large static fields of up to ~ 1 T may have existed.

8.2.1 Cancer

8.2.1.1 Welders

A large number of studies have investigated cancer risks among welders. Unfortunately, none of the studies contained adequate exposure assessment for static fields and they thus do not allow for a meaningful analysis. Welders are also exposed to a varying degree to other potentially harmful agents, e.g. welding fumes, ELF and RF magnetic fields. Furthermore, most of the studies did not provide enough information to determine the type of welding used, further limiting the usefulness of this data in the review of potential health effects of static magnetic field exposure. Thus, the studies of welders are not reviewed in any detail. However, these studies are important, given a relatively high exposure to static fields in some of the welding processes. Two meta-analyses provide the most information. A meta-analysis of brain tumors in 38 studies of occupational EMF exposure (Kheifets et al., 1995) reported a small but significantly elevated risk for welders (relative risk [RR] = 1.25; 95% confidence interval [CI]: 1.06 - 1.47). Another meta-analysis of 29 occupational studies of leukaemia found no risk increase in welders (Kheifets et al., 1997).

8.2.1.2 Aluminium Workers

Various studies investigated the cancer risk in aluminium plant workers. In 1982 Andersen et al. reported overall mortality and cancer incidence in 7,410 male employees from 4 Norwegian aluminium plants (Andersen et al., 1982). The mortality in the cohort was compared to the general population, and the cancer incidence was compared to the incidence in the population living in the counties where the aluminium plants were located. Only lung cancer incidence was increased, but the risk was essentially confined to two production subgroups: workers with a short duration of employment and workers with a very long duration of employment in older plants. The interpretation of the results is restricted due to the healthy worker effects and the incomplete smoking histories.

Rockette and Arena (1983) studied a cohort of 27,829 male aluminium workers employed for ≥ 5 years between 1946 and 1977 in 14 reduction plants in the USA, comparing the mortality among aluminium workers to that of the general US male population. They reported a slightly higher than expected, but not statistically significant mortality from pancreatic, genito-urinary and lymphohaematopoietic cancers. Deaths from lymphohaematopoietic cancer were not confined to one subcategory of disease, or to one industrial process. As would be expected from a healthy worker effect, they found a reduced mortality from all cases of death, and also for several major causes of death such as all malignant neoplasms combined, cardiovascular disease, and diabetes mellitus. The healthy worker effect makes the modestly increased risks for some cancer sites interesting, despite the lack of statistical significance. Static magnetic fields were not measured, and other exposures (e.g. polycyclic aromatic hydrocarbons, PAH) were present in the same jobs. As a result, these could not be separated from exposure to static magnetic fields.

In a cohort study of aluminium reduction workers in France, Mur et al. (1987) analysed the mortality between 1950 and 1976 of 6,455 workers in order to assess occupational risks. The study focused on lung cancer risks from air pollutants. Cancer mortality (standardised mortality ratio [SMR] = 1.09; 95%-CI: 0.97 - 1.22) and mortality from all causes (SMR = 0.85; 95%-CI: 0.80 - 0.91) was not significantly increased compared to the general population. Although not statistically significant, an SMR of about 2 was observed for malignant tumours in the liver, brain, bone, skin and bladder. Analysis of workers involved in electrolysis, maintenance or smelting yielded statistically nonsignificant SMRs of 1.09, 1.03, and 0.80, respectively. The cancer risk of electrolysis workers decreased with length of employment. No exposure levels to static magnetic fields were reported. In addition to exposure to static magnetic fields, the workers were exposed to numerous chemicals such as coal tar pitch and PAH, substances that are known to increase the risk of some of these cancers. Only limited information about other confounding factors, e.g. smoking, was available. Information about cause of death could only be obtained for 71% of the cohort.

A cohort study was carried out in British Columbia, Canada, involving 4,213 male workers with ≥ 5 years of work experience at an aluminium reduction plant between 1954 and 1985 (Spinelli et al., 1991). The static magnetic fields usually generated in the plant ranged between 1 - 10 mT. The potential exposure to magnetic fields and to coal-tar pitch volatiles was determined for each job by industrial hygienists using a job-exposure matrix. Mortality and incidence rates were compared to the general male population. Potential confounding from smoking was controlled for in the analyses. The SMR in the total cohort was 0.77 (90% CI: 0.70 - 0.84) for all causes of death, and 2.2 (90% CI: 1.2 - 3.7) for tumours of the brain and central nervous system (International Code of Disease (ICD)-9 191, 192) and 1.8 (90% CI: 0.8 – 3.3) for leukaemia (ICD-9 204 – 208). For cancer incidence ascertained from 1970 onwards, the standardized incidence ratio (SIR) was 1.9 (90% CI: 0.97 - 3.5) for brain cancer (ICD-9 191), and 0.76 (90% CI: 0.21 - 2.0) for leukaemia. However, no individual cause of cancer death or incident cancer was related to cumulative exposure to magnetic fields, as estimated from the job-exposure matrix. The incidence of bladder cancer was strongly related to cumulative exposure to coal-tar pitch volatiles.

In 1995 Rønneberg and Andersen determined cancer morbidity in a cohort of 1,137 men working in a prebake smelter for at least 6 months during the period 1922 - 1975 (Rønneberg, 1995; Rønneberg & Andersen, 1995). The cohort was followed in the Norwegian Cancer registry during the period 1953 - 1991. In the prebake process, the anodes made from coke and coal tar paste are fabricated in a separate facility and then introduced into the electrolysis vessel. This is likely to result in reduced concentrations of air-borne polycyclic aromatic hydrocarbons and coal tar particulate volatiles as compared to the newer Söderberg process, where the electrodes are introduced as a liquid paste and hardened in the electrolysis vessel itself. The intensity of exposure to coal tar pitch volatiles, asbestos, pot emissions, heat stress, and magnetic fields had been previously assessed for all jobs at the smelter (Rønneberg, 1995). The cancer incidence in the cohort was compared to the incidence in the general male population. No association was found between static magnetic field exposure and cancers of the nervous system or haematopoietic system, but the number of observed cases was very small. There is probably some overlap between this study and the study by Andersen et al. (1982).

Rønneberg et al. (1999) studied cancer incidence in a population composed of 2,647 male short-term workers and two cohorts of men employed for at least four years in a Norwegian aluminium smelter (2,888 production workers and 373 maintenance workers). Of the 5,962 men who initially satisfied the inclusion criteria, six had died before the observation period started in 1953 and 48 were lost to follow-up. The remaining 5,908 men were linked to the files of the Norwegian Cancer Registry and followed up from 1953 (or date of first employment) until date of death or emigration, or the end of 1993. There was an association between exposure to coal tar pitch volatiles and bladder cancer. There was no association between static magnetic fields and cancers of the brain or lymphatic and haematopoietic tissues. Cancer incidence was not elevated in any of the cohorts when compared with the expected incidence calculated on the basis of the age- and calendar year-specific cancer incidence of all men in Norway applied to the person-years at risk among cohort members. In contrast, there was a significant positive association between employment as a maintenance electrician working mainly with 220-V alternating current and lymphatic and haematopoietic cancer, and a statistically nonsignificant association between PAH and lung cancer. The healthy worker effect may have caused an underestimation of potential effects. There was only limited control of confounding variables.

Milham (1982) calculated proportionate mortality ratios (PMR) for leukaemia and non-Hodgkin's lymphoma with respect to the occupation. In extended analyses of a larger material additional cancer sites were analysed (Milham, 1985). Elevated PMRs were found among aluminium workers for several cancer sites; pancreatic, lung, and haematological malignancies. The highest PMR was seen for acute leukaemia (PMR = 233) and for other lymphomas (PMR = 260). This study has numerous limitations, including cross-sectional design, unknown contribution of different exposure sources, and confounding from other exposures.

8.2.1.3 Chloralkali Plants

Barregård et al. (1985) studied cancer mortality and cancer incidence in a group of 157 male workers at a Swedish chloralkali plant compared to the general Swedish male population. The employees had all worked regularly or permanently for at least one year during the period 1951 - 1983 in the cell room where the electrolysis process took place and where they had been exposed to static magnetic fields (average: 14 mT). The investigators reported no excess incidence of, or mortality from, cancer. The results might be due to the healthy worker effect. Only unspecific outcomes were studied (all causes of death, all types of cancers combined). The study had poor statistical power.

The study was later expanded to include workers at eight chloralkali plants, a total of 1,190 men (Barregård et al., 1990). This study was focused on exposure to inorganic mercury, and no magnetic field measurements were made. An increased risk of lung cancer was observed. Workers at some of the plants were also exposed to asbestos, which could explain some of the observed risk increase. A slightly higher mortality from circulatory diseases was also noted. The healthy worker effect may have also affected the results in the expanded study. Information about smoking habits was not available. The statistical power was poor for specific cancer types.

Ellingsen et al. (1993) studied cancer incidence and mortality in 674 workers employed for the first time before 1980 at two Norwegian chloralkali plants. Cancer incidence and mortality were compared to expected rates in the general Norwegian male population, based on five year age groups and calendar years from 1953 - 1989. The main hypothesis concerned mercury vapour, and no magnetic field measurements were taken. A modest increase in lung cancer incidence was found. No risk increases were found for cancers of the nervous system or lymphatic and haematopoietic tissues. The overall mortality was close to that expected and there were no increased risk for any specific cause of death. The healthy worker effect is likely to have affected the results. There was no control for confounding factors, other than age and calendar. The study had poor statistical power.

8.2.2 Haematology, Immune Status and Blood Pressure

After the identification of a cluster of B-cell lymphoma in an aluminium reduction plant, Davis and Milham (1990) used a pilot study to investigate the immune status of 23 workers, as immuno-deficiency is a known risk factor for B-cell lymphoma. Out of the 350 employees, 44 volunteered for the study but only 23 could be included. Twenty of these workers worked in the potroom, where there was potential for high exposure to static magnetic fields as well as coal tar pitch. Three workers were considered as unexposed because they had never worked in the potroom. Potroom workers had significantly higher T8 levels (mean = 1,227 cells/μl) than non-potroom workers (mean = 558 cells/μl) or in comparison to normal for the general population values (median = 450 cells/μl). T4 levels were higher for potroom workers (mean = 1,017 cells/μl) than for non potroom workers (mean = 597 cells/μl) ($p < 0.1$) or normal values (median = 756 cells/μl). The subject selection procedure was not well described. In addition, there were only 3 unexposed subjects. Population values are reported as medians, which are likely to be lower than mean values. Smoking may be a confounding variable, but even the non-smoking potroom workers had higher T8 counts than the general population.

Tuschl et al. (2000) studied immune parameters in hospital personnel exposed to different sources of EMF. The immune parameters of 10 MRI workers (generally exposed to static magnetic fields of 0.5 mT in the operator room and occasionally to higher field strengths) did not differ from those of the control group (23 persons). Other immune parameters examined that showed no difference between exposed and unexposed workers included relative and absolute numbers of lymphocytic subsets, the proliferative activity of T and B cells, the production of interleukin 2, interferon gamma and tumour necrosis factor alpha, serum immunoglobulins, non-specific immunity of monocytes and granulocytes. The subject selection procedure was not well described. The MRI workers were an average of 10 years younger than the other groups, and smoking was half as prevalent. The actual individual exposure for the working group could not be measured and could only be roughly estimated.

Marsh et al. (1982) studied 320 exposed and 186 unexposed workers in various industrial plants using large electrolytic cells in chemical separation processes. The averaged static field level in the exposed work environment was 7.6 mT and the maximum field was 14.6 mT. Based on theoretical considerations, the authors separately examined vertical and horizontal components of magnetic fields. Horizontal fields were considered as most relevant with respect to induced currents. Vertical fields may be relevant for processes with a certain latency period, as only vertical fields remain constant over time in a moving upright body. The authors did not find major health problems in this population. While the mean values of both the exposed and unexposed groups were within the normal range, white cell counts were decreasing with increasing horizontal magnetic fields. The percentage of lymphocyte and percentage of monocyte increased with increasing horizontal magnetic field. An increase in the systolic and diastolic blood pressure with increasing exposure to the vertical component of the magnetic field was observed in black subjects. The opposite trend was observed in the whole study population, with a tendency for a decreasing systolic and diastolic pressure with increasing vertical magnetic field strength ($p = 0.08$). Results for whites and Hispanics were not reported. It was noted that the description of the results in the text did not always correspond to the numbers reported in the specified models. The subject selection procedure was not well described. The 320 exposed workers were likely to have been exposed to mercury and chlorine as well, whereas the unexposed group was not. Only large long-term health effects could have been detected in this small study population.

8.2.3 Chromosome Aberrations

Skyberg et al. (1993) compared chromosome aberration in the lymphocytes of 13 high voltage laboratory cable splicers with 20 referents not exposed to electric and magnetic fields. The cable splicers were generally exposed to static and alternating magnetic field strength of 5 - 15 µT. They could also occasionally be exposed to magnetic fields strengths up to 10 mT by touching the cable. Generally, no differences between exposed and unexposed workers were found. However, exposed smokers had more chromosome breaks than smokers, in comparison to the control group (based on 7 exposed smokers). It is not known what property of the EMF exposure, if any, was responsible for the observed effect. In addition, there were only a small number of subjects.

8.2.4 Reproduction

Several indicators of reproductive health were studied in aluminium and metal workers, as well as MRI operators.

Mur et al. (1998) compared the birth-rate of 692 potroom male workers exposed to static magnetic fields ranging from 4 - 30 mT to that from 588 unexposed male workers from the same aluminium plants (all blue-collar workers). The birth rate was calculated for each couple by dividing the number of children by the number of years since marriage. To control for cultural differences, only French men were included in the study. The authors found a statistically significant increase in the birth rate (relative birth-rate ratio of 1.1; $p < 0.001$). This result was interpreted as an indicator that the fertility of the male workers was not decreased due to exposure to static magnetic fields or heat. However, the age of the husband/wife was not controlled for in the analysis.

Irgens et al. (1997) studied the male proportion in offspring of workers in metal smelters, welders and workers involved in production of electric wires during the period 1970 - 1993. The male proportion among offspring to fathers and mothers not working in any of the investigated occupations were used as a reference. In total, 1.2 million births were included. Aluminium workers were exposed to static magnetic fields of up to 10 mT and to alternating fields of up to 0.1 mT. Workers in plants producing magnesium, nickel or iron were assumed to be exposed to 50 Hz magnetic fields up to 2 mT. The production of electric wire is associated with 50 Hz magnetic fields up to 0.015 mT, and occasional exposure of the hand to static and alternating magnetic fields of up to 10 mT. Common static and alternating field strengths to which the welders were reported to be exposed were 0.001 - 0.05 mT. The offspring of male aluminium workers or welders had a proportion of males similar to that of the unexposed population (RR = 0.98; 95% CI: 0.94 - 1.03, and RR = 1.01; 95% CI: 0.99 - 1.03, respectively). The offspring of women working in the smelter industry had a significantly reduced male proportion, which was particularly reduced for women working in the aluminium plants (RR = 0.72; 95% CI: 0.59 - 0.90, based on 81 exposed births). Exposure misclassification was very likely in this study because the job title was reported only every 10 years by an imprecise three digit coding system. There was no o control of any confounding factors, not even the age of the parents.

Evans et al. (1993) investigated infertility and pregnancy outcome in a cross-sectional study among MRI workers in the USA: 1,915 female

MRI operators reported 1,421 pregnancies, of which 287 pregnancies occurred during work as an MRI operator, the remaining during work in another job or while being a homemaker. The risk of miscarriage for pregnancies during MRI work was slightly (but not statistically significantly) increased compared to work in other jobs, and was considerably higher than the risk of homemakers. Minor differences were found for early delivery and low birth weight when compared to homemakers, but not when compared to other workers. The gender ratio of offspring in the same study was not changed (Kanal et al., 1993). There was no control for age: for example, women with pregnancies during work as MRI operators were markedly older than other groups. Homemakers below 30 years of age at pregnancy had a very low miscarriage rate, which may have influenced the risk estimate. Selection bias and reporting bias cannot be ruled out in this study, as it cannot be determined what proportion of the total female MRI workers participated in the study.

Baker et al. (1994) carried out limited follow-up of 20 children with a variety of abnormalities imaged *in utero* with 0.5 T echo planar MRI. Only case reports are presented, with no comparison group.

Myers et al. (1998) investigated effects on intrauterine growth following *in utero* exposure to MRI. A total of 74 pregnant volunteer women were recruited through advertisements, and underwent up to five MRI scans during pregnancy. A control group consisted of 148 unexposed pregnant women matched on maternal age, parity, ethnic origin, smoking history, and postcode. No effect was found on gestational age-adjusted birth weight, although unadjusted birth weights and gestational age were significantly lower in the MRI group. The study is small, and the results are difficult to interpret.

Clements et al. (2000) followed 20 children exposed to MRI for four times between 20 weeks to term and 35 unexposed children, from birth until 9 month of age. A small decrease in length was found in exposed children, and an increase in gross motor function. No other effects were found. It is unclear how the subjects were selected to be participants in the study, and no participation rates were reported. It seems likely that this was not a random sample, and that selection bias may therefore have affected the results. The statistical analyses were questionable. Furthermore, the number of children is very small, and thus only very large effects could have been detected.

8.2.5 Musculoskeletal Symptoms

A retrospective cohort study in an aluminium plant compared the occurrence of musculoskeletal symptoms during 1986 to 1991 among an exposed (N = 342) and an unexposed group (N = 277) of workers (Moen et al., 1995). Employees were exposed in potrooms to static magnetic fields between 3 and 20 mT, and to ripple components (alternating currents) as well. The unexposed group consisted of workers from the cast house, the rolling mill and transport workers. The exposed and unexposed groups had similar exposures to other risk factors for musculoskeletal disorders, e.g. chemical substances, vibration, work load, etc. The analysis was based on the symptoms reported to the occupational health care unit in 1986 and 1991. No difference was found between the exposed and unexposed groups. Further analyses focusing on sick leave due to musculoskeletal disorders also failed to detect an association to the exposure with static magnetic field (Moen et al., 1996). Selection bias may have been present if health is a consideration in the selection of workers to work in the potroom. Minor health problems may not have been included in this study, because they probably did not get reported to the health care unit.

8.2.6 Conclusions

The few epidemiological studies published to date leave a number of unresolved issues concerning the possibility of increased cancer risk from exposure to static magnetic fields. Assessment of exposure has been poor, and the number of participants in some of the studies has been very small, and thus these studies are able to detect only very large risks for such rare diseases. Most of the studies were conducted in aluminium plants or other smelter plants. The inability of these studies to provide useful information is supported by the lack of clear evidence for other, more established carcinogenic factors present in some of the work environments studies. Other non-cancerous health effects have been considered even more sporadically. Most of these studies are based on very small numbers and have numerous methodological limitations. Other environments with a potential for high fields have not been adequately evaluated, e.g. MRI operators. In short, there is insufficient material for a health evaluation.

Table 46. Epidemiology						
Authors	**Population**	**Endpoint**	**Type**	**Exposure**	**Results**	**Comments**
Cancer						
Aluminium workers						
(Andersen et al., 1982)	7,410 male employees from 4 Norwegian aluminium plants	Mortality and cancer incidence	Cohort	SMF: no levels stated	Increased lung cancer incidence; essentially only in workers with short duration of employment and workers with very long duration of employment in older plants.	Interpretation of results restricted due to healthy worker effects and incomplete smoking histories.
(Rockette & Arena, 1983)	21,829 workers in the aluminium industry	Mortality	Cohort	SMF: 4 - 50 mT	Cancer of pancreas ($p<0.01$); leukaemia (n.s.).	Healthy worker effect makes modestly increased risks for some cancer sites interesting despite lack of statistical significance. SMF not measured. Other exposures, e.g. PAH, could not be separated from SMF exposure.

(Mur et al., 1987)	6,455 workers in French aluminium plants between 1950 and 1976	Mortality	Cohort	SMF: no levels stated	No increased cancer mortality and mortality from all causes.	No SMF exposure levels reported. Also exposure to numerous chemicals such as coal tar pitch and PAH, that are known to increase risk of some cancers. Limited information on other confounding factors, e.g. smoking. Information on cause of death only obtained for 71% of the cohort.
(Spinelli et al., 1991)	4,213 workers of an aluminium plant in BC, Canada	Mortality and cancer incidence	Cohort	SMF: no levels stated	All causes of mortality: SMR=0.77; all cancer: SMR=0.92; brain cancer: SMR=2.2 (1.2 - 3.1); bladder cancer: SMR=1.7 (1.1 - 2.6).	
(Rønneberg & Andersen, 1995) (Rønneberg et al., 1999)	5,908 workers in Norwegian aluminium smelters	Mortality and cancer morbidity	Cohort	SMF: 2 - 10 mT ELF: 0.3 - 10 µT	No increased risk for brain cancer and lymphatic and haemopoietic tissue cancer. Increased leukaemia risk for employment as an electrician.	Possible underestimation of potential effects due to healthy worker effect. Limited confounding control. Probably some overlap with Andersen et al., (1982).

(Milham, 1985)	12,714 death records of 'electrical' workers	Mortality	Cross-sectional	SMF: possible exposure	Acute leukaemia: PMR=162; other lymphomas: PMR=164.	Numerous limitations, e.g. cross-sectional design, unknown contribution of different exposure sources.
Chloralkali Plants						
(Barregård et al., 1985)	157 exposed men in a chloralkali plant engaged in the electrolytic production of chlorine	Cancer mortality and incidence	Cohort	SMF: 4 - 29 mT	Mortality: SMR= 0.8 (0.4 - 1.3); cancer: SIR=0.8 (0.3 - 1.9).	Results might be due to healthy worker effect. Unspecific outcomes (all causes of death, all types of cancers combined). Poor statistical power.
(Barregård et al., 1990)	1,190 exposed men in eight chloralkali plants	Mortality and cancer incidence	Cohort	SMF: no levels stated	Slightly increased cardio-vascular mortality, increased lung cancer incidence.	Healthy worker effect possible, comparison to general population. Poor statistical power for specific cancer types. Limited confounding control.
(Ellingsen et al., 1993)	674 exposed men in two chloralkali plants	Mortality and cancer incidence	Cohort	SMF: no levels stated	Slightly increased lung cancer risk. Incidence of all cancers combined and total mortality close to unity.	Healthy worker effect possible, comparison to general population. Poor statistical power. Limited confounding control.

Haematology, immune status and blood pressure						
(Davis & Milham, 1990)	20 exposed potroom workers and 3 unexposed worker from the same plant	Immune status	Cross-sectional	SMF: no levels stated	More T8 cells ($p<0.05$) and T4 cells ($p<0.1$).	Selection procedure not well described. Only 3 unexposed subjects. Population values reported as medians (likely to be lower than means). Smoking may be a confounding factor, but even non-smoking potroom workers had higher T8 counts than general population value.
(Tuschl et al., 2000)	Hospital personnel: 10 MRI worker 10 workers at induction heaters 23 controls	Immune para-meters	Cross-sectional	MRI: SMF: 0.5 T (operator room) Induction heater: ELF/IF (50 Hz - 21.3 kHz): 2 mT	No effects on number of natural killer cells and oxidative burst in monocytes in MRI workers.	Selection procedure not well described. Exposed and unexposed groups not comparable in terms of age and smoking habits.

(Marsh et al., 1982)	320 workers exposed to SMF from electrolytic cells and 186 unexposed workers	General health indicators	Cross-sectional	SMF: mean = 7.6 mT, max = 14.6 mT	Decrease in white cell counts. Increase in lymphocyte and monocyte percentages. No effects on red cell count haemoglobin and haematocrit reading. Only in people of colour: increase in systolic and diastolic pressure.	Selection procedure not well described. SMF-exposed workers likely to be also exposed to mercury and chlorine, whereas unexposed group was not. Exposure to magnesium dust likely for exposed and unexposed workers.
Chromosome aberrations						
(Skyberg et al., 1993)	13 high voltage laboratory employees and 20 referents	Chromosome aberrations	Cross-sectional	Static or 50 Hz B-field: 5 - 15 μT, sometimes up to 10 mT Static or alternating E-field 5 - 10 kV/m	More chromosome aberrations in exposed smokers than in non-exposed smokers.	Small numbers of subjects. Not known what property of EMF exposure, if any, is responsible for observed effect.
Reproduction						
(Mur et al., 1998)	692 potroom workers in aluminium plants and 588 controls from the same plants	Birth rate	Cross-sectional	SMF: 4 - 30 mT	Birth rate ratio exposed/ control: 1.1 ($p<0.001$).	Not controlled for the age of husband/wife.

(Irgens et al., 1997)	Norwegian workers in metal reduction plants and electric wire production	Offspring sex ratio	Register	SMF: up to 10 mT ELF: up to 1 mT	Male: smelter works: RR=0.97 (0.92 - 1.02) wire production: RR=0.92 (0.80 - 1.05) welders: RR=1.01 (0.99 - 1.03) Female: aluminium works: RR=0.72 (0.59 - 0.90) all smelter works: RR=0.88 (0.79 - 0.99)	Exposure misclassification very likely, because job title reported only every 10 years by an imprecise three digit coding system. No control of confounding factors, not even age of parents.
(Evans et al., 1993) (Kanal et al., 1993)	1,915 female MRI technol-ogists and nurses from USA	Infertility and pregnancy outcome	Cross-sectional	SMF: 6% of working hours: 0.5 - 2 T 6% of working hours: 10 mT remaining time: < 10mT	MRI vs other workers: miscarriage: relative risk ratio (RRR)=1.3 (0.9 - 1.8) early delivery: RRR=1.2 (0.8 - 1.9) low birthweight: RRR=1.0 (0.5 - 2.0) MRI vs home-makers: miscarriage: RRR=3.2 (1.7 - 6.0) early delivery: RRR=1.7 (0.9 - 3.4) low birthweight: RRR=1.5 (0.5 - 4.41)	Women with pregnancies during work as an MRI operator markedly older than other groups. Pregnant homemakers below age 30 had a very low miscarriage rate - may have influenced risk estimate. Possible selection and reporting bias. Unknown participation rate of female MRI workers.

(Baker et al., 1994)	20 exposed children, no un-exposed comparison group	Hearing deficit	Appear to be case reports	0.5 T echo planar MRI	No effect found at 8 months hearing test.	No quantitative data. Varying follow-up time. Sound levels not reported.
(Myers et al., 1998)	74 children exposed to MRI *in utero*	Intra-uterine growth	Cohort	Up to five MRI scans *in utero*	No effect on gestational age-adjusted birth weight. Lower unadjusted birth weight and lower gestational age in exposed children.	Exposed participants recruited through advertisement
(Clements et al., 2000)	20 children exposed to MRI *in utero*, and 35 unexposed children	Develop-ment at 9 month of age	Cohort	Four MRI scans *in utero*	Small decrease in length, increase in gross motor function.	Subject selection procedure not described. Statistical analyses are questionable.
Musculoskeletal system						
(Moen et al., 1995) (Moen et al., 1996)	342 exposed potroom workers in an aluminium plant and 277 unexposed workers from the same plants	Symptoms of musculo-skeletal system	Cohort	SMF: 3 - 20 mT and ELF ripple components	Musculo-skeletal symptoms from neck, shoulders, arms: OR=0.9 (0.3 - 4.0). Musculo-skeletal symptoms from back, hips, legs: OR=1.1 (0.3 - 3.2).	Possible exposure to coal tar pitch. Selection bias may be present if health is a consideration in the selection of workers to work in the potroom. Minor health problems may not be included in study (probably not reported to health care unit).