

## Power frequency electromagnetic fields: summary of epidemiologic evidence

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### 1. Overall summary

This section summarizes epidemiologic evidence cited in the tables below and will be updated as new evidence becomes available. I would appreciate feedback on any errors or omissions. [don.wigle@sympatico.ca](mailto:don.wigle@sympatico.ca)

Health effect	Level of evidence <sup>a</sup>	Comments
Early fetal death (spontaneous abortions)	Postconceptual maternal expos, VDTs Inadequate	A literature review and a meta-analysis of 7 case-control studies (Brent et al. 1993, Parazzini et al, 1993) both concluded that early fetal death was not associated with self-reported postconceptual VDT use or intensity of use. A retrospective cohort study of US telephone operators found no association between early fetal death and maternal 1 <sup>st</sup> trimester VDT use (Schnorr et al 1991). A Finnish case-control study (nested within a cohort of clerical workers) not included in the meta-analysis by Parazzini found a dose-response relationship between early fetal death and measured average magnetic field levels of 17 different VDT models in use ((Lindbohm et al. 1992). Two reviews during 1994-1995 concluded that there was little evidence for an association between early fetal deaths and occupational VDT use or intensity of use (Delpizzo 1994, Lindbohm and Hietanen 1995). A hospital-based case-control study in Italy found no association between early fetal deaths and self-reported postconceptual VDT use or intensity of use (Grasso et al. 1997). A 1998 review of epidemiologic studies concluded that there was limited evidence for an association between early fetal death and exposure to magnetic fields at home or work of at least 0.3 $\mu$ T (Huuskonen et al.). Two recent reviews both concluded that there is inadequate evidence for an association between early fetal deaths and postconceptual maternal VDT use or residential magnetic field exposure (Shaw 2001, Ahlbom et al. 2001).
	Residential magnetic fields (Inadequate)	Relatively small case-control studies in Finland and Colorado incorporated direct measures of residential magnetic fields but had inconsistent findings. The Finnish case-control study (nested within a cohort of healthy women trying to become pregnant) of early fetal deaths found associations with measured front door and interior residential magnetic field levels (Juutilainen et al. 1993) but the Colorado study found no association with measured front door fields or wire codes (Savitz and Ananth 1994). A cohort study in Connecticut found no association between early fetal death and maternal residential wire codes (Belanger et al. 1998). An expert panel concluded in 1997 that there was inadequate evidence for an association between adverse pregnancy outcomes in humans and residential 60 Hz magnetic fields (National Academy of Sciences 1997). A 1998 review of epidemiologic studies concluded that there was limited evidence for an association between early fetal death and exposure to magnetic fields at home or work of at least 0.3 $\mu$ T (Huuskonen et al.). Two recent reviews both

	<p>Electric appliance use (Inadequate)</p> <p>Maternal prenatal personal magnetic fields (Limited)</p> <p>Experimental animal studies</p>	<p>concluded that there is inadequate evidence for an association between early fetal deaths and postconceptual maternal VDT use or residential magnetic field exposure (Shaw 2001, Ahlbom et al. 2001).</p> <p>A cohort study in Connecticut found a borderline association between early fetal death and maternal postconceptual electric blanket use but not with heated waterbed use (Belanger et al. 1998). A prospective cohort study of over 5,000 Californian women during the 1<sup>st</sup> trimester of pregnancy found no associations between early fetal deaths and self-reported use or intensity of use of electric blankets or waterbeds (Lee et al. 2000). In a recent California cohort study, early fetal death was associated with postconceptual hot tub or whirlpool bath use, especially during very early pregnancy; there was a dose-response relationship between early fetal deaths and frequency of hot tub or whirlpool use (Li et al. 2003). Hot tub and whirlpool bath use involves both heating and power frequency magnetic field exposure.</p> <p>A nested case-control and a prospective cohort study in California both found associations and dose-response relationships between early fetal death and 24-hour personal magnetic field indices (Lee et al. 2002, Li et al. 2002). The associations were stronger for the relation between early fetal death and maximum and rate of change 24-hr personal magnetic fields (as opposed to time-weighted average fields). The prospective cohort study found that the relationship was stronger for fetal deaths before gestation week 10, for women with a history of previous miscarriages and for women with longer cumulative exposure above 1.6 <math>\mu</math>T (Li et al. 2002). Savitz (2002) speculated that the higher 24-hour personal magnetic fields among women who had early fetal deaths may have reflected behavioural differences between cases and controls in the study by Lee et al. (2002); case exposures were measured several months after miscarriage whereas controls were in their 3<sup>rd</sup> trimester and less mobile. Savitz also conjectured that the association in the prospective cohort study by Li et al. (2002) may have reflected lower mobility among women with nausea of pregnancy who are at lower risk of early fetal death.</p> <p>Two reviews of studies of animals prenatally exposed to power frequency magnetic fields concluded that there was inconsistent evidence of increased early fetal deaths (resorptions) and little evidence of other adverse pregnancy outcomes (Huuskonen et al. 1998, Brent 1999).</p>
Late fetal death (stillbirths)	Maternal prenatal exposure Inadequate	A California case-control study found <i>inverse</i> associations between late fetal deaths and maternal prenatal occupational VDT use (Pastore et al. 1997). An expert panel concluded in 1997 that there was inadequate evidence for an association between adverse pregnancy outcomes in humans and residential 60 Hz magnetic fields (National Academy of Sciences 1997).

	Paternal occupl exposure (Inadequate)	A Swedish cohort study found no increased risk of late fetal deaths among offspring of male electrical workers (Tornqvist 1998).
Intrauterine growth retardation (IUGR)	Maternal prenatal exposure Inadequate	A cohort study of women in the 1 <sup>st</sup> trimester of pregnancy found a weak association of borderline statistical significance between IUGR and prenatal maternal use of electrically heated beds but no associations with use of VDTs, residential wire codes or 7-day personal average magnetic field levels (Bracken et al. 1995). A review by Lindbohm (1995) noted that 3 of 4 epidemiologic studies found no association between fetal growth retardation and maternal postconceptual VDT use. Two recent reviews concluded that there is inadequate evidence of an association between IUGR and residential or occupational power frequency magnetic fields (Huuskonen et al. 1998, Shaw 2001). A review of experimental studies concluded that there was little evidence for an effect of power frequency EMF on growth retardation in experimental animals (Brent 1999).
Preterm birth	Maternal prenatal exposure Inadequate	A small case-control study of preterm birth in Denver found no association with spot magnetic field levels or wire codes (Savitz and Ananth 1994). A cohort study of telephone operators in United States found no relationship between preterm birth and use or intensity of use of VDTs (Grajewski et al. 1997). Two recent reviews concluded that there is inadequate evidence of an association between preterm birth and residential or occupational power frequency magnetic fields (Huuskonen et al. 1998, Shaw 2001).
Low birth weight	Maternal prenatal exposure Inadequate	A pooled analysis of two other case-control studies of low birth weight (McDonald et al. 1988, Windham et al. 1990) found no association with maternal prenatal VDT use (Parazzini et al. 1993). A small case-control study of low birth weight in Denver found no association with spot magnetic field levels or wire codes (Savitz and Ananth 1994). A cohort study of women in the 1 <sup>st</sup> trimester of pregnancy found no association between low birth weight and prenatal maternal use of electrically heated beds or VDTs, residential wire codes or 7-day personal average magnetic field levels (Bracken et al. 1995). A cohort study of telephone operators in United States found no relationship between low birth weight and use or intensity of use of VDTs (Grajewski et al. 1997). Two recent reviews concluded that there is inadequate evidence of an association between low birth weight and residential or occupational power frequency magnetic fields (Huuskonen et al. 1998, Shaw 2001). A review of experimental studies concluded that there was little evidence for an effect of power frequency EMF on fetal growth retardation in experimental animals (Brent 1999).
	Paternal occupl exposure (Inadequate)	A Swedish cohort study of men in the electric power industry found no increased risk of low birth weight offspring (Tornqvist 1998).

Total birth defects	Maternal prenatal exposure Inadequate	A pooled analysis of 5 case-control studies of birth defects reported during 1985-1991 found no association with maternal postconceptual occupational use of VDTs (Parazzini et al. 1993). Similarly, a review by Brent et al. (1993) observed that 7 of 9 epidemiologic studies found no association between birth defects and postconceptual VDT use. A review by Lindbohm and Hietanen (1995) noted that 5 of 6 epidemiologic studies found no association between birth defects and maternal postconceptual VDT use. A small case-control study of birth defects in France found no association with residential proximity to high-voltage power lines (Robert et al. 1996). Reviews by Huuskonen et al. (1998) and (Shaw 2001) concluded that there is inadequate evidence for an association between birth defects and residential or occupational power frequency EMF exposure. Other reviewers (Brent et al. 1999) concluded that animal studies provide little evidence for an association between power frequency EMF and birth defects or other adverse pregnancy outcomes. A Norwegian ecologic study found no association between all birth defects combined and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003).
	Paternal occuptl exposure (Inadequate)	A Swedish cohort study found no association with paternal employment in the electrical power industry (Tornqvist 1998).
Neural tube birth defects	Maternal prenatal exposure (Inadequate)	A case-control study in New York State found no association between neural tube birth defects (NTDs) and maternal use of electric blankets or heated waterbeds (Dlugosz et al. 1992). A cohort study in the northeastern United States found a borderline association between NTDs and maternal 1 <sup>st</sup> trimester heat exposure (electric heat from a sauna, hot tub or electric blanket or a febrile illness) and a significant association with 1 <sup>st</sup> trimester hot tub use (Milunsky et al. 1992). Heat is a known animal teratogen, raising the possibility that the association reported by Milunsky may have been caused by heat <i>per se</i> and not the associated EMF. A Dutch case-control study found no link between spina bifida and paternal occupational EMF exposure but there were only 4 exposed case fathers (Blatter et al. 1997). A large case-control study of NTDs in California found an association with postconceptual maternal use of electric blankets but not heated waterbeds; a smaller case-control study by the same authors found no association with maternal postconceptual use of electric blankets or heated waterbeds (Shaw et al. 1999). A retrospective cohort study found an association between spina bifida and maternal occupational EMF exposure (Blaasaas et al 2002). A Norwegian ecologic study found no association between NTDs and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003). A case-control study in Norway found no association between CNS birth defects and prenatal maternal residential proximity to power lines (Blaasaas et al 2004).
	Paternal occuptl	A retrospective cohort study found no association between spina bifida paternal occupational EMF

	exposure (Inadequate)	exposure (Blaasaas et al 2002).
Genitourinary birth defects	Maternal prenatal exposure (Inadequate)	A review of 9 epidemiologic studies by Brent et al. (1993) noted an association between urinary tract birth defects and occupational VDT use during early pregnancy in a Montreal cohort study. A case-control study of urinary tract birth defects in Washington State found no association with prenatal maternal use of electric blankets, electrically heated waterbeds or VDTs (Li et al. 1995). A Norwegian ecologic study found no association between cleft lip and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003).
	Paternal occuptl exposure (Inadequate)	A Swedish cohort study found a non-significant imprecise association between hypospadias and paternal employment in the electrical power industry (Tornqvist 1998).
Cardiovascular birth defects	Maternal prenatal exposure (Inadequate)	A Norwegian ecologic study found no association between cardiac birth defects and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003). However, a case-control study in Norway found a borderline association between cardiac birth defects and prenatal maternal residential proximity to power lines (Blaasaas et al 2004).
Orofacial birth defects	Maternal prenatal exposure (Inadequate)	A case-control study in New York State found no association between oral clefts and maternal use of electric blankets or heated waterbeds (Dlugosz et al. 1992). A large case-control study of orofacial birth defects in California found no association between isolated cleft lip ( $\pm$ cleft palate) or isolated cleft palate and postconceptual maternal use of electric blankets or heated waterbeds (Shaw et al. 1999). This study did find a borderline association between cleft lip ( $\pm$ cleft palate) combined with other birth defects in the same individuals and maternal postconceptual heated waterbed use but there was no dose-response relationship. A retrospective cohort study found an association between cleft lip and maternal occupational EMF exposure (Blaasaas et al 2002).
	Paternal occuptl exposure (Inadequate)	A retrospective cohort study found no association between cleft lip and paternal occupational EMF exposure (Blaasaas et al 2002).
Other birth defects	Maternal prenatal exposure (Inadequate)	A Norwegian ecologic study found a borderline association between esophageal birth defects and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003). A case-control study in Norway found no association between respiratory defects or clubfoot and prenatal maternal residential proximity to power lines (Blaasaas et al 2004).

Childhood leukemia: recent meta-analyses and literature reviews	Residential expos, high wire code Limited and inconsistent	Several meta-analyses found an association between childhood leukemia and residential wire code categories (Miller et al. 1995, Meinert and Michaelis 1996, Wartenberg 1998, Angelillo and Villari 1999, Greenland et al. 2000). In a pooled analysis of two North American studies, Ahlbom et al. (2000) found a non-significant association between childhood leukemia and wire codes. A subsequent review of six North American studies noted that childhood leukemia was associated with wire codes in three studies and that the association was not explainable by residential mobility, social class or neighbourhood characteristics (Savitz and Poole 2001). These authors did note, however, that ambiguity persists because of modest associations, inconsistent findings, complex relationships between wire codes and magnetic fields, limited knowledge of risk factors for childhood leukemia and limited evaluation of wire code covariates.
	Residential proximity, high-voltage power lines Inadequate	Two meta-analyses found an association between childhood leukemia and proximity to high-voltage power lines (Washburn et al. 1994, Miller et al. 1995). More recent meta-analyses have shown borderline or non-significant associations between childhood leukemia and proximity to high-voltage power lines (Meinert and Michaelis 1996, Wartenberg 1998, Angelillo and Villari 1999, Wartenberg 2001).
	Residential expos, measured or calculated magnetic fields Limited	Spot measurements of residential magnetic fields were not associated with childhood leukemia in three meta-analyses (Miller et al. 1995, Wartenberg 1998, Angelillo and Villari 1999). Several meta-analyses found an association between childhood leukemia and 24-hour or calculated residential magnetic fields (Meinert and Michaelis 1996, Wartenberg 1998, Angelillo and Villari 1999, Greenland et al. 2000, Wartenberg 2001). In a recent pooled analysis of individual records from 11 studies, Greenland et al. (2000) found that the association between childhood leukemia and residential magnetic fields persisted after adjustment for potential confounders including age, sex and socioeconomic status).
		<i>General conclusions</i> Based mainly on the limited epidemiologic evidence of an association between childhood leukemia and power frequency magnetic fields, expert groups and reviewers have concluded that power frequency EMF is a possible human carcinogen (National Institute of Environmental Health Sciences 1999, National Radiological Protection Board 2001, Ahlbom et al. 2001, International Agency for Research on Cancer 2002, Linet et al. 2003, Habash et al. 2003). The association between childhood leukemia and power frequency magnetic fields was largely limited to a small proportion of cases with average 24-hour exposures above 0.3-0.4 $\mu\text{T}$ (Ahlbom et al. 2000, Greenland et al. 2000). The International Agency for Research on Cancer (2002) noted that there is inadequate evidence for associations between childhood cancers other than leukemia and power frequency magnetic fields.
Childhood CNS tumours	Residential expos,	A population-based case-control study in Los Angeles found an association between childhood brain

	high wire code Inadequate	tumours and underground wires but not other residential wire code categories (Preston-Martin et al. 1996b). Similarly, a case-control study in Washington State (based on a subset of the subjects in the previous study) found no associations between childhood brain tumours and wire codes (Gurney et al. 1996). A meta-analysis of 3 epidemiologic studies (two in Denver, one in California and Washington State) found no association between childhood CNS tumours and two-level wire codes (Meinert and Michaelis 1996). A review (Kheifets et al. 1999) noted that two west-coast studies failed to replicate the association between childhood brain tumours and wire codes reported by two studies conducted in Denver.
	Residential proximity, high-voltage power lines (Inadequate)	A meta-analysis of 7 epidemiologic studies found an association between childhood CNS tumours and residential proximity to electric power transmission and distribution lines (Washburn et al. 1994). A case-control study nested within census cohorts of children living in regions crossed by high-voltage power lines in Norway found no association between childhood CNS tumours and residential proximity to high-voltage power lines (Tynes and Haldorsen 1997). A review by Kheifets et al. (1999) noted that 3 of the 4 epidemiologic studies of childhood brain tumours and residential proximity to power lines found no association while the fourth study found a borderline association.
	Residential expos, measured or calculated magnetic fields Inadequate	A population-based case-control study in Los Angeles found no association between childhood brain tumours and 24-hour magnetic field levels in the children's bedrooms (Preston-Martin et al. 1996b). A meta-analysis of 6 epidemiologic studies found no association between childhood CNS tumours and residential average magnetic fields (Meinert and Michaelis 1996). A case-control study nested within census cohorts of children living in regions crossed by high-voltage power lines in Norway found no association between childhood CNS tumours and calculated lifetime average residential magnetic fields (Tynes and Haldorsen 1997). A large population-based case-control study in the UK found no association between incident childhood CNS cancers and average residential magnetic fields during the year before diagnosis (UK Childhood Cancer Study Investigators 1999). Three literature reviews concluded that there is inadequate evidence for an association between childhood brain tumours and measured or calculated residential magnetic fields (Kheifets et al. 1999, National Institute of Environmental Health Sciences 1999, Ahlbom et al. 2001).
	Parental occuptl expos (Inadequate)	A small case-control study in Ohio found an association between childhood brain tumours and paternal occupation as welder but no association with overall paternal occupations exposed to magnetic fields (Wilkins and Wellage 1996). A large population-based case-control study in the UK found no association between childhood brain cancer deaths and maternal prenatal occupational magnetic field exposure (Sorahan et al. 1999). A census-based birth cohort study (Feychting et al. 2000) found no association between childhood CNS cancer and maternal or paternal occupational magnetic field exposure; exposure was inferred from census-based information on occupation and industry and survey

		data on average magnetic fields in various occupations. A review by Linet et al. (2003) concluded that there is limited evidence for an association between childhood brain tumours and paternal occupational magnetic field exposure.
	Electrical appliances (Inadequate)	A population-based case-control study in Los Angeles found a borderline association between childhood brain tumours and prenatal but not childhood use of electrically heated waterbeds; there was no association with prenatal or childhood use of electric blankets (Preston-Martin et al. 1996b). A large population-based case-control study in west-coast States found no association between childhood brain tumours and maternal prenatal or childhood use of electric blankets or heated waterbeds (Preston-Martin et al. 1996a). Similarly, a case-control study in Washington State (based on a subset of the subjects in the previous study) found no associations between childhood brain tumours and maternal prenatal or childhood use of electric blankets or heated waterbeds (Gurney et al. 1996). A small case-control study in New Zealand found no association between childhood CNS tumours and prenatal or childhood use of electric blankets, heated waterbeds or VDTs; there was an association with electric heating in children's day room but not with such heating in their bedroom (Dockerty et al. 1998). A population-based case-control study in Germany found an association between medulloblastoma but not total CNS tumours and maternal prenatal electric blanket use (Schuz et al. 2001b).
	Electric fields (Inadequate)	A population-based case-control study in the UK found no overall association between childhood CNS tumours and spot electric field levels in the children's bedrooms; there was a borderline association with spot electric fields in the subset of subjects with verified electric field measurements (Skinner et al. 2002).
Childhood lymphomas	Inadequate	A meta-analysis of 5 epidemiologic studies of childhood lymphomas found a borderline association with residential proximity to electric power transmission and distribution equipment (Washburn et al. 1994). A subsequent meta-analysis of 5 epidemiologic studies (including 4 studies also assessed by Washburn et al. 1994) found a non-significant association between childhood lymphomas and average residential magnetic fields (Meinert and Michaelis (1996). A census-based birth cohort study (Feychting et al. 2000) found no association between childhood lymphomas (there were only 40 cases) and maternal or paternal occupational magnetic field exposure; exposure was inferred from census-based information on occupation and industry and survey data on average magnetic fields in various occupations. Two recent reviews both concluded that there is inadequate epidemiologic evidence for an association between childhood lymphomas and residential magnetic field indices (National Institute of Environmental Health Sciences 1999, Ahlbom et al. 2001).
Kidney cancer	(Inadequate)	A Swedish census-based birth cohort study (Feychting et al. 2000) found no association between childhood kidney cancer (there were only 28 cases) and maternal or paternal occupational magnetic

		field exposure; exposure was inferred from census-based information on occupation and industry and survey data on average magnetic fields in various occupations.
Neuroblastoma	(Inadequate)	A Swedish census-based birth cohort study (Feychting et al. 2000) found no association between childhood neuroblastoma (there were only 25 cases) and maternal or paternal occupational magnetic field exposure; exposure was inferred from census-based information on occupation and industry and survey data on average magnetic fields in various occupations. A large case-control study of childhood neuroblastoma in United States and Canada found no overall association with maternal or paternal occupational magnetic field exposure but did find a borderline association with paternal occupational exposure to magnetic fields above 0.4 $\mu$ T; magnetic field exposure was estimated from self-reported occupational history and published estimates of average occupation-specific exposures (De Roos et al. 2001).
Other childhood cancers	(Inadequate)	A case-control study nested within census cohorts of children living in regions crossed by high-voltage power lines in Norway found a dose-response relationship between childhood cancers other than leukemia or brain and residential proximity to high-voltage power lines; this study also found a borderline association between such cancers and estimated lifetime average residential magnetic fields (Tynes and Haldorsen 1997).

<sup>a</sup> Sufficient evidence = based on peer-reviewed reports of expert groups or authoritative reviews that concluded that a causal relationship existed; limited evidence = relationships for which several epidemiologic studies, including at least one case-control or cohort study, found fairly consistent associations and evidence of exposure-risk relationships after control for potential confounders; inadequate evidence = relationships for which epidemiologic studies were limited in number and quality (e.g., small studies, ecologic studies, limited control of potential confounders), had inconsistent results, or found little or no evidence of exposure-risk relationships. Levels in parentheses are the author's interpretation of available evidence; other levels are based on expert group reviews.

**2. Fetal death**

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
(Schnorr et al. 1991), USA	Retrospective cohort study, 730 married telephone operators, enrolled during 1987-1988; self-reported reproductive history	VDTs were used by directory-assistance but not general operators	Early fetal death not associated with maternal 1 <sup>st</sup> trimester VDT use; odds ratio	0.9 (0.6-1.4)		Previous spontaneous abortion, alcohol, smoking, thyroid disease
(Lindbohm et al. 1992), Finland	Case-control study nested within cohort of clerical workers employed during 1975-1985, age 20-35 yr; 191 cases of early fetal death, 394 matched control healthy live births; linked employment and national pregnancy database to identify pregnancy outcomes	Self-reported VDT use, employer information on VDT models, measured magnetic fields on sample of 17 VDT models	Early fetal death associated with VDT use (odds ratios for ever/never use)	1.1 (0.7-1.6)		Matched for YOB, maternal age
			Early fetal death associated with intensity of VDT use (odds ratios for 11-20 and >20 vs ≤10 hr/wk)	1.7 (0.9-3.4) 2.0 (0.8-3.7)		As above
			Early fetal death associated with magnetic field exposure (odds ratios for 0.4-0.9 and >0.9 vs <0.4 μT)	1.9 (0.9-3.9) 3.4 (1.4-8.6)		Hr/wk VDT use, quantity of work, frequency of equipment breakdown, organic solvent

<sup>1</sup> Entries in this column include odds ratios, relative risks and certain other statistical measures of association as published in original epidemiologic studies; an entry of '+' means the measure of association was not an odds ratio or relative risk and was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

<sup>2</sup> 'DR' refers to a dose-response relationship in an epidemiologic study; an entry of '+' means the measure of dose-response relationship used in the citation was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
						exposure, parity, previous miscarriage, IUD use
(Parazzini et al. 1993), Italy	Meta-analysis of 9 case-control studies of pregnancy outcomes and VDT use published during 1985-1991; analyzed pooled data		Early fetal death not associated with VDT use during pregnancy (pooled odds ratio)	1.0 (0.9-1.0)		
			No dose-response relationship between early fetal death and VDT use during pregnancy (pooled odds ratios for <20 and ≥20 vs 0 hr/wk; calculated from data in report)	1.34 1.02		
(Juutilainen et al. 1993), Finland	Case-control study nested within cohort of 443 healthy women attempting to become pregnant; 89 cases spontaneous abortion, 102 term live birth controls	Spot residential magnetic field measurements at front door and indoors including parents' bedroom; self-reported occupations	Spontaneous abortion associated with magnetic fields at residence front door (odds ratios for 0.13-0.62 and ≥0.63 vs ≤0.12 μT)	1.0 (0.6-1.9) 5.1 (1.0-26)		Smoking
			Spontaneous abortion associated with avg indoor magnetic fields (odds ratios for 0.06-0.24 and ≥0.25 vs <0.06 μT)	0.8 (0.4-1.9) 4.7 (0.9-25)		
(Brent et al. 1993), USA	Review of literature on epidemiologic and toxicologic studies of pregnancy outcomes and power frequency magnetic	Exposures in human studies included VDTs, power lines and household electric appliances; rarely measured	10 of 12 epidemiologic found no association between early fetal death and postconceptual VDT use			

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
	fields	exposure directly and often had small sample sizes				
			4 studies of early fetal death and residential EMF sources found little evidence for an association			
(Savitz and Ananth 1994), Denver, Colorado	Case-control study, self-reported pregnancy outcomes of mothers of subjects in a case-control study of childhood cancer; 52 cases early fetal death	Spot EMF measurements and wire code assessments at maternal residence during pregnancy	Early fetal death not associated with spot magnetic field levels (odds ratio, $\geq 0.2$ vs $< 0.2 \mu\text{T}$ )(4 exposed cases)	0.8 (0.3-2.3)		
			Early fetal death not associated with wire code (odds ratio, high vs low current)(6 exposed cases)	0.7 (0.3-1.8)		
(Delpizzo 1994), Australia	Review of literature (1985-1992) on adverse pregnancy outcomes and occupational exposure to video display terminals	Whole-body exposure to VDT operators is usually below $0.1 \mu\text{T}$ but in a few cases may be as high as $0.2-0.3 \mu\text{T}$	Limited and inconsistent evidence for an association between early fetal deaths and occupational use of VDTs; a few studies found some evidence of an association but little evidence of a dose-response relationship			
(Lindbohm and Hietanen 1995), Finland	Review of literature on pregnancy outcome and postconceptual occupational VDT use	Range of measured magnetic fields 50 cm from VDTs was $0.09-0.6 \mu\text{T}$	7 of 9 epidemiologic studies found no association between early fetal death and maternal postconceptual VDT use			

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
			Among the 2 studies with some direct measurements of VDT magnetic fields, one found an association between early fetal death and measured fields and the other did not			
			Among the 2 studies that measured residential magnetic fields, one found an association between early fetal death and measured fields and the other did not			
			Little evidence of an association between early fetal death and exposure to electric blankets, heated waterbeds or ceiling cable heat			
(Pastore et al. 1997), California	Case-control study, 332 stillbirths (gestation wk $\geq$ 20), 357 live birth controls	Parent-reported exposure information	Inverse or borderline inverse associations between stillbirths and occupational use of VDTs during 1 <sup>st</sup> , 2 <sup>nd</sup> or 3 <sup>rd</sup> trimester (odds ratios)	0.6 (0.3-1.1) 0.5 (0.3-1.0) 0.4 (0.2-0.8)		County of residence, per capita income, smoking, alcohol, maternal race, age, previous pregnancy loss
(Grasso et al. 1997), Milan, Italy	Hospital-based case-control study, 508 spontaneous abortion cases (pathologically verified), age 17-44 yr, 1,148 healthy term live birth controls	Self-reported VDT use	Early fetal deaths not associated with VDT use (odds ratio, ever vs never use)	1.1 (0.8-1.4)		Maternal age, education, marital status, previous miscarriage, alcohol, coffee, 1 <sup>st</sup> trimester

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
						smoking
			No dose-response relationship (odds ratios, <11, 11-20 and ≥20 vs 0 hr/wk)	1.0 (0.7-1.5) 1.0 (0.6-1.6) 1.1 (0.8-1.6)		As above
(National Academy of Sciences 1997), USA	Expert panel review of potential health effects of residential 60-Hz electric and magnetic fields	The most appropriate EMF exposure metric for human health studies is unknown; wire codes are only weakly correlated with measured residential magnetic field levels and are associated with housing age and density and neighbourhood traffic density	There is inadequate epidemiologic evidence for an association between adverse pregnancy outcomes and 60 Hz EMF			
(Belanger et al. 1998), Connecticut	Prospective cohort study, 2,967 women from private practices and two HMOs; 135 spontaneous abortions (gestation < 28 wk) during follow-up	Exposure information from interview during 1 <sup>st</sup> trimester; measured Wertheimer-Leeper wire codes, electric blanket use	Borderline association between early fetal death and electric blanket use at interview; somewhat stronger association for temperature setting (odds ratios for any use and for low and high settings vs no use)	any use 1.6 (0.8-3.2) low setting 1.1 (0.3-1.6) high setting 2.1 (0.7-1.8)		Ethnicity, maternal age, gestational age at interview, caffeine
			Early fetal death not associated with heated waterbed use at interview	0.6 (0.4-1.1)		As above
			Early fetal death not associated with wire code (odds ratios for increasing categories vs buried	1.0 (0.6-1.6) 0.6 (0.4-1.0) 0.7 (0.4-1.2)		As above

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
			wires)	0.4 (0.1-1.1)		
(Tornqvist 1998), Sweden	Two cohort studies: 2077 infants of men who likely worked in the electric power industry at time of conception and 1273 infants of unexposed men and a prospective cohort study involving 178 infants of men with high occupational power frequency EMF exposures, 62 infants of men with intermediate EMF exposure and 186 infants of men with low EMF exposure; pregnancy outcome data from birth, birth defect and cancer registries	Linked birth records to census records to identify paternal occupational exposure; identified electrical workers in the power industry; conducted 278 full-shift EMF measurements involving 16 work tasks, self-reported information on % of time on each work task	Stillbirths not elevated among offspring of electrical workers in the power industry (risk relative to general population)	1.1 (0.6-2.0)		YOB, maternal age, parity
(Huuskonen et al. 1998), Finland	Review of literature on teratogenic and reproductive effects of low-frequency magnetic fields	Animal experiments do not suggest strong effects of ELF magnetic fields on fetal development; inconsistent evidence of increased early fetal deaths (resorptions)	Limited epidemiologic evidence of an association between early fetal death and exposure to magnetic fields > 0.3 $\mu$ T			
(Brent 1999), USA	Review of developmental effects of low-frequency EMF in experimental systems and animals		In experimental mammalian animals prenatally exposed to EMF, there was little evidence of fetal death, birth defects, reduced fetal growth or neurobehavioural abnormalities			
(Lee et al.	Prospective cohort study, 5,342	Self-reported use of electric	Early fetal death not associated	0.8 (0.6-1.2)		Maternal age,

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
2000), Kaiser Permanente Medical Care Program, California	women age 18+ in 1 <sup>st</sup> trimester; medical record documented early fetal deaths (gestation ≤ 20 wk)	blankets (10%) and electric waterbed heaters (15%) during 1 <sup>st</sup> trimester; avg overnight magnetic fields at middle body surface based on testing of 4 electric blankets at low, medium or high settings were 0.1, 1.5 and 2.0 μT	with electric blanket or waterbed use (respective odds ratios)	1.0 (0.7-1.3)		race, income, heat on at night, perceived health, tap water use, alcohol, smoking, caffeine, location, gestational age at interview
			No dose-response relationship with temperature setting of either device (odds ratio for low, medium, high vs non-user)	0.7 (0.5-1.1) 0.7 (0.4-1.0) 1.1 (0.8-1.6)		
(Shaw 2001), USA	Review of literature on developmental outcomes and power-frequency EMF	There are too few studies using direct measures of EMF exposure and pregnancy outcome to draw firm conclusions	VDT use does not appear to substantially increase the risk of early fetal death			
						Too few findings from studies of occupational EMF exposure and pregnancy outcome to draw firm conclusions
						Equivocal findings from studies of residential EMF exposure and early fetal death
(Ahlbom et al. 2001), International Commission	Review of epidemiologic literature on EMF and health		Among pregnancy outcomes, only early fetal deaths have been assessed in several studies of reasonable quality and the			

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
for Non-Ionizing Radiation Protection			evidence suggests no association with maternal power frequency EMF exposure			
			Evidence from animal and epidemiologic studies offer little reason for further research on pregnancy outcomes and power frequency EMF exposure			
(Lee et al. 2002), Kaiser Permanente Medical Care Program, northern California	Nested case-control study within cohort recruited by Swan et al (Swan et al. 1998), 155 spontaneous abortion cases (gestation wk < 20), 509 controls still living in same home as during 1 <sup>st</sup> trimester	Evaluated wire codes and magnetic field levels through spot measures at 4 areas in home and 24-hr personal dosimetry; measurements occurred several mos after miscarriage (cases) or during late pregnancy (controls); assessed avg difference between consecutive levels (a rate-of-change metric), maximum level and time-weighted avg	Early fetal death associated with time-weighted avg 24-hr personal magnetic fields (odds ratios for 0.072-0.092, 0.093-0.127 and $\geq 0.128$ vs <0.072 $\mu\text{T}$ ); no dose-response relationship	1.7 (0.9-3.3) 1.7 (0.9-3.3) 1.7 (0.9-3.2)		Maternal age, gestation wk at interview, coffee at conception, income, race
			Early fetal death associated with 24-hr personal magnetic field rate of change (odds ratios for rate-of-change of 0.043-0.061, 0.062-0.093 and $\geq 0.094$ vs <0.043 $\mu\text{T}$ )	1.5 (0.8-3.1) 2.3 (1.2-4.4) 3.1 (1.6-6.0)	+	As above
			Early fetal death associated with 24-hr personal magnetic fields maximum levels (odds ratios for 1.431-2.341, 2.342-	1.4 (0.7-2.8) 1.9 (1.0-3.5) 2.3 (1.2-4.4)	+	As above

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
			3.504 and $\geq 3.505$ vs $< 1.431$ $\mu\text{T}$ )			
			Early fetal death not associated with wire codes or area measures (odds ratio, VHCC vs other)	1.2 (0.7-2.2)		Maternal age, gestation wk, prior fetal loss, race, smoking, alcohol and coffee at LMP, BMI, income
(Li et al. 2002), Kaiser Permanente Medical Care Program, northern California	Population-based prospective cohort study, 969 women with positive pregnancy test at gestation wk $\leq 10$ ); pregnancy outcomes identified through health records and telephone follow-up	Interviews, personal magnetic field dosimeter worn for 24 hr, activity diary	Early fetal death associated with 24-hr max personal magnetic field (odds ratio, $\geq 1.6$ vs $< 1.6$ $\mu\text{T}$ )	1.8 (1.2-2.7)		Previous miscarriage, education, maternal age, gravidity, race, smoking since LMP
			Association between early fetal death and 24-hr max personal magnetic field stronger for women with previous miscarriage (odds ratio, $\geq 1.6$ vs $< 1.6$ $\mu\text{T}$ )	3.1 (1.3-7.7)		As above
			Fetal death before gestation wk 10 associated with 24-hr max exposure (odds ratios for $\geq 1.6$ vs $< 1.6$ $\mu\text{T}$ )	0-9 wk 2.2 (1.2-4.0)		As above
				$\geq 10$ wk 1.4 (0.8-2.5)		
			Early fetal death associated	1.7 (1.1-2.8)		As above

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
			with duration of exposure over 1.6 $\mu$ T during 24-hr (odds ratios for 16-107, 108-475 and $\geq$ 476 vs <16 $\mu$ T.sec)	1.8 (1.1-2.9)	2.0 (1.2-3.1)	
(Savitz 2002), USA	Commentary on epidemiologic studies of early fetal death and magnetic fields	Residential exposure to electric blankets, heated waterbed or ceiling cable heat	Inconsistent evidence for an association between early fetal death			
		General residential magnetic field exposures	Conflicting evidence from two studies of early fetal deaths			
		Occupational exposure to VDTs; most do not increase exposure to power frequency magnetic fields	Most studies of early fetal deaths found no association with VDT use			
			Lindbohm et al. (1992) found an association between early fetal deaths and VDTs with the highest measured magnetic fields			
		Personal dosimetry	Savitz speculated that the higher 24-hr personal magnetic fields among women who had early fetal deaths may have reflected behavioural differences between cases and controls in the study by Lee et al. (2002)(see above); case exposures were measured several months after			

Reference, location	Design	Exposure	Results	Association <sup>1</sup>	DR <sup>2</sup>	Covariates
			miscarriage whereas controls were in their 3 <sup>rd</sup> trimester and less mobile			
			Conjectured that the association in the prospective cohort study by Li et al. (2002) (see above) may have reflected lower mobility among women with nausea of pregnancy who are at lower risk of early fetal death			
(Li et al. 2003), California [ordered]	Cohort study, 1,063 women enrolled in the Kaiser Permanente Medical Care Program in Oakland; identified fetal deaths before gestation wk 20	Self-reported information on hot tub or whirlpool bath use	Early fetal death associated with postconceptual hot tub or whirlpool bath use (odds ratio, yes/no)	2.0 (1.3-3.1)		
			Dose-response relationship between early fetal death and postconceptual hot tub or whirlpool bath use (odds ratios for <1, 1 and 2+ vs 0/wk)	1.7, 2.0, 2.7	+	
			Early fetal death associated with very early gestational hot tub or whirlpool bath use (odds ratios for initial use during wk 1-4 and wk 5+ vs no use)	2.3, 1.5		

#### **Fetal death: summary**

##### *Early fetal death (spontaneous abortion)*

A literature review and a meta-analysis of 7 case-control studies (Brent et al. 1993, Parazzini et al, 1993) both concluded that early fetal death was not associated with self-reported postconceptual VDT use or intensity of use. A retrospective cohort study of US telephone operators found no association between early fetal

death and maternal 1<sup>st</sup> trimester VDT use (Schnorr et al 1991). A Finnish case-control study (nested within a cohort of clerical workers) not included in the meta-analysis by Parazzini found a dose-response relationship between early fetal death and measured average magnetic field levels of 17 different VDT models in use ((Lindbohm et al. 1992). Relatively small case-control studies in Finland and Colorado incorporated direct measures of residential magnetic fields but had inconsistent findings. A Finnish case-control study (nested within a cohort of healthy women trying to become pregnant) of early fetal deaths found associations with measured front door and interior residential magnetic field levels (Juutilainen et al. 1993) but the Colorado study found no association with measured front door fields or wire codes (Savitz and Ananth 1994). Two reviews during 1994-1995 concluded that there was little evidence for an association between early fetal deaths and occupational VDT use or intensity of use (Delpizzo 1994, Lindbohm and Hietanen 1995). A hospital-based case-control study in Italy found no association between early fetal deaths and self-reported postconceptual VDT use or intensity of use (Grasso et al. 1997). A cohort study in Connecticut found a borderline association between early fetal death and maternal postconceptual electric blanket use but not with heated waterbed use or wire codes (Belanger et al. 1998). An expert panel concluded in 1997 that there was inadequate evidence for an association between adverse pregnancy outcomes in humans and residential 60 Hz magnetic fields (National Academy of Sciences 1997). A prospective cohort study of over 5,000 Californian women during the 1<sup>st</sup> trimester of pregnancy found no associations between early fetal deaths and self-reported use or intensity of use of electric blankets or waterbeds (Lee et al. 2000). A 1998 review of epidemiologic studies concluded that there was limited evidence for an association between early fetal death and exposure to magnetic fields of at least 0.3  $\mu\text{T}$  (Huuskonen et al.). Two reviews of studies of animals prenatally exposed to power frequency magnetic fields concluded that there was inconsistent evidence of increased early fetal deaths (resorptions) and little evidence of other adverse pregnancy outcomes (Huuskonen et al. 1998, Brent 1999). Two recent reviews both concluded that there is inadequate evidence for an association between early fetal deaths and postconceptual maternal VDT use or residential magnetic field exposure (Shaw 2001, Ahlbom et al. 2001). A nested case-control and a prospective cohort study in California both found associations and dose-response relationships between early fetal death and 24-hour personal magnetic field indices (Lee et al. 2002, Li et al. 2002). The associations were stronger for the relation between early fetal death and maximum and rate of change 24-hr personal magnetic fields (as opposed to time-weighted average fields). The prospective cohort study found that the relationship was stronger for fetal deaths before gestation week 10, for women with a history of previous miscarriages and for women with longer cumulative exposure above 1.6  $\mu\text{T}$  (Li et al. 2002). Savitz (2002) speculated that the higher 24-hour personal magnetic fields among women who had early fetal deaths may have reflected behavioural differences between cases and controls in the study by Lee et al. (2002); case exposures were measured several months after miscarriage whereas controls were in their 3<sup>rd</sup> trimester and less mobile. Savitz also conjectured that the association in the prospective cohort study by Li et al. (2002) may have reflected lower mobility among women with nausea of pregnancy who are at lower risk of early fetal death. In a recent California cohort study, early fetal death was associated with postconceptual hot tub or whirlpool bath use, especially during very early pregnancy; there was a dose-response relationship between early fetal deaths and frequency of hot tub or whirlpool use (Li et al. 2003). Hot tub and whirlpool bath use involves both heating and power frequency magnetic field exposure.

#### *Late fetal death (stillbirths)*

A California case-control study found *inverse* associations between late fetal deaths and occupational postconceptual VDT use (Pastore et al. 1997). An expert panel concluded in 1997 that there was inadequate evidence for an association between adverse pregnancy outcomes in humans and residential 60 Hz magnetic fields (National Academy of Sciences 1997). A Swedish cohort study found no increased risk of late fetal deaths among offspring of male electrical workers (Tornqvist 1998).

**3. IUGR, preterm birth, low birth weight**

Reference, location	Design	Exposure	Results	Association <sup>3</sup>	DR <sup>4</sup>	Covariates
(Parazzini et al. 1993), Italy	Meta-analysis of 9 case-control studies of pregnancy outcomes and VDT use published during 1985-1991; analyzed pooled data		Low birth weight not associated with VDT use during pregnancy (pooled odds ratio, 2 case-control studies)(322 exposed cases)	1.0 (0.9-1.2)		
(Savitz and Ananth 1994), Denver, Colorado	Case-control study, self-reported pregnancy outcomes of mothers of subjects in a case-control study of childhood cancer; 16 cases low birth weight, 23 cases preterm birth	Spot EMF measurements and wire code assessments at maternal residence during pregnancy	Low birth weight not associated with spot magnetic field levels (odds ratio, $\geq 0.2$ vs $< 0.2$ $\mu\text{T}$ )(1 exposed case)	0.3 (0.0-2.4)		
			Low birth weight not associated with wire code (odds ratio, high vs low current)(2 exposed cases)	0.7 (0.2-2.3)		
			Preterm delivery not associated with spot magnetic field levels (odds ratio, $\geq 0.2$ vs $< 0.2$ $\mu\text{T}$ )(1 exposed case)	0.7 (0.1-4.0)		
			Preterm delivery not associated with wire code	0.2 (0.0-1.5)		

<sup>3</sup> Entries in this column include odds ratios, relative risks and certain other statistical measures of association as published in original epidemiologic studies; an entry of '+' means the measure of association was not an odds ratio or relative risk and was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

<sup>4</sup> 'DR' refers to a dose-response relationship in an epidemiologic study; an entry of '+' means the measure of dose-response relationship used in the citation was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

Reference, location	Design	Exposure	Results	Association <sup>3</sup>	DR <sup>4</sup>	Covariates
			(odds ratio, high vs low current)(1 exposed case)			
(Bracken et al. 1995), Connecticut	Cohort study, 2,967 pregnant women, gestation wk < 16; medical record documented gestation length and birth weight	Monitored EMF exposure among women who reported (at first interview) using electrically heated beds and a sample of unexposed women; assessed use of electric blankets, heated waterbeds, VDTs; determined wire code at conception; measured 24-hr area and 7-day personal EMF exposure at gestation wks 20, 28, and 36	Low birth weight (< 2500g) not associated with daily use of electrically heated beds at conception or during 1 <sup>st</sup> or 3 <sup>rd</sup> trimesters (respective odds ratios)	1.1 (0.6-1.8) 1.2 (0.7-2.0) 1.3 (0.7-2.3)		Maternal religion, race, height, weight, gravidity, age, work during pregnancy, 3 <sup>rd</sup> trimester smoking, caffeine
			Low birth weight not associated with VDT use during pregnancy (odds ratio, $\geq 20$ vs 0 hr/wk)	0.6 (0.3-1.1)		As above
			Low birth weight not associated with wire code (odds ratio, very high current vs buried lines)	0.8 (0.3-2.1)		As above
			Low birth weight not associated with 7-day avg personal magnetic field level (odds ratio, 0.1-0.19 and $\geq 0.2$ vs < 0.1 $\mu$ T)	0.7 (0.2-2.9) 1.4 (0.3-6.1)		As above
			Borderline associations between IUGR and daily	1.2 (0.8-1.7) 1.3 (0.9-1.9)		As above

Reference, location	Design	Exposure	Results	Association <sup>3</sup>	DR <sup>4</sup>	Covariates
			use of electrically heated beds during 1 <sup>st</sup> or 3 <sup>rd</sup> trimesters (respective odds ratios for exposure at conception or during 1 <sup>st</sup> or 3 <sup>rd</sup> trimesters)	1.3 (0.9-2.0)		
			IUGR not associated with VDT use during pregnancy (odds ratio, $\geq 20$ vs 0 hr/wk)	1.2 (0.8-1.8)		As above
			IUGR not associated with wire code (odds ratio, very high current vs buried lines)	0.8 (0.4-1.6)		As above
			IUGR not associated with 7-day avg personal magnetic field level (odds ratio, 0.1-0.19 and $\geq 0.2$ vs $< 0.1$ $\mu$ T)	0.4 (0.1-1.2) 1.2 (0.4-3.1)		As above
(Lindbohm and Hietanen 1995), Finland	Review of literature on pregnancy outcome and postconceptual occupational VDT use	Range of measured magnetic fields 50 cm from VDTs was 0.09-0.6 $\mu$ T	3 of 4 epidemiologic studies show no association between fetal growth retardation and maternal postconceptual VDT use			
(Grajewski et al. 1997), 8 southeastern	Cohort study, 707 pregnancies among 2,430 telephone operators, age 18-33 yr; self-reported	Used VDTs at work	Birth weight $< 2800$ g not associated with VDT use or with intensity of use	any use 0.9 (0.5-1.7)		Age, race, parity, gravidity, alcohol, smoking, infant sex,

Reference, location	Design	Exposure	Results	Association <sup>3</sup>	DR <sup>4</sup>	Covariates
states, USA	reproductive history		(relative to 0 hr/wk)	1-25 hr/wk 0.4 (0.1-1.0)		gestational age, previous adverse pregnancy outcome, diabetes, maternal weight gain, thyroid condition, hypertension, toxemia, time since last pregnancy
				> 25 hr/wk 1.4 (0.7-3.1)		
			Preterm birth not associated with VDT use or with intensity of use (relative to 0 hr/wk)	any use 0.7 (0.4-1.1)		As above
				1-25 hr/wk 0.8 (0.4-1.7)		
				> 25 hr/wk 0.6 (0.3-1.3)		
(Tornqvist 1998), Sweden	Two cohort studies: 2077 infants of men who likely worked in the electric power industry at time of conception and 1273 infants of unexposed men and a prospective cohort study involving 178 infants of men with high occupational power frequency EMF exposures, 62 infants of men with intermediate EMF exposure and 186 infants of men with low EMF exposure; pregnancy outcome data from birth, birth defect and cancer registries	Linked birth records to census records to identify paternal occupational exposure; identified electrical workers in the power industry; conducted 278 full-shift EMF measurements involving 16 work tasks, self-reported information on % of time on each work task	Very low and low birth weight risk not elevated among offspring of electrical workers in the power industry (risk relative to general population)	<1500 g 1.3 (0.6-2.0)		YOB, maternal age, parity
				<2500 g 0.9 (0.6-1.1)		

Reference, location	Design	Exposure	Results	Association <sup>3</sup>	DR <sup>4</sup>	Covariates
(Huuskonen et al. 1998), Finland	Review of literature on teratogenic and reproductive effects of low-frequency magnetic fields	Animal experiments do not suggest strong effects of ELF magnetic fields on fetal development	Inadequate epidemiologic evidence of an association between low birth weight, IUGR or preterm birth and ELF magnetic fields			
(Brent 1999), USA	Review of developmental effects of low-frequency EMF in experimental systems and animals		In experimental mammalian animals prenatally exposed to EMF, there was little evidence of fetal death, birth defects, reduced fetal growth or neurobehavioural abnormalities			
(Shaw 2001), USA	Review of literature on developmental outcomes and power-frequency EMF	Too few studies using direct measures of EMF exposure and pregnancy outcome to draw firm conclusions	VDT use does not appear to substantially increase the risk of low birth weight, IUGR or preterm birth			
			Equivocal findings from studies of residential EMF exposure and low birth weight, IUGR or preterm birth			
			Too few findings from studies of occupational EMF exposure and pregnancy outcome to draw firm conclusions			

**IUGR, preterm birth, low birth weight: summary***IUGR*

A cohort study of women in the 1<sup>st</sup> trimester of pregnancy found a weak association of borderline statistical significance between IUGR and prenatal maternal use of electrically heated beds but no associations with use of VDTs, residential wire codes or 7-day personal average magnetic field levels (Bracken et al. 1995). A review by Lindbohm (1995) noted that 3 of 4 epidemiologic studies found no association between fetal growth retardation and maternal postconceptual VDT use. Two recent reviews concluded that there is inadequate evidence of an association between IUGR and residential or occupational power frequency magnetic fields (Huuskonen et al. 1998, Shaw 2001). A review of experimental studies concluded that there was little evidence for an effect of power frequency EMF on growth retardation in experimental animals (Brent 1999).

*Preterm birth*

A small case-control study of preterm birth in Denver found no association with spot magnetic field levels or wire codes (Savitz and Ananth 1994). A cohort study of telephone operators in United States found no relationship between preterm birth and use or intensity of use of VDTs (Grajewski et al. 1997). Two recent reviews concluded that there is inadequate evidence of an association between preterm birth and residential or occupational power frequency magnetic fields (Huuskonen et al. 1998, Shaw 2001).

*Low birth weight*

A pooled analysis of two other case-control studies of low birth weight (McDonald et al. 1988, Windham et al. 1990) found no association with maternal prenatal VDT use (Parazzini et al. 1993). A small case-control study of low birth weight in Denver found no association with spot magnetic field levels or wire codes (Savitz and Ananth 1994). A cohort study of women in the 1<sup>st</sup> trimester of pregnancy found no association between low birth weight and prenatal maternal use of electrically heated beds or VDTs, residential wire codes or 7-day personal average magnetic field levels (Bracken et al. 1995). A cohort study of telephone operators in United States found no relationship between low birth weight and use or intensity of use of VDTs (Grajewski et al. 1997). A Swedish cohort study of men in the electric power industry found no increased risk of low birth weight offspring (Tornqvist 1998). Two recent reviews concluded that there is inadequate evidence of an association between low birth weight and residential or occupational power frequency magnetic fields (Huuskonen et al. 1998, Shaw 2001). A review of experimental studies concluded that there was little evidence for an effect of power frequency EMF on fetal growth retardation in experimental animals (Brent 1999).

**4. Birth defects**

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
(Dlugosz et al. 1992), NY State	Population-based case-control study, 224 cases neural tube defects, 318 cases oral cleft defects, 1:1 matched controls	Self-reported periconceptual use of electric blanket or heated waterbeds	Neural tube birth defects not associated with maternal electric blanket or heated waterbed use (respective odds ratios, yes vs no)	1.0 (0.5-1.6) 1.1 (0.6-1.9)		Matched for maternal age, race, county, month of LMP, infant sex
			Neural tube birth defects not associated with maternal electric blanket or heated waterbed use (odds ratio, low or high setting vs none)	elec blanket 1.0 (0.4-2.3) 0.8 (0.3-1.8) waterbed 1.0 (0.5-1.9) 1.8 (0.6-5.4)		As above
			Oral cleft birth defects not associated with maternal electric blanket or heated waterbed use (respective odds ratios, yes vs no)	0.8 (0.5-1.4) 0.7 (0.4-1.1)		As above
			Oral cleft birth defects not associated with maternal electric blanket or heated waterbed use (odds ratio, low or high setting vs none)	elec blanket 1.1 (0.5-2.7) 0.6 (0.3-1.1) waterbed 0.8 (0.5-1.4)		As above

<sup>5</sup> Entries in this column include odds ratios, relative risks and certain other statistical measures of association as published in original epidemiologic studies; an entry of '+' means the measure of association was not an odds ratio or relative risk and was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

<sup>6</sup> 'DR' refers to a dose-response relationship in an epidemiologic study; an entry of '+' means the measure of dose-response relationship used in the citation was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
				0.4 (0.1-1.4)		
(Milunsky et al. 1992), Boston	Cohort study, 22,754 women referred for serum $\alpha$ -fetoprotein or amniocentesis; based mainly on private obstetric practices in New England; outcomes included 49 neural tube birth defects	Self-reported exposure information	Neural tube defects associated with fever (borderline significance) and with use hot tubs but not with use of saunas or electric blankets during early pregnancy (respective odds ratios)	fever 1.8 (0.8-4.1) hot tubs 2.8 (1.2-6.5) saunas 1.8 (0.4-7.9) electric blankets 1.2 (0.5-2.6)		Maternal age, folic acid supplements, family history of NTDs, other heat sources
			Neural tube defects associated with number of heat sources other than electric blankets during early pregnancy (odds ratios for 1 or 2 vs 0 sources)(too few exposed women to assess 3 sources)	1.9 (0.9-3.7) 6.2 (2.2-17)		
(Parazzini et al. 1993), Italy	Meta-analysis of 9 case-control studies of pregnancy outcomes and VDT use published during 1985-1991; analyzed pooled data		Birth defects not associated with VDT use during pregnancy (pooled odds ratio, 5 case-control studies, 451 exposed cases)	1.0 (0.9-1.2)		
(Brent et al. 1993), USA	Review of literature on epidemiologic (1983-1990) and toxicologic studies of pregnancy outcomes and power frequency magnetic fields	Exposures in human studies included VDTs, power lines and household electric appliances; rarely measured exposure directly and often had	7 of 9 epidemiologic studies of birth defects found no association with postconceptual VDT use; one cohort study found an association with renal birth defects and a case-control			

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
		small sample sizes	study found an association with all birth defects combined			
			2 studies of birth defects and other residential EMF sources found little evidence for an association			
(Li et al. 1995), western Washington State	Registry-based case-control study, 118 urinary tract birth defect cases, 369 controls, 1990-1991; mothers interviewed	Mother-reported information on prenatal use of electric blankets, electrically heated waterbeds, VDTs during each trimester	Urinary tract birth defects not associated with maternal 1 <sup>st</sup> trimester electric appliance use; odds ratios	Electric blanket 1.2 (0.5-3.0)  Elec-heated waterbed 0.9 (0.2-3.7)  VDT use 1.3 (0.8-2.2)		Maternal race, family income, parity, county of residence, YOB
(Lindbohm and Hietanen 1995), Finland	Review of literature on pregnancy outcome and postconceptual occupational VDT use	Range of measured magnetic fields 50 cm from VDTs was 0.09-0.6 $\mu$ T	5 of 6 epidemiologic studies show no association between birth defects and maternal postconceptual VDT use			
(Robert et al. 1996), France	Population-based case-control study, 151 birth defect cases, 302 matched controls, residents in municipalities where at least one residence was within 500 m of a high-voltage power line	Measured maternal residential proximity to high voltage power lines	Birth defects not associated with residential proximity to high-voltage power lines (odds ratio, $\leq$ 100 m vs >100 m)	1.0 (0.5-2.0)		Matched for municipality, DOB
(Blatter et al.	Case-control study, 222 spina	122 case and 411 control	Spina bifida not associated	0.7 (0.2-2.1)		Excluded infants with

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
1997), Holland	bifida cases (hospital-based), 1980-1992, 764 controls (hospital- and community-based)	fathers had occupations potentially exposed to chemical or physical hazards and were interviewed re periconceptual occupational exposures	with paternal occupational EMF exposure (only 4 exposed case fathers)			maternal use of anticonvulsants, homocysteinemia, diabetes, consanguinity; adjusted for fertility drugs, oral contraceptives, parity, family history of NTDs, parental smoking, alcohol
(Tornqvist 1998), Sweden	Two cohort studies: 2077 infants of men who likely worked in the electric power industry at time of conception and 1273 infants of unexposed men and a prospective cohort study involving 178 infants of men with high occupational power frequency EMF exposures, 62 infants of men with intermediate EMF exposure and 186 infants of men with low EMF exposure; pregnancy outcome data from birth, birth defect and cancer registries	Linked birth records to census records to identify paternal occupational exposure; identified electrical workers in the power industry; conducted 278 full-shift EMF measurements involving 16 work tasks, self-reported information on % of time on each work task	Total birth defects not associated with paternal occupation as electrical workers in the power industry (risk relative to infants of unexposed men); non-significant association between hypospadias and paternal occupation as electrical worker in the power industry (7 exposed case fathers)	total defects 1.1 (0.8-1.5)  hypospadias 2.2 (0.4-21)		YOB, maternal age, parity
(Huuskonen et al. 1998), Finland	Review of literature on teratogenic and reproductive effects of low-frequency magnetic fields	Animal experiments do not suggest strong effects of ELF magnetic fields on fetal development; inconsistent evidence of increased minor skeletal defects	Inadequate epidemiologic evidence of an association between birth defects and ELF magnetic fields			

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
(Brent 1999), USA	Review of developmental effects of low-frequency EMF in experimental systems and animals		Experimental evidence suggests that EMFs do not cause mutations, cell death or cell proliferation as doses to which populations are usually exposed			
			In experimental mammalian animals prenatally exposed to EMF, there was little evidence of fetal death, birth defects, reduced fetal growth or neurobehavioural abnormalities			
(Shaw et al. 1999), California	Two case-control studies, 538 cases neural tube birth defects, 539 live birth controls; 265 neural tube and 662 orofacial birth defects, 734 live birth controls	Mother-reported exposure information	Neural tube birth defects associated with electric blanket use in larger but not in smaller study (respective odds ratios); no evidence of a dose-response relationship in either study	1.8 (1.2-2.6) 1.2 (0.6-2.3)		Maternal race/ethnicity, education, BMI, periconceptual multivitamin use
			Neural tube birth defects not associated with heated waterbed use in either study (respective odds ratios); no evidence of a dose-response relationship in either study	1.2 (0.8-1.8) 1.2 (0.8-1.9)		As above
			Isolated cleft lip ± cleft palate not associated with electric blanket or heated waterbed use (respective	0.8 (0.5-1.5) 1.0 (0.7-1.5)		As above

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
			odds ratios); no evidence of a dose-response relationship with either exposure			
			Cleft lip ± cleft palate plus other birth defects not associated with electric blanket use but borderline association with heated waterbed use (respective odds ratios); no convincing evidence of a dose-response relationship with either exposure	1.3 (0.5-3.4) 1.8 (1.0-3.2)	As above	
			Isolated cleft palate not associated with electric blanket or heated waterbed use (respective odds ratios); no evidence of a dose-response relationship with either exposure	0.8 (0.4-1.9) 1.0 (0.6-1.7)	As above	
			Cleft palate plus other birth defects not associated with electric blanket or heated waterbed use (respective odds ratios); no evidence of a dose-response relationship with either exposure	1.5 (0.6-3.8) 1.2 (0.6-2.3)	As above	
(Shaw 2001), USA	Review of literature on developmental outcomes and power-frequency EMF	There are too few studies using direct measures of EMF exposure and	Inadequate evidence to assess relation between birth defects and residential EMF			

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
		pregnancy outcome to draw firm conclusions	exposure			
			There are too few findings from studies of occupational EMF exposure and pregnancy outcome to draw firm conclusions			
(Blaasaas et al. 2002), Norway	Retrospective cohort study, births in Norway during 1967-1995	Linked birth to census record information on parental occupations during 1970, 1980 and 1990; expert assessment of likelihood that self-reported occupation was exposed to EMF levels above 0.1 $\mu$ T for <4, 4-24 or >24 hr/wk	Spina bifida and cleft lip associated with maternal occupational EMF exposure; odds ratios, likely exposure >24 hr/wk vs <4 hr/wk	Spina bifida 2.3 (1.1-4.9), p-trend=0.04  Cleft lip 1.7 (1.0-3.0), p-trend=0.12	+	Highest family education level, place of birth, maternal age, YOB
			Birth defects not associated with paternal occupational EMF exposure; range of odds ratios for various defects	0.70-1.39, p-trend>0.05 for specific defects		As above
(Blaasaas et al. 2003), Norway	Ecologic study, birth defect incidence in Norway, 1980-1997; linked GIS coordinates for homes to those for power lines	Used power company data on line voltage and currents combined with distance between lines and homes to estimate average home exposures to power frequency magnetic fields; information on	All birth defects combined not associated with residential magnetic field exposure > 0.1 $\mu$ T (odds ratio)	0.9 (0.8-1.0)		Parental education, place of birth, mothers' age and YOB

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
		occupational exposure to magnetic fields available for subset of parents				
			Spina bifida not associated with residential magnetic field exposure > 0.1 $\mu$ T (odds ratio)	1.3 (0.6-2.9)		As above
			Cardiac defects not associated with residential magnetic field exposure > 0.1 $\mu$ T (odds ratio)	0.5 (0.3-0.9)		As above
			Cleft lip not associated with residential magnetic field exposure > 0.1 $\mu$ T (odds ratio)	0.8 (0.4-1.4)		As above
			Esophageal defects associated with residential magnetic field exposure > 0.1 $\mu$ T (odds ratio)	2.5 (1.0-5.9)		As above
(Blaasaas et al. 2004), Norway	Case-control study, 465 birth defect cases, 930 population controls, enrolled during 1980 and 1986-1997	Maternal residence during at least half of gestation within 25m of a 25 Kv power line or within 300m of a 420 Kv line	Borderline association between cardiac birth defects and prenatal maternal residential proximity to power lines; odds ratio	1.5 (0.9-2.7)		Matched for sex, YOB, municipality; adjusted for highest family education level and maternal age
			CNS, respiratory defects and clubfoot not associated with prenatal maternal residential proximity to power lines;	CNS 0.9 (0.3-2.3) Respiratory		

Reference, location	Design	Exposure	Results	Association <sup>5</sup>	DR <sup>6</sup>	Covariates
			odds ratios	0.8 (0.3-2.2)		
				Clubfoot 0.8 (0.6-1.2)		

### Birth defects: summary

#### *Total birth defects*

A pooled analysis of 5 case-control studies of birth defects reported during 1985-1991 found no association with maternal postconceptual occupational use of VDTs (Parazzini et al. 1993). Similarly, a review by Brent et al. (1993) observed that 7 of 9 epidemiologic studies found no association between birth defects and postconceptual VDT use. A review by Lindbohm and Hietanen (1995) noted that 5 of 6 epidemiologic studies found no association between birth defects and maternal postconceptual VDT use. A small case-control study of birth defects in France found no association with residential proximity to high-voltage power lines (Robert et al. 1996). A Swedish cohort study found no association with paternal employment in the electrical power industry (Tornqvist 1998). Reviews by Huuskonen et al. (1998) and (Shaw 2001) concluded that there is inadequate evidence for an association between birth defects and residential or occupational power frequency EMF exposure. Other reviewers (Brent et al. 1999) concluded that animal studies provide little evidence for an association between power frequency EMF and birth defects or other adverse pregnancy outcomes. A Norwegian ecologic study found no association between all birth defects combined and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003).

#### *Neural tube birth defects*

A case-control study in New York State found no association between neural tube birth defects (NTDs) and maternal use of electric blankets or heated waterbeds (Dlugosz et al. 1992). A cohort study in the northeastern United States found a borderline association between NTDs and maternal 1<sup>st</sup> trimester heat exposure (electric heat from a sauna, hot tub or electric blanket or a febrile illness) and a significant association with 1<sup>st</sup> trimester hot tub use (Milunsky et al. 1992). Heat is a known animal teratogen, raising the possibility that the association reported by Milunsky may have been caused by heat *per se* and not the associated EMF. A Dutch case-control study found no link between spina bifida and paternal occupational EMF exposure but there were only 4 exposed case fathers (Blatter et al. 1997). A large case-control study of NTDs in California found an association with postconceptual maternal use of electric blankets but not heated waterbeds; a smaller case-control study by the same authors found no association with maternal postconceptual use of electric blankets or heated waterbeds (Shaw et al. 1999). A retrospective cohort study found an association between spina bifida and maternal but not paternal occupational EMF exposure (Blaasaas et al 2002). A Norwegian ecologic study found no association between NTDs and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003). A case-control study in Norway found no association between CNS birth defects and prenatal maternal residential proximity to power lines (Blaasaas et al 2004).

#### *Genitourinary birth defects*

A review of 9 epidemiologic studies by Brent et al. (1993) noted an association between urinary tract birth defects and occupational VDT use during early pregnancy in a Montreal cohort study. A case-control study of urinary tract birth defects in Washington State found no association with prenatal maternal use of electric blankets, electrically heated waterbeds or VDTs (Li et al. 1995). A Swedish cohort study found a non-significant imprecise association between

hypospadias and paternal employment in the electrical power industry (Tornqvist 1998). A Norwegian ecologic study found no association between cleft lip and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003).

#### *Cardiovascular birth defects*

A Norwegian ecologic study found no association between cardiac birth defects and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003). However, a case-control study in Norway found a borderline association between cardiac birth defects and prenatal maternal residential proximity to power lines (Blaasaas et al 2004).

#### *Orofacial birth defects*

A case-control study in New York State found no association between oral clefts and maternal use of electric blankets or heated waterbeds (Dlugosz et al. 1992). A large case-control study of orofacial birth defects in California found no association between isolated cleft lip ( $\pm$  cleft palate) or isolated cleft palate and postconceptual maternal use of electric blankets or heated waterbeds (Shaw et al. 1999). This study did find a borderline association between cleft lip ( $\pm$  cleft palate) combined with other birth defects in the same individuals and maternal postconceptual heated waterbed use but there was no dose-response relationship. A retrospective cohort study found an association between cleft lip and maternal but not paternal occupational EMF exposure (Blaasaas et al 2002).

#### *Other birth defects*

A Norwegian ecologic study found a borderline association between esophageal birth defects and residential magnetic field levels based on proximity and voltage of power lines (Blaasaas et al. 2003). A case-control study in Norway found no association between respiratory defects or clubfoot and prenatal maternal residential proximity to power lines (Blaasaas et al 2004).

### 5. Childhood leukemia: meta-analyses and recent literature reviews

Reference, location	Design	Analysis	Association
(Washburn et al. 1994), USA	Meta-analysis of 13 studies of childhood leukemia and residential proximity to electric power transmission and distribution equipment, 1979-1993	Summary odds ratio for association between childhood leukemia and residence within 50 m of transmission and distribution lines  Odds ratios of individual studies were not associated with any of 15 indicators of epidemiologic quality	1.5 (1.1- 2.0)
(Miller et al. 1995), USA	Meta-analysis of 7 case-control studies of childhood leukemia and exposure to power frequency EMF based on wiring configuration, distance, spot measurements and calculated exposures, 1979-1992	Summary odds ratio for association between childhood leukemia and wire codes (4 studies)	1.6 (1.3-2.0)
		Summary odds ratio for association between childhood leukemia and proximity to high voltage lines (2 studies)	2.1 (1.2-3.7)
		Summary odds ratio for association between childhood leukemia and spot measurements (4 studies)	1.1 (0.7-1.7)
(Levallois 1995), Canada	Review of 1 cohort and 8 case-control studies of childhood leukemia and wire codes, spot and 24-hr residential measurements, other characteristics of power lines, use of electric appliances	Range of odds ratios in the 5 most recent studies; significant dose-response relationships in 3 studies  The observed associations are not explainable by misclassification of exposure, selection bias or confounders	1.5-2.7
(Meinert and Michaelis 1996), Germany	Meta-analysis of 1 cohort and 11 case-control studies of childhood leukemia and wire code, proximity to high-voltage wires and magnetic field measures, 1979-1994	Summary odds ratio for association between leukemia and two-level wire code (4 studies)	1.7 (1.1- 2.5)
		Summary odds ratio for association between leukemia residence within 50 m of high voltage lines (5 studies)	1.3 (0.9-1.9)
		Summary odds ratio for association between leukemia and 24-hr avg or median magnetic field level >0.2 $\mu$ T (4 studies)	1.9 (1.1-3.3)
(National Academy of	Expert panel review of potential health effects of	The most appropriate EMF exposure metric for human	

Reference, location	Design	Analysis	Association
Sciences 1997), USA	residential 60-Hz electric and magnetic fields	health studies is unknown; wire codes are only weakly correlated with measured residential magnetic field levels and are associated with housing age and density and neighbourhood traffic density  Several epidemiologic studies have shown associations between childhood leukemia and residential wire codes but not with contemporary measured magnetic fields; the significance of the association with wire codes remains uncertain	
(Theriault and Li 1997), Montreal, Canada	Review of literature on leukemia and residential proximity to high-voltage power lines; 6 studies of children and 3 of adults, 1989-1997	In the 3 studies of children with the highest exposures, only 8-13% of children had avg exposures of 0.1 $\mu$ T or more  Summary odds ratio for association between leukemia (childhood and adult) and residence <50 vs >100 m from high voltage lines  Summary odds ratios for association between leukemia (childhood and adult) and avg residential exposure $\geq 0.2$ vs <0.1 $\mu$ T	1.4 (1.2-1.7)  1.3 (1.0-1.7)
	Did not report summary odds ratios for childhood leukemia	3 studies of children: odds ratio of leukemia for residence <50 vs >100 m from high voltage lines  4 studies of children: odds ratio of leukemia for avg exposures $\geq 0.2$ vs <0.1 $\mu$ T	0.6 (0.3-1.3) 1.1 (0.5-2.7) 2.9 (1.0-7.3)  0.8 (0.3-2.4) 1.6 (0.3-4.5) 1.7 (0.3-6.7) 2.7 (1.0-6.3)
(Wartenberg 1998), USA	Meta-analysis of 1 cohort and 10 case-control studies of childhood leukemia and residential power frequency magnetic fields, 1979-1993	Summary odds ratio for association between leukemia and wire codes (4 studies)	1.5 (1.1-2.1)

Reference, location	Design	Analysis	Association
		Summary odds ratio for association between leukemia and residence less than 50 m from power lines (3 studies)	1.5 (0.8-2.8)
		Summary odds ratio for association between leukemia and spot measurements $\geq 0.2 \mu\text{T}$ (4 studies)	0.9 (0.5-1.8)
		Summary odds ratio for association between leukemia and calculated historic fields $\geq 0.2 \mu\text{T}$ (3 studies)	1.9 (1.1-3.4)
(Angelillo and Villari 1999), Italy	Pooled analysis of 1 cohort and 14 case-control studies of childhood leukemia and residential magnetic field exposure based on wire codes, proximity to power lines and spot and 24-hr magnetic fields, 1979-1998; rated quality of reports improved with more recent date of publication	Summary odds ratio for association between leukemia and wire code (6 studies)	1.5 (1.1-2.0)
		Summary odds ratio for association between leukemia and proximity to power lines (4 studies)	1.2 (0.7-2.2)
		Summary odds ratio for association between leukemia and spot magnetic fields (5 studies)	1.1 (0.7-1.8)
		Summary odds ratio for association between leukemia and 24-hr avg magnetic fields (4 studies)	1.6 (1.1-2.2)
		Summary odds ratio for association between leukemia and calculated magnetic fields (4 studies)	1.6 (0.7-3.3)
(National Institute of Environmental Health Sciences 1999), USA	Expert group review of health effects from power frequency EMF	Individual epidemiologic studies did not provide convincing evidence of an association between childhood leukemia and magnetic fields	
		Meta-analyses suggest a weak dose-response relationship between childhood leukemia and magnetic fields but the small numbers of highly exposed cases preclude clear demonstration of this association	

Reference, location	Design	Analysis	Association
		Concluded that ELF-EMF is a possible human carcinogen (based on associations between childhood leukemia and residential exposure and between adult chronic lymphocytic leukemia and occupational exposure)	
(Ahlbom et al. 2000), Finland	Pooled analysis of childhood leukemia (age 0-14 yr) and 24/48-hr measured or estimated magnetic fields; used individual records from 9 large-scale, population-based case-control studies with extended indoor measurements or calculated fields, 1993-1999 (3,203 leukemia cases, 10,338 controls); 1.4% of cases and 0.6% of controls were exposed to magnetic fields $\geq 0.4 \mu\text{T}$	Pooled odds ratios for measured or calculated residential magnetic field levels of 0.1-0.19, 0.20-0.39 and $\geq 0.4$ vs $< 0.1 \mu\text{T}$ ; adjusted for age, sex, SES	1.1 (0.9-1.3) 1.1 (0.8-1.5) 2.0 (1.3-3.1)
		Pooled odds ratio per 0.2 $\mu\text{T}$ measured or calculated residential magnetic field level (analyzed as a continuous variable)	1.15 (1.04-1.27)
		Pooled odds ratios for wire code (higher vs lowest categories); adjusted for age, sex, SES, mobility (studies in Canada and USA only)	1.0 (0.8-1.3) 0.9 (0.7-1.2) 1.2 (0.8-1.9)
(Greenland et al. 2000), USA	Pooled analysis of individual data from 15 epidemiologic studies of childhood leukemia and residential wire configuration or EMF levels, 1979-1999	Pooled odds ratios for association between leukemia and residential magnetic field levels 0.21-0.30 and $> 0.30$ vs $\leq 0.2 \mu\text{T}$ (12 studies, adjusted for sex)	1.1 (0.9-1.4) 1.7 (1.2-2.4)
		Pooled odds ratios for association between leukemia and residential magnetic field levels 0.21-0.30 and $> 0.30$ vs $\leq 0.2 \mu\text{T}$ (11 studies, subjects with complete covariate data, adjusted for age, sex, SES)	0.9 (0.7-1.4) 2.1 (1.4-3.0)
		Pooled odds ratios for association between leukemia and residential wire codes (2 higher vs lowest category); based on 4 studies that included both EMF measurements and wire coding	1.1 (0.9-1.4) 1.6 (1.2-2.3)

Reference, location	Design	Analysis	Association
(National Radiological Protection Board 2001), UK	<p>Expert panel review of extremely low frequency EMF (ELF-EMF) and cancer</p> <p><i>In vitro</i> studies: There is no convincing evidence that ELF-EMF is directly genotoxic or that it can cause cell transformation <i>in vitro</i></p> <p>Animal studies: ELF-EMF does not increase spontaneous or radiation-induced leukemia incidence in mice</p> <p>Mixed evidence that ELF-EMF increases the incidence of chemically-induced breast cancer in rats</p> <p>Human volunteer studies: most show no effect of ELF-EMF on endogenous melatonin levels</p>	<p>Authors concluded that measured magnetic field levels are not less consistently related to childhood leukemia than wire codes, that the wire code link is not explained by measured magnetic flux densities and that any effects of magnetic fields may be limited to the few children with relatively high exposures (&gt;0.3 <math>\mu</math>T)</p> <p>At levels above 100 <math>\mu</math>T, ELF-EMF may enhance genotoxicity of known genotoxic agents and modulate calcium flux and gene expression</p> <p>ELF-EMF does not increase the incidence of spontaneous breast cancer in rats</p> <p>ELF-EMF did not increase the incidence of chemically-induced brain cancer in a study of female rats</p> <p>Epidemiologic studies: pooled analyses suggest that exposure to avg magnetic fields <math>\geq 0.4 \mu</math>T may double the risk of childhood leukemia</p> <p>Limited evidence that occupational ELF-EMF exposure increases the risk of adult leukemia; conflicting evidence that association is strongest for myeloid leukemia</p> <p>Inadequate evidence that occupational ELF-EMF exposure increases the risk of adult brain cancer</p>	
(Ahlbom et al. 2001), International Commission for Non-Ionizing Radiation	Review of epidemiologic literature on EMF and health	Conclusions: (1) the quality of epidemiologic studies has improved and recent studies on childhood leukemia are close to the achievable limits with regard to size and methodology, (2) the appropriate exposure metric is	

Reference, location	Design	Analysis	Association
Protection		unknown and there are no biologic data to support a specific metric	
		Best evidence of an association between health and EMF is that for childhood leukemia and postnatal power-frequency magnetic field exposures above 0.4 $\mu$ T (pooled odds ratio of 2.0 (CI 1.3-3.1) – see Ahlbom et al. 2000 above)	
		Limited data and little evidence of an association between childhood leukemia and prenatal maternal or childhood use of electric appliances (inconsistent findings, little evidence of dose-response relationships)	
(Savitz and Poole 2001), USA	Review of literature, 6 case-control studies of childhood leukemia and wire code in United States and Canada, 1979-1999	3 of the 6 studies reported positive associations and all found some relationship with wire codes; use of refined wire codes tends to strengthen the association with leukemia	
		Residential mobility, social class and neighbourhood characteristics are unlikely to explain a wire code effect	
		Ambiguity persists because of modest associations, inconsistent findings, complex relation between wire codes and magnetic fields, limited knowledge of risk factors for childhood leukemia and limited evaluation of wire code covariates	
(Milham and Ossiander 2001), USA	Review of childhood leukemia mortality rates below age 5 yr and hypothesis formation	Hypothesized that appearance of a peak in childhood leukemia mortality rates below age 5 yr after 1930 in the USA was caused by residential electrification	
		State childhood leukemia death rates (age 0-4 yr) during 1928-1932 were associated with percent of residences electrified	
(Wartenberg 2001),	Meta-analysis of 19 case-control studies of childhood	Pooled odds ratio for association between childhood	1.3

Reference, location	Design	Analysis	Association
USA	leukemia and residential EMF exposure, 1979-2000	leukemia and calculated/measured magnetic fields $\geq 0.2 \mu\text{T}$ (or closest cut-point, 14 studies)	(1.1-1.7)
		Pooled odds ratio for association between childhood leukemia and residence <25-50 m from high voltage wires or substations (13 studies)	1.2 (1.0-1.6)
		Among 4 studies that assessed dose-response between leukemia and spot measured magnetic fields, 3 found some evidence of higher odds ratios in the higher exposure categories	
		2 studies of leukemia and wire codes combined with spot magnetic field measurements both found dose-response relationships	
		1 of 2 studies of leukemia and wire codes combined with 24-hr bedroom magnetic field measurements found a dose-response relationship	
		Only 1 of 4 studies of leukemia and calculated residential magnetic field levels found a significantly elevated risk at levels above 0.2-0.4 $\mu\text{T}$	
(International Agency for Research on Cancer 2002), France	Expert panel review of ELF-EMF and cancer	Classified power-frequency magnetic fields as possibly carcinogenic to humans based on epidemiologic studies of childhood leukemia, particularly two recent pooled analyses of epidemiologic studies; some uncertainty remains as to whether magnetic field exposure or some other factor(s) might have accounted for the increased leukemia	
		Inadequate evidence for all other cancers in children and adults and for other EMF exposures (i.e., static fields and power-frequency electric fields) to classify the likelihood of cause-effect relationships	

Reference, location	Design	Analysis	Association
		Animal studies conducted suggest that ELF fields do not initiate or promote cancer	
(Linnet et al. 2003), USA	Review of epidemiologic literature on childhood cancer	Limited epidemiologic evidence for an association between childhood ALL and childhood exposure to 60-Hz magnetic fields $\geq 0.4 \mu\text{T}$	
(Habash et al. 2003), Canada	Review of literature on health risks of ELF-EMF	Limited evidence for an association between childhood cancer and ELF-EMF exposure	

### **Childhood leukemia: summary of recent meta-analyses and literature reviews**

#### *Wire code*

Several meta-analyses found an association between childhood leukemia and residential wire code categories (Miller et al. 1995, Meinert and Michaelis 1996, Wartenberg 1998, Angelillo and Villari 1999, Greenland et al. 2000). In a pooled analysis of two North American studies, Ahlbom et al. (2000) found a non-significant association between childhood leukemia and wire codes. A subsequent review of six North American studies noted that childhood leukemia was associated with wire codes in three studies and that the association was not explainable by residential mobility, social class or neighbourhood characteristics (Savitz and Poole 2001). These authors did note, however, that ambiguity persists because of modest associations, inconsistent findings, complex relationships between wire codes and magnetic fields, limited knowledge of risk factors for childhood leukemia and limited evaluation of wire code covariates.

#### *Proximity to high-voltage power lines*

Two meta-analyses found an association between childhood leukemia and proximity to high-voltage power lines (Washburn et al. 1994, Miller et al. 1995). More recent meta-analyses have shown borderline or non-significant associations between childhood leukemia and proximity to high-voltage power lines (Meinert and Michaelis 1996, Wartenberg 1998, Angelillo and Villari 1999, Wartenberg 2001).

#### *Measured and calculated residential magnetic field levels*

Spot measurements of residential magnetic fields were not associated with childhood leukemia in three meta-analyses (Miller et al. 1995, Wartenberg 1998, Angelillo and Villari 1999). Several meta-analyses found an association between childhood leukemia and 24-hour or calculated residential magnetic fields (Meinert and Michaelis 1996, Wartenberg 1998, Angelillo and Villari 1999, Greenland et al. 2000, Wartenberg 2001). In a recent pooled analysis of individual records from 11 studies, Greenland et al. (2000) found that the association between childhood leukemia and residential magnetic fields persisted after adjustment for potential confounders including age, sex and socioeconomic status).

#### *General conclusions*

Based mainly on the limited epidemiologic evidence of an association between childhood leukemia and power frequency magnetic fields, expert groups and reviewers have concluded that power frequency EMF is a possible human carcinogen (National Institute of Environmental Health Sciences 1999, National

Radiological Protection Board 2001, Ahlbom et al. 2001, International Agency for Research on Cancer 2002, Linet et al. 2003, Habash et al. 2003). The association between childhood leukemia and power frequency magnetic fields was largely limited to a small proportion of cases with average 24-hour exposures above 0.3-0.4  $\mu\text{T}$  (Ahlbom et al. 2000, Greenland et al. 2000). The International Agency for Research on Cancer (2002) noted that there is inadequate evidence for associations between childhood cancers other than leukemia and power frequency magnetic fields.

### 6. Childhood leukemia: recent original studies

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
(Hatch et al. 1998), Children's Cancer Group, 9 States, USA	Case-control study, 640 cases ALL, age 0-14 yr, 1989-1993, 640 matched controls	Mother-reported exposure information on prenatal and childhood use of electrical appliances	Borderline associations between leukemia and prenatal maternal use of electric blanket/mattress pad, heating pad and television (respective odds ratios for highest vs lowest exposure categories)	1.6 (1.0-2.7) 1.5 (0.9-2.5) 1.9 (0.8-4.5)		Matched for age, telephone exchange, race; adjusted for child sex, household income, maternal education
			Leukemia not associated with prenatal maternal use of waterbed, electric stove or several other appliances			As above
			Leukemia associated with childhood use of electric blanket/mattress pad, hair dryer, curling iron, sound system headset, video arcade machine and video games attached to television (odds ratios for highest vs lowest exposure categories)	2.6 (1.1-6.6) 1.5 (1.0-2.3) 3.6 (1.0-12) 3.0 (1.5-6.3) 2.8 (1.6-4.7) 2.4 (1.3-4.3)		As above

<sup>7</sup> Entries in this column include odds ratios, relative risks and certain other statistical measures of association as published in original epidemiologic studies; an entry of '+' means the measure of association was not an odds ratio or relative risk and was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

<sup>8</sup> 'DR' refers to a dose-response relationship in an epidemiologic study; an entry of '+' means the measure of dose-response relationship used in the citation was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Leukemia associated with child's time spent watching television (odds ratios for 2-3, 4-5 and 6+ vs <2 hr/d)	1.0 (0.7-1.5) 1.4 (0.9-2.1) 2.4 (1.5-3.8)	+	As above
			Leukemia associated with proximity to television (odds ratios for 4-6 and <4 vs 7+ feet)	1.7 (1.2-2.4) 1.6 (1.1-2.4)		As above
			Leukemia not associated with childhood use of several other appliances including waterbed, personal computer, air conditioning or electric heat			As above
(Dockerty et al. 1999), New Zealand	Population-based case-control study, 115 cases leukemia, age 0-14 yr, 117 matched controls	24-hr avg 50 Hz EMF measured in child's bedroom and living room; time-weighted avg computed	Childhood leukemia not associated with 24-hr avg residential magnetic fields (odds ratios for 0.10-0.19 and $\geq 0.2$ vs $< 0.1 \mu\text{T}$ )	1.5 (0.3-7.2) 3.3 (0.5-24)		Matched for age and sex; adjusted for maternal education, prenatal smoking, farm residence
			Childhood leukemia not associated with 24-hr avg residential electric fields (odds ratios for 5.0-13.9 and $\geq 14.0$ vs $< 5.0 \text{ V/m}$ )	2.0 (0.4-10) 1.3 (0.2-6.7)		Matched for age and sex; adjusted for maternal education, home ownership, prenatal smoking, household crowding, farm residence

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates		
(Green et al. 1999a), Toronto, Canada	Hospital-based case-control study, 88 cases leukemia, age 0-14 yr, resident in hospital catchment area at diagnosis, 1985-1993, 133 matched controls; note – the cases are a subset of those in the study by Green et al. 1999b shown below	48-hr personal EMF dosimetry, spot measurements in child's bedroom and 2 other frequently used rooms; adjusted for avg daily power consumption; conducted Wertheimer-Leeper and Kaune-Savitz wire coding	Childhood leukemia associated with 48-hr avg personal magnetic field quartiles (odds ratio for 0.03-0.06, 0.07-0.13 and $\geq 0.14$ vs $< 0.03$ $\mu\text{T}$ ); dose-response relationship not statistically significant	2.0 (0.6-6.8) 4.0 (1.1-14) 4.5 (1.3-16)	+	Matched for sex and DOB; adjusted for avg power consumption, family income, child's exposure to pesticides, solvents, siblingship, maternal prenatal exposure to cleaning products		
			Stronger association among younger children between leukemia and 48-hr avg personal magnetic field quartiles (odds ratio, 0.03-0.06, 0.07-0.13 and $\geq 0.14$ vs $< 0.03$ $\mu\text{T}$ )	age 0-5 yr 1.6 (0.5-4.8) 3.1 (1.0-9.6) 3.7 (1.1-13)			+	Matched for sex and DOB; unadjusted odds ratios
				age 6-14 yr 1.4 (0.3-5.6) 1.5 (0.5-5.2) 1.5 (0.5-5.1)				
			Non-significant associations between childhood leukemia and spot measurements in child's bedroom (odds ratio for 0.03-0.05, 0.06-0.10 and $\geq 0.11$ vs $< 0.03$ $\mu\text{T}$ )	2.1 (0.7-6.3) 1.8 (0.5-6.0) 2.3 (0.8-6.8)		Matched for sex and DOB; adjusted for power consumption, family income, child's exposure to pesticides or solvents, prenatal maternal pesticide exposure, siblingship		

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Childhood leukemia not associated with Wertheimer-Leeper wire code (odds ratio for two highest levels vs lowest level)	1.7 (0.6-4.9) 0.6 (0.2-1.5)		Matched for sex and DOB; adjusted for family income, residential mobility, maternal education, child's exposure to pesticides or solvents, sibblingship
			Childhood leukemia not associated with 48-hr avg personal electric field quartiles (odds ratio for 5.6-7.8, 7.9-11.5 and $\geq 11.6$ vs $< 5.6$ V/cm); no association in subgroups age 0-5 or 6-14 yr	0.3 (0.1-1.1) 0.3 (0.1-1.2) 0.3 (0.1-0.9)		Matched for sex and DOB; adjusted for family mobility, family income, maternal education, child's exposure to pesticides, sibblingship, maternal prenatal medication use
(Green et al. 1999b), Ontario	Population-based case-control study, 189 cases leukemia, age 0-14 yr, 1985-1993, 381 matched controls	For current and previous residences, conducted spot measurements in child's bedroom and 2 other rooms most often used by child, external perimeter of home, conducted 3 wire code categorizations	Childhood leukemia not associated with magnetic fields in child's bedroom (odds ratios for 0.03-0.06, 0.07-0.12 and $\geq 0.13$ vs $< 0.03$ $\mu$ T)	0.9 (0.3-3.0) 1.2 (0.3-4.6) 1.1 (0.3-4.1)		Matched for YOB and sex; adjusted for maternal prenatal hair dye use, sibblingship
			Childhood leukemia not associated with avg interior magnetic fields (odds ratios for 0.04-0.08, 0.09-0.14 and $\geq 0.15$ vs $< 0.04$ $\mu$ T)	0.5 (0.1-1.9) 0.8 (0.2-3.0) 1.5 (0.4-4.9)		As above

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Childhood leukemia risk inconsistently related to avg exterior perimeter magnetic fields (odds ratios for 0.04-0.08, 0.09-0.14 and $\geq 0.15$ vs $< 0.04$ $\mu$ T)	4.1 (1.3-13) 1.9 (0.6-6.6) 3.5 (1.1-10)		Matched for YOB and sex; adjusted for family income, residential mobility, siblingship, child's exposure to pesticides and solvents, maternal prenatal use of hair dyes
			Childhood leukemia not associated with Wertheimer-Leeper wire codes (odds ratios, higher vs lowest categories)	0.9 (0.5-1.5) 0.8 (0.4-1.6) 0.8 (0.2-3.0)		Matched for YOB and sex; adjusted for family income, maternal education, residential mobility, birth defects, siblingship, child's exposure to pesticides and household bleach, common childhood diseases, maternal prenatal use of hair dyes, x-rays or diseases
			Some indication of higher risks among highly exposed children age 0-5 yr at diagnosis (odds ratios for highest vs lowest exposure categories)	bedroom 1.9 (0.5-7.9) int avg 2.5 (0.5-14) outside avg 4.6 (1.0-22) W-L wire 2.9 (0.6-14)		Matched for YOB and sex; adjusted for various combinations of potential confounders

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Inconsistently higher risks for external magnetic field levels at residences of child at age 0-2 yr (odds ratios for 0.04-0.07, 0.08-0.14 and $\geq 0.15$ vs $< 0.04$ $\mu\text{T}$ )	3.6 (0.7-18) 2.7 (0.5-15) 4.9 (0.8-30)		Matched for YOB and sex; adjusted for residential mobility, race, child's exposure to household bleach and pesticides
			Some indication of an association with wire codes at residences early in child's life (odds ratios for two higher vs lowest categories)	1.0 (0.3-3.6) 3.5 (0.6-22)		Matched for YOB and sex; adjusted for child's exposure to household bleach, siblingship, prenatal maternal medication use
(McBride et al. 1999), 5 provinces, Canada	Population-based case-control study, 399 leukemia cases, age 0-14 yr, 1990-1994, 399 matched controls	48-hr personal EMF dosimetry, 24-hr child's bedroom EMF measurement; conducted Wertheimer-Leeper and Kaune-Savitz wire coding and spot outdoor measurements around perimeter of dwelling at all residences since 1 yr before birth of child	Childhood leukemia not associated with categorized 48-hr avg personal magnetic field levels (odds ratio for 0.08-0.14, 0.15-0.26 and 0.27-1.61 vs $< 0.08$ $\mu\text{T}$ ); similar results for ALL alone	0.6 (0.4-0.9) 1.1 (0.6-1.8) 0.7 (0.4-1.3)		Matched for age, sex, region; adjusted for maternal age at birth of subject, maternal education, household income, ethnicity, number of residences since birth
			Childhood leukemia not associated with dichotomized 48-hr avg personal magnetic field levels (odds ratio for $\geq 0.2$ vs $< 0.2$ $\mu\text{T}$ ); similar results for ALL alone	1.1 (0.7-1.8)		

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Childhood leukemia not associated with 48-hr avg personal magnetic field levels analyzed as a continuous variable (odds ratio per 0.2 $\mu$ T) ; similar results for ALL alone	1.0 (0.7-1.3) p-trend=0.73		
			Childhood leukemia not associated with calculated lifetime avg magnetic field exposure (odds ratio for 0.08-0.14, 0.15-0.26 and 0.27-1.61 vs < 0.08 $\mu$ T)	0.7 (0.5-1.1) 1.2 (0.7-1.9) 1.0 (0.6-1.9)		
			Childhood leukemia not associated with wire code categories (odds ratios, 4 increasing Wertheimer-Leeper codes vs buried power lines) ; similar results for ALL alone	0.7 (0.4-1.2) 0.8 (0.5-1.3) 0.6 (0.4-1.1) 1.2 (0.6-2.3) p-trend=0.71		
			Childhood leukemia not associated with categorized avg 48-hr electric field exposure (odds ratio for 12.2-17.1, 17.2-24.5 and 24.6-64.7 vs <12.2 V/m)	0.8 (0.5-1.2) 0.8 (0.5-1.2) 0.8 (0.5-1.5)		

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Childhood leukemia not associated with dichotomized avg 48-hr electric field exposure (odds ratio, $\geq 20$ vs $< 20$ V/m)	0.8 (0.5-1.3)		
			Borderline <i>inverse</i> association between childhood leukemia and avg 48-hr electric field exposure analyzed as a continuous variable (odds ratio per 20 V/m)	0.7 (0.4-1.0) p-trend=0.06	(+)	
(Thomas et al. 1999), Los Angeles	Population-based case-control study, 232 cases leukemia, age 0-9 yr, 1980-1987, 232 controls	Conducted Wertheimer-Leeper wire coding, spot indoor and outdoor and 24-hr child's bedroom magnetic field measurements; time-weighted avg magnetic field exposure based on Bowman model using wiring configuration and duration in each residence since birth)	Leukemia not associated with GM 24-hr avg magnetic field in child's bedroom (odds ratios, 50-75, 75-89 and 90-100 vs 0-49 percentiles)	0.5 (0.3-0.9) 0.7 (0.4-1.4) 1.8 (0.7-4.3) p-trend=0.88		
			Leukemia associated with residential W-L wire code (odds ratios, increasing vs lowest categories)	0.8 (0.4-1.6) 1.6 (0.8-3.2) 2.1 (0.9-4.7) p-trend=0.02	+	

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Leukemia associated with predicted avg lifetime residential magnetic fields (odds ratios, 50-75, 75-89 and 90-100 vs 0-49 percentiles)	1.4 (0.9-2.2) 1.6 (0.9-2.8) 2.0 (1.0-3.9) p-trend=0.02	+	
(UK Childhood Cancer Study Investigators 1999), UK	Population-based case-control study, 2226 incident childhood cancer cases, age 0-14 yr, 1991-1996, 2226 matched controls	Estimated EMF exposure during year before diagnosis; conducted residential spot measurements in child's bedroom, family room, 48-hr measurement in child's bedroom, spot measurements in school; proximity to power lines and line load data used to estimate avg magnetic field levels during study year	Leukemia not associated with avg residential magnetic field levels during year before diagnosis (odds ratios, 0.10-0.19, 0.20-0.39 and $\geq 0.40$ vs $< 0.10$ $\mu\text{T}$ )	0.8 (0.6-1.1) 0.8 (0.4-1.5) 1.7 (0.4-7.1) p-trend > 0.3		Matched for sex, DOB; adjusted for deprivation index
(Sorahan et al. 1999), Oxford Survey of Childhood Cancers, UK	Population-based case-control study, 15,041 cancer deaths, age 0-15 yr, 1953-1981, 15,041 matched controls	Self-reported occupational history; categorized jobs into five levels based on exposure to electrical machinery	Childhood leukemia deaths not associated with maternal prenatal occupational magnetic field exposure (odds ratios, increasingly higher vs lowest categories)	1.1 (0.7-1.5) 0.5 (0.3-0.9) 0.4 (0.2-0.8) 0.5 (0.2-1.2)		Matched for sex and DOB; adjusted for maternal age at child's birth, SES, parity
(Auvinen et al. 2000), Children's Cancer Group, USA,	Population-based case-control study, 515 cases ALL, age < 15 yr, 516 matched controls; resided in one home for at least 70% of the 5 yr before diagnosis	Conducted 24-hr bedroom and spot magnetic field measurements; assessed exposure metrics incl central tendency, peak, threshold and short-term temporal variability	ALL associated with mean night-time magnetic field level in child's bedroom (odds ratio per $\mu\text{T}$ ); exposure analyzed as continuous variable	1.1 (1.0-1.3) p-trend=0.06	(+)	Age, sex, mother's education, family income

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			ALL associated with peak night-time magnetic field level in child's bedroom (odds ratios for 50-74, 75-89 and 90-100 vs 0-49 percentiles); no association with peak night-time levels when analyzed as continuous variable	1.2, 1.5, 1.4 p-trend=0.04	+	As above
			Borderline association between ALL and night-time magnetic field > 0.3 $\mu$ T (odds ratio for % of values exceeding 0.3 $\mu$ T analyzed as a continuous variable) (	1.088 (1.00-1.02) p-trend=0.04	+	As above
(Feychting et al. 2000), Sweden	Cohort study, 235,635 children born during 1976-77 and 1981-82; linked to national cancer registry records up to 1993; 522 cancer cases (161 leukemia, 162 CNS, 40 lymphoma, 25 neuroblastoma, 134 other)	Parental occupation, industry and SES from census records close to children's date of birth; estimated avg parental occupational magnetic field exposure using a job-exposure matrix and survey data on avg exposure levels in various occupations	Leukemia not associated with maternal occupational magnetic field exposure (relative risks, 0.12-0.18, $\geq$ 0.19 vs <0.12 $\mu$ T)	1.1 (0.7-1.8) 1.0 (0.6-1.9)		Sex, census year
			Leukemia associated with paternal occupational magnetic field exposure (relative risks, 0.13-0.29, $\geq$ 0.30 vs <0.13 $\mu$ T)	1.4 (0.9-2.2) 2.0 (1.1-3.5)	+	As above

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
(Hatch et al. 2000), Children's Cancer Group, 9 states, USA	Reanalysis of case-control study that found little association between childhood ALL and wire code; assessed potential sources of bias and confounding	"Partial participants" had lower SES than full participants	Odds ratio for ALL vs highest wire code category increased about 20% when "partial participants" were excluded (revised odds ratio, highest vs lowest wire code categories)	1.2 (0.7-2.0)		
			Excluding partial participants and simultaneous adjustment for several potential confounders reduced risk estimates by up to 15% (revised odds ratio, highest vs lowest wire code categories)	0.8 (0.5-1.4)		
			Concluded that confounding does not cause much bias in studies of magnetic fields but selection bias may be important in case-control studies with low response rates among controls			

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
(Bianchi et al. 2000), Italy	Population-based case-control study, 101 cases leukemia, age 0-14 yr, 1976-1992, 412 matched controls	Proximity to high-voltage power lines, spot magnetic field measurements in case homes; estimated avg residential magnetic field exposure based on line load and proximity for the 23 subjects living within 150 m	Leukemia associated with estimated exposure from proximity to high-voltage power lines (odds ratios for $\leq 0.1$ and $> 0.1$ $\mu\text{T}$ vs unexposed, i.e., 150+ m from power lines)	3.3 (1.1-9.7) 4.5 (0.9-23)		Matched for sex, DOB, residence in province
(UK Childhood Cancer Study Investigators 2000), United Kingdom Childhood Cancer Study	Population-based case-control study, 3,380 incident cancer cases, age 0-14 yr, 1991-1995, 3,390 matched controls	Measured distances to high-voltage lines, underground cables, substations and distribution circuits; estimated avg residential magnetic field exposure based on distance, phase arrangement, tower design, conductor clearance and avg load data (for the residence occupied longest by study subjects)	Leukemia associated with proximity to 66 kV but not other voltage power lines (odds ratio per unit increase in 100/distance in metres)	3.2 (1.0-9.7)	+	Matched for sex and DOB; adjusted for age, sex, region, SES
			Leukemia not associated with estimated avg residential magnetic field levels (odds ratios for 0.10-0.19 and $\geq 0.20$ vs $< 0.1$ $\mu\text{T}$ )(only 6 and 2 cases in these exposure categories)	1.5 (0.5-4.5) 0.4 (0.1-1.9)		As above

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
(Kleinerman et al. 2000), Children's Cancer Group, USA	Population-based case-control study, 408 cases childhood ALL, age 0-14 yr, 1989-1993, matched controls	Measured distance to power transmission lines; assessed components of Wertheimer-Leeper wire codes for homes within 40 m of power lines; developed exposure index based on distance and relative load of all power lines within 40 m of residence	ALL not associated with residential proximity to closest power line (odds ratios, 24-40, 15-23 and 0-14 vs >40 m)	1.2 (0.8-2.0) 1.0 (0.6-1.7) 0.8 (0.5-1.3)		Matched for age, race, region; adjusted for sex, maternal education, annual family income
			ALL not associated with residential proximity to closest transmission line (odds ratios, 34-40, 24-35 and 0-23 vs >40 m)	1.2 (0.8-2.0) 1.0 (0.6-1.7) 0.8 (0.5-1.3)	As above	
			ALL not associated with residential proximity to closest distribution line (odds ratios, 24-40, 15-23 and 0-14 vs >40 m)	1.5 (0.9-2.5) 1.2 (0.7-2.0) 0.8 (0.4-1.3)	As above	
			ALL not associated with exposure index (odds ratios, <0.66, 0.66-1.29 and ≥1.30 vs 0 μT)	1.3 (0.8-2.2) 0.7 (0.4-1.3) 1.0 (0.6-1.6)	As above	
(Reynolds et al. 2001) San Diego county, USA,	Population-based case-control study, 90 cases leukemia, age < 5 yr, 1983-1994, 349 matched controls	Assessed average daily traffic flow on streets within 165 m of residence, assumed Gaussian dispersion of motor vehicle exhaust contaminants	Leukemia not associated with median family income of block group (odds ratios for \$18,000-55,999 and ≥\$56,000 vs <\$18,000)	1.0 (0.5-2.2) 0.9 (0.3-2.6)		Matched for sex, DOB, county of birth; adjusted for race

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Leukemia not associated with traffic density near the birth address (odds ratios for avg traffic densities of 10,000-19,999 and $\geq 20,000$ vs $< 10,000$ vehicles/d)  Concluded that neither SES nor traffic density were strong enough risk factors for leukemia to be major confounders for wire code	1.4 (0.6-3.2) 1.6 (0.8-3.3)		Matched for sex, DOB, county of birth; adjusted for race and median family income of block group
(Schuz et al. 2001a), Germany	Population-based case-control study (nation-wide cases during 1993-1997 plus cases from regions near nuclear facilities during 1990-1994), 514 cases acute leukemia, age 0-14yr, 1,301 matched controls; conducted pooled analysis of this and two previous studies by same research group	Measured residential 24-hr magnetic fields in child's bedroom and family living room (only 1.5% exceeded $0.2 \mu\text{T}$ )	Acute leukemia associated with median magnetic field strength in child's bedroom (odds ratios, 0.10-0.19, 0.20-0.39 and $\geq 0.4$ vs $< 0.1 \mu\text{T}$ ) (3 cases in highest exposure category)	1.2 (0.7-1.8) 1.1 (0.4-3.0) 5.3 (0.7-40) p-trend = 0.11	(+)	Matched for sex, DOB, community; adjusted for urban/rural and SES

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Acute leukemia associated with night-time median magnetic field strength in child's bedroom (odds ratios, 0.10-0.19, 0.20-0.39 and $\geq 0.4$ vs $< 0.1 \mu\text{T}$ ) (5 cases in highest exposure category)	1.4 (0.9-2.3) 2.6 (0.9-7.7) 5.3 (1.1-26) p-trend = 0.04	+	As above
			Pooled analysis: acute leukemia associated with median magnetic field strength in child's bedroom (odds ratios, 0.10-0.19, 0.20-0.39 and $\geq 0.4$ vs $< 0.1 \mu\text{T}$ ) (7 cases in highest exposure category)	1.1 (0.7-1.6) 1.2 (0.6-2.6) 3.5 (1.0-12) p-trend = 0.05	+	As above
			Pooled analysis: acute leukemia associated with night-time median magnetic field strength in child's bedroom (odds ratios, 0.10-0.19, 0.20-0.39 and $\geq 0.4$ vs $< 0.1 \mu\text{T}$ ) (7 cases in highest exposure category)	1.3 (0.9-2.0) 2.4 (1.1-5.4) 4.3 (1.3-15) p-trend = 0.02	+	As above

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
(Skinner et al. 2002), Childhood Cancer Study, UK	Population-based case-control study, 426 incident cancer cases (173 ALL, 45 other leukemia, 73 CNS, 135 other cancers), 1992-1996, age 0-14 yr, 419 matched controls	Conducted spot <i>electric</i> field measurements in child's bedroom and family living-room and a 48-hr measurement near child's bed	ALL not associated with electric fields (odds ratio, 10-19 and $\geq 20$ vs $< 10$ V/m)	1.1 (0.7-1.6) 0.9 (0.5-1.5)		Matched for age, sex, location; adjusted for age, sex, region, SES
			In subset with verified electric field measurements, non-significant association between ALL and electric fields (odds ratio, 10-19 and $\geq 20$ vs $< 10$ V/m)	1.4 (0.8-2.3) 1.3 (0.7-2.5)	As above	
(Soderberg et al. 2002), Sweden	Case-control study nested within cohort of 1.7 million infants born during 1973-1989, identified cancer cases by linkage to national cancer registry, 647 incident leukemia cases, age 0-16 yr, 647 matched controls	Assessed exposure to magnetic fields in neonatal incubators based on duration (from medical records) and magnetic field measurements on 17 different incubator models	Childhood leukemia not associated with duration in incubators (odds ratios, $\leq 30$ and $> 30$ vs 0 hr)	0.8 (0.5-1.3) 1.2 (0.6-2.1)		Matched for sex, DOB
			Childhood leukemia not associated with avg magnetic field in incubators (odds ratios, $\leq 0.6$ and $> 0.6$ $\mu\text{T}$ vs unexposed)	0.9 (0.5-1.5) 0.9 (0.5-1.7)		

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Childhood leukemia not associated with cumulative magnetic field exposure in incubators (odds ratios, $\leq 10$ and $>10$ vs $0 \mu\text{T-hr}$ )	0.6 (0.3-1.3) 1.0 (0.6-1.6)		
			Non-significant association between ALL at age 5-9 yr and avg magnetic fields in incubators (odds ratios, $\leq 0.6$ and $>0.6 \mu\text{T}$ vs unexposed)(6 and 5 exposed cases, respectively)	2.4 (0.6-11) 5.0 (0.5-48)		
(Infante-Rivard and Deadman 2003), Quebec, Canada	Population-based, case-control study, 491 incident ALL cases, age 0-9 yr, 1980-1993, 491 matched healthy controls	Mother-reported occupational history; estimated time-weighted magnetic field exposure based on job-specific work environment, magnetic field sources and intensity of exposure (hr/wk); assessed cumulative exposure ( $\mu\text{T-days}$ ), avg exposure, maximum weekly avg exposure	Borderline association between ALL and cumulative gestational magnetic field exposure (odds ratio $\geq 47.7$ vs $<47.7 \mu\text{T-days}$ )	all women 1.6 (1.0-2.5)  employed women 1.7 (1.0-3.0)		Matched for age and sex; adjusted for maternal age, prenatal maternal diseases, other children at time of pregnancy
			Borderline association between ALL and avg gestational magnetic field exposure (odds ratio $\geq 0.2$ vs $<0.2 \mu\text{T}$ )	all women 1.4 (1.0-2.2)  employed women 1.6 (1.0-2.7)		As above

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
			Association between ALL and maximum weekly gestational magnetic field exposure (odds ratio $\geq 0.4$ vs $< 0.4 \mu\text{T}$ )	all women 2.4 (1.3-4.2)  employed women 2.5 (1.3-5.0)		As above
(Linnet et al. 2003), USA	Review of epidemiologic literature on childhood cancer	Concluded that there is limited epidemiologic evidence for an association between childhood ALL and childhood exposure to 60-Hz magnetic fields $\geq 0.4 \mu\text{T}$				
(Brain et al. 2003), USA	Summary of workshop on childhood leukemia and power-frequency EMF	Carcinogenicity studies in rodents	Continuous or intermittent exposure to magnetic fields up to 5T did not increase incidence of leukemia or lymphoma in standard or genetically susceptible rodents  Prolonged exposure to magnetic fields up to 1.4T did not increase the incidence of radiation or DMBA initiated lymphomas  At residential EMF levels, no obvious biologic mechanism influenced by EMF			

Reference, location	Design	Exposure	Results	Association <sup>7</sup>	DR <sup>8</sup>	Covariates
(Hone et al. 2003), UK	<i>In vitro</i> study of influence of ELF magnetic fields and ionizing radiation on dicentric chromosome exchange in human lymphocytes	Lymphocyte cultures exposed to 50 Hz magnetic fields at 0.23, 0.47 or 0.7 mT for 12 hr after exposure to 2 Gy of <sup>60</sup> Co ionizing radiation	Magnetic fields alone caused no increase in dicentric chromosomes; little evidence of any interaction with ionizing radiation			

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### Childhood leukemia: recent original studies: summary

#### *Wire codes*

An Ontario case-control study found no association between childhood leukemia and Wertheimer-Leeper wire codes (Green et al. 1999a, 1999b). A large population-based case-control study of childhood leukemia in five Canadian provinces found no association with Wertheimer-Leeper wire codes (McBride et al. 1999). A population-based case-control study in Los Angeles found a dose-response relationship between leukemia among children age 0-9 years and Wertheimer-Leeper wire codes (Thomas et al. 1999). A reanalysis of a large US case-control study of childhood that originally found no association between ALL and wire codes, found that the odds ratio for highest versus lowest wire code categories increased somewhat after excluding subjects who declined access for direct measurement of interior magnetic fields but there was still no significant association; this revised odds ratio decreased substantially after adjustment for several potential confounders (Hatch et al. 2000). A small case-control study in San Diego county concluded that the traffic density and median family income could not explain an association between childhood leukemia and wire code (Reynolds et al. 2001).

#### *Proximity to high-voltage power lines*

A large UK case-control study of childhood leukemia found an association with proximity to 66 kV but not other voltage power lines (UK Childhood Cancer Study Investigators 2000). ). A large population-based case-control study of childhood ALL in the USA found no association with residential proximity to any power line, to a transmission line or to a distribution line (Kleinerman et al. 2000).

#### *Measured and calculated residential magnetic field levels*

A small case-control study in New Zealand found no association between childhood leukemia and 24-hour magnetic fields in the subjects' bedrooms or living rooms (Dockerty et al. 1999). An Ontario case-control study found associations between childhood leukemia and spot perimeter magnetic fields but there was no dose-response relationship; there was also no association with spot magnetic fields in children's bedrooms or with the average of spot measurements in three interior rooms (including the child's bedroom) (Green et al. 1999a, 1999b). A large population-based case-control study of childhood leukemia in five Canadian provinces found no association with calculated lifetime average magnetic fields (McBride et al. 1999). A population-based case-control study in Los Angeles found that leukemia among children age 0-9 years was associated with calculated lifetime residential magnetic fields but not with 24-hour magnetic fields in the children's bedrooms (Thomas et al. 1999). A very large population-based case-control study of childhood leukemia in the UK found no association with average residential magnetic fields during the year before diagnosis (estimated from spot and 48-hour residential measurements, spot school measurements and proximity and load data of power distribution lines (UK Childhood Cancer Study Investigators 1999). A large population-based case-control study of childhood ALL in the USA found a dose-response relationship with peak night-time magnetic fields and percent of night-time magnetic field measurements exceeding 0.3  $\mu$ T in the

children's bedrooms (Auvinen et al. 2000). A small Italian case-control study found an association between childhood leukemia and residential magnetic field levels calculated from data on proximity, line load and spot interior magnetic field measurements (Bianchi et al. 2000). A large UK case-control study of childhood leukemia found no association with calculated residential magnetic fields based on data on proximity, tower design, line load and phase (UK Childhood Cancer Study Investigators 2000). A large population-based case-control study of childhood ALL in the USA found no association with calculated residential magnetic fields based on proximity and load of all power lines within 40 metres (Kleinerman et al. 2000). A large population-based case-control study of childhood leukemia in Germany found dose-response relationships with 24-hour median and night-time median magnetic field levels in children's bedrooms (Schuz et al. 2001). A large nested case-control study in Sweden (Soderberg et al. 2002) found no association between childhood leukemia and time in neonatal incubators or with average or cumulative magnetic field levels while in incubators (estimated from measurements on 17 different models of incubators).

#### *Personal magnetic field levels*

A small case-control study in Toronto found an association between childhood leukemia and 48-hour personal magnetic field levels and a statistically non-significant dose-response relationship; the association was stronger among children age 0-5 years compared to older children (Green et al. 1999a). A large population-based case-control study of childhood leukemia in five Canadian provinces found no association with 48-hour personal magnetic fields analyzed as averages or continuous variables or dichotomized at  $0.2\mu\text{T}$  (McBride et al. 1999).

#### *Parental occupational magnetic field exposures*

A large case-control study of childhood leukemia deaths in the UK found no association with self-reported maternal prenatal occupations categorized by likely magnetic field exposure from electrical machinery (Sorahan et al. 1999). A large Swedish birth cohort study found that childhood leukemia was associated with paternal but not maternal occupational magnetic field exposure based on census record information on occupation/industry, a job-exposure matrix and a survey of magnetic field exposures in various occupations (Feychting et al. 2000). A large population-based case-control study of ALL in Quebec (Infante-Rivard et al. 2003) found an association with maternal prenatal maximum weekly occupational magnetic field exposures based on self-reported occupational history and job-specific estimated average magnetic fields derived from magnetic field sources, work environment and intensity of exposure (hours per week).

#### *Electric heating devices*

A large US case-control study found that childhood ALL was weakly related to maternal prenatal use of electric blankets/mattress pads, heating pads and television but not with use of heated waterbeds or several other electric appliances (Hatch et al. 1998). This study found associations between ALL and childhood use of electric blankets/mattress pads and curling irons but not with heated waterbeds or other electric appliances.

#### *Television, other electronic devices*

A large US case-control study found that childhood ALL was associated with childhood use of sound system headsets, video arcade machines and video games attached to television; there were associations between ALL and time spent watching television and with proximity to television set (Hatch et al. 1998). This study found no association between ALL and childhood use of personal computers.

#### *Power-frequency electric fields*

A small case-control study in Toronto found no association between childhood leukemia and 48-hour personal electric fields (Green et al. 1999a). A small case-control study in New Zealand found no association between childhood leukemia and 24-hour electric fields in the subjects' bedrooms or living rooms (Dockerty et al. 1999). A large population-based case-control study of childhood leukemia in five Canadian provinces found no association with 48-hour personal electric

fields analyzed as averages or continuous variables or dichotomized at 20 V/m; in fact, there was a borderline *inverse* association with personal electric fields analyzed as a continuous variable (McBride et al. 1999). A population-based case-control study of childhood ALL in the UK found no association with 48-hour electric field in children's bedrooms (Skinner et al. 2002).

*General considerations*

A workshop on childhood leukemia and power-frequency EMF concluded that continuous or intermittent exposure to magnetic fields up to 5T did not increase the incidence of leukemia or lymphoma in standard or genetically susceptible rodents; fields up to 1.4T did not increase the incidence of radiation or DMBA initiated lymphomas (Brain et al. 2003).

### 7. Childhood CNS tumours: recent meta-analyses, literature reviews and original studies

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates
(Washburn et al. 1994), USA	Meta-analysis of 7 studies of childhood CNS tumours, 1979-1993	Residential proximity to electric power transmission and distribution equipment	Childhood CNS tumours associated with proximity to transmission and distribution lines (summary odds ratio)	1.9 (1.3- 2.7)		
(Meinert and Michaelis 1996), Germany	Meta-analysis of 1 cohort and 6 case-control studies of childhood CNS tumours and EMF, 1979-1994	60 Hz magnetic field exposure based on wire code, proximity to high-voltage wires and magnetic field measures	CNS tumours not associated with two-level wire code (summary odds ratio, 3 studies)	1.5 (0.7-3.3)		
			CNS tumours not associated with measured or calculated residential avg magnetic fields (summary odds ratio, avg field >0.2 µT, 5 studies)	1.3 (0.8-2.2)		
(Preston-Martin et al. 1996a), West Coast Childhood Brain Tumor Study, USA	Population-based case-control study, 540 brain tumour cases, age 0-19 yr, 1984-1991, 801 controls	Mother-reported exposure information including prenatal and childhood use of electric blankets and electrically heated beds	Brain tumours not associated with prenatal maternal electric blanket or heated waterbed use (respective odds ratios, yes vs no)	0.9 (0.6-1.2) 0.9 (0.6-1.3)		Little variation in subgroups defined by sex, age, SES or histologic brain tumour type
			Brain tumours not	1.0 (0.6-1.7)		As above

<sup>9</sup> Entries in this column include odds ratios, relative risks and certain other statistical measures of association as published in original epidemiologic studies; an entry of '+' means the measure of association was not an odds ratio or relative risk and was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

<sup>10</sup> 'DR' refers to a dose-response relationship in an epidemiologic study; an entry of '+' means the measure of dose-response relationship used in the citation was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates
			associated with childhood electric blanket or heated waterbed use (respective odds ratios, yes vs no)	1.2 (0.7-2.0)		
(Preston-Martin et al. 1996b), Los Angeles	Population-based case-control study, 298 brain tumour cases, age 0-19 yr, 1984-1991, 298 matched controls	Conducted spot magnetic field measurements outside home (over water meter and pipes, front door, perimeter of dwelling), 24-hr measurements in child's bedroom and another most frequently used room; Wertheimer-Leeper wire coding of current and previous residences in Los Angeles county	Brain tumours not associated with avg, median or 90 <sup>th</sup> percentile 24-hr magnetic field levels in child's bedroom (odds ratios for median levels of 0.052-0.102, 0.103-0.203 and 0.204-1.04 vs < 0.052 $\mu$ T); similar results for other most often used room	1.5 (0.7-3.2) 1.8 (0.7-4.5) 1.2 (0.4-3.2)	p-trend=0.98	Matched for sex and YOB
			Brain tumours associated with underground but not other W-L wire code categories (odds ratios for underground and increasing categories)	2.3 (1.2-4.3) 1.0 (referent) 0.8 (0.6-1.2) 1.2 (0.6-2.2)		Age, sex, YOB, SES, maternal prenatal waterbed use
			Borderline association between brain tumours and prenatal but not childhood use of electrically heated waterbeds (respective odds ratios)	2.1 (1.0-4.2) 2.0 (0.6-6.8)		
			Brain tumours not associated with prenatal	1.2 (0.6-2.2) 1.2 (0.5-3.0)		

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates
			or childhood electric blanket use (respective odds ratios)			
(Gurney et al. 1996), Washington State	Population-based case-control study, 133 brain tumour cases, age 0-19 yr, 1984-1990, 270 controls	Mother-reported exposure information including prenatal and childhood use of electric blankets and electrically heated beds; conducted Wertheimer-Leeper wire coding based on power distribution maps for homes occupied during 3 yr before diagnosis	Brain tumours not associated with residential W-L wire codes (odds ratios for higher vs lowest categories)	1.3 (0.7-2.1) 0.7 (0.3-1.6) 1.1 (0.6-2.1) 0.5 (0.2-1.6)		Analysis found that sex, race, county, maternal education, family history of brain tumours, ETS, farm residence, head injury, head/neck x-rays and history of seizures were not confounders
			Brain tumours not associated with childhood or prenatal exposure to electric blankets or heated waterbeds (respective odds ratios)	childhood 0.5 (0.2-1.4) 0.8 (0.3-1.9) prenatal 0.9 (0.5-1.6) 0.7 (0.4-1.3)		
			Brain tumours not associated with childhood or prenatal exposure to electric heating devices (respective odds ratios)	childhood 0.6 (0.4-1.0) prenatal 0.7 (0.4-1.2)		
(Wilkins and Wellage 1996), Ohio	Population-based case-control study, 94 cases brain tumours, age 0-19	Parent-reported occupational history from 1 yr before conception to cancer diagnosis; literature-based	Brain tumours not associated with paternal occupations exposed to	1.3 (0.6-3.0)		Matched for sex, YOB, race

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates
	yr, 1975-1982, 166 matched controls	estimates of avg magnetic field exposures for specific occupations	magnetic fields (odds ratio, ever vs no)			
			Borderline association between brain tumours and paternal occupation as welder (odds ratio, ever vs no)	3.8 (1.0-16)		
(Tynes and Haldorsen 1997), Norway	Case-control study nested within census-based cohorts totaling 168,450 children age 0-14 yr living in census wards crossed by a high-voltage power line in Norway; cancer cases identified by linking cohort to national cancer registry for 1965-1989; 532 cancer cases, 2112 matched controls	Estimated lifetime residential magnetic fields based on proximity to power lines, distance between phases, line load; a substudy of children monitored by personal dosimetry for 24-hr found that children living within 50 m of power lines were exposed to 0.4-1.6 $\mu$ T for 75% of the 24-hr; those living at least 150 m from power lines were exposed to less than 0.1 $\mu$ T for 83% of the 24-hr; correlation between geometric mean 24-hr measured and estimated magnetic fields was 0.86 (Spearman's)	Childhood CNS cancers not associated with lifetime time-weighted avg magnetic field exposure in residences near power lines (odds ratios for 0.05-0.13 and $\geq$ 0.14 vs $<$ 0.05 $\mu$ T)(there were, respectively, 8 and 4 cases in these exposure categories)	1.9 (0.8-4.6) 0.7 (0.2-2.1)		Matched for sex, YOB, municipality
			Childhood CNS cancers not associated with proximity of residence to power lines (odds ratios for 51-100 and $\leq$ 50 vs $\geq$ 101 m)(10 and 14 cases, respectively, in these exposure categories)	0.6 (0.3-1.3) 0.8 (0.4-1.6)		As above
(Dockerty et al.	Population-based case-	24-hr avg 50 Hz EMF measured in	CNS cancers not	1.6 (0.6-4.3)		Matched for age

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates
1998), New Zealand	control study, 58 CNS cancer cases leukemia, age 0-14 yr, 1990-1993, 58 matched controls	child's bedroom and living room; mother-reported information on periconceptual/prenatal and childhood electrical appliance use	associated with prenatal maternal electric blanket, electrically heated waterbed or VDT use (respective odds ratios, yes vs no)	0.4 (0.1-1.9) 0.3 (0.0-1.9)		and sex
			No association between CNS cancers and childhood electric blanket, electrically heated waterbed or VDT use (respective odds ratios, yes vs no)	1.6 (0.4-7.1) 5.5 (0.4-85) 0.9 (0.3-2.7)		As above
			Association between CNS cancers and electric heating in child's day room but not bedroom during 2 yr before diagnosis (respective odds ratios, yes vs no)	4.2 (1.0-17) 0.5 (0.1-1.9)		
(Sorahan et al. 1999), Oxford Survey of Childhood Cancers, UK	Population-based case-control study, 15,041 cancer deaths, age 0-15 yr, 1953-1981, 15,041 matched controls	Self-reported occupational history; categorized jobs into five levels based on exposure to electrical machinery	Childhood brain cancer deaths not associated with maternal prenatal occupational magnetic field exposure (odds ratios, increasingly higher vs lowest categories)	1.4 (0.8-2.5) 0.3 (0.1-1.1) 1.6 (0.7-3.7) 1.1 (0.3-4.0)		Matched for sex and DOB; adjusted for maternal age at child's birth, SES, parity
(UK Childhood Cancer Study Investigators	Population-based case-control study, 2226 incident childhood cancer	Estimated EMF exposure during year before diagnosis; conducted residential spot measurements in	CNS cancers not associated with avg residential magnetic field	2.4 (1.2-5.1) 0.7 (0.2-3.2)		Matched for sex, DOB; adjusted for deprivation index

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates
1999), UK	cases, age 0-14 yr, 1991-1996, 2226 matched controls	child's bedroom, family room, 48-hr measurement in child's bedroom, spot measurements in school; proximity to power lines and line load data used to estimate avg magnetic field levels during study year	levels during year before diagnosis (odds ratios, 0.10-0.19 and 0.20-0.39 vs <0.10 µT)	p-trend > 0.3		
(Kheifets et al. 1999), USA	Review of literature on descriptive and analytic epidemiologic studies of childhood brain tumours and residential EMF	Included 10 studies 1979-1997; 9 studies used residential EMF exposure indices such as wire codes, proximity to power lines, magnetic field measurements or modeling; 6 studies assessed prenatal or childhood use of electric appliances	Inadequate evidence of an association between childhood brain tumours and any index of residential power frequency magnetic field exposure			
(National Institute of Environmental Health Sciences 1999), USA	Expert group review of health effects from power frequency EMF	Inadequate evidence of an association between childhood brain tumours and magnetic field exposure				
(Feychting et al. 2000), Sweden	Cohort study, 235,635 children born during 1976-77 and 1981-82; linked to national cancer registry records up to 1993; 522 cancer cases (161 leukemia, 162 CNS, 40 lymphoma, 25 neuroblastoma, 134 other)	Parental occupation, industry and SES from census records close to children's date of birth; estimated avg parental occupational magnetic field exposure using a job-exposure matrix and survey data on avg exposure levels in various occupations	CNS cancer not associated with maternal occupational magnetic field exposure (relative risks, 0.12-0.18, ≥0.19 vs <0.12 µT)	0.8 (0.4-1.3) 1.0 (0.6-1.9)		Sex, census year
			CNS cancer not associated with paternal	0.8 (0.6-1.2) 0.5 (0.3-1.0)		As above

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates
			occupational magnetic field exposure (relative risks, 0.13-0.29, $\geq 0.30$ vs $< 0.13 \mu\text{T}$ )			
(Schuz et al. 2001b), Germany	Population-based case-control study, 466 CNS tumour cases, age $< 15$ yr, 2,458 controls	Parent-reported information on occupational and other exposures	CNS tumours not associated with maternal electric blanket use during pregnancy (odds ratio, yes vs no)	1.3 (0.8-2.0)		Family net income, parental education, urban/rural
			Borderline association between medulloblastoma and maternal electric blanket use during pregnancy (odds ratio, yes vs no)	2.0 (1.0-4.3)		As above
(Ahlbom et al. 2001), International Commission for Non-Ionizing Radiation Protection	Review of epidemiologic literature on EMF and health		Recent, large, well-conducted studies suggest no association between childhood brain tumours and residential EMF exposure			
			Limited data and little evidence of an association between childhood brain tumours and prenatal maternal or childhood use of electric appliances (only 3 studies with inconsistent findings)			

Reference, location	Design	Exposure	Results	Association <sup>9</sup>	DR <sup>10</sup>	Covariates	
(Skinner et al. 2002), Childhood Cancer Study, UK	Population-based case-control study, 426 incident cancer cases (173 ALL, 45 other leukemia, 73 CNS, 135 other cancers), 1992-1996, age 0-14 yr, 419 matched controls	Conducted spot <i>electric</i> field measurements in child's bedroom and family living-room and a 48-hr measurement near child's bed	CNS cancers not associated with bedroom spot electric field level (odds ratio, 10-19 and $\geq 20$ vs $<10$ V/m)	0.9 (0.5-1.7)		Matched for age, sex, location; adjusted for age, sex, region, SES	
			CNS cancers not associated with bedroom spot electric field level analyzed as a continuous variable (odds ratio per 10 V/m increment)	1.4 (0.7-3.0)	1.1 (0.9-1.5)		
			In subset with verified electric field measurements, non-significant association between CNS cancers and spot electric fields (odds ratio, 10-19 and $\geq 20$ vs $<10$ V/m)	0.7 (0.3-1.8)	2.1 (0.8-5.8)		As above
(Linnet et al. 2003), USA	Review of epidemiologic literature on childhood cancer	Concluded that there is limited epidemiologic evidence for an association between childhood brain tumours and paternal occupational exposure to electromagnetic fields					

### Childhood CNS tumours: summary

#### Wire codes

A population-based case-control study in Los Angeles found an association between childhood brain tumours and underground wires but not other residential wire code categories (Preston-Martin et al. 1996b). Similarly, a case-control study in Washington State (based on a subset of the subjects in the previous study)

found no associations between childhood brain tumours and wire codes (Gurney et al. 1996). A meta-analysis of 3 epidemiologic studies (two in Denver, one in California and Washington State) found no association between childhood CNS tumours and two-level wire codes (Meinert and Michaelis 1996). A review (Kheifets et al. 1999) noted that two west-coast studies failed to replicate the association between childhood brain tumours and wire codes reported by two studies conducted in Denver.

#### *Proximity to high-voltage power lines*

A meta-analysis of 7 epidemiologic studies found an association between childhood CNS tumours and residential proximity to electric power transmission and distribution lines (Washburn et al. 1994). A case-control study nested within census cohorts of children living in regions crossed by high-voltage power lines in Norway found no association between childhood CNS tumours and residential proximity to high-voltage power lines (Tynes and Haldorsen 1997). A review by Kheifets et al. (1999) noted that 3 of the 4 epidemiologic studies of childhood brain tumours and residential proximity to power lines found no association while the fourth study found a borderline association.

#### *Measured and calculated residential magnetic field levels*

A population-based case-control study in Los Angeles found no association between childhood brain tumours and 24-hour magnetic field levels in the children's bedrooms (Preston-Martin et al. 1996b). A meta-analysis of 6 epidemiologic studies found no association between childhood CNS tumours and residential average magnetic fields (Meinert and Michaelis 1996). A case-control study nested within census cohorts of children living in regions crossed by high-voltage power lines in Norway found no association between childhood CNS tumours and calculated lifetime average residential magnetic fields (Tynes and Haldorsen 1997). A large population-based case-control study in the UK found no association between incident childhood CNS cancers and average residential magnetic fields during the year before diagnosis (UK Childhood Cancer Study Investigators 1999). Three literature reviews concluded that there is inadequate evidence for an association between childhood brain tumours and measured or calculated residential magnetic fields (Kheifets et al. 1999, National Institute of Environmental Health Sciences 1999, Ahlbom et al. 2001).

#### *Parental occupational magnetic field exposures*

A small case-control study in Ohio found an association between childhood brain tumours and paternal occupation as welder but no association with overall paternal occupations exposed to magnetic fields (Wilkins and Wellage 1996). A large population-based case-control study in the UK found no association between childhood brain cancer deaths and maternal prenatal occupational magnetic field exposure (Sorahan et al. 1999). A census-based birth cohort study (Feychting et al. 2000) found no association between childhood CNS cancer and maternal or paternal occupational magnetic field exposure; exposure was inferred from census-based information on occupation and industry and survey data on average magnetic fields in various occupations. A review by Linet et al. (2003) concluded that there is limited evidence for an association between childhood brain tumours and paternal occupational magnetic field exposure.

#### *Electric heating devices*

A population-based case-control study in Los Angeles found a borderline association between childhood brain tumours and prenatal but not childhood use of electrically heated waterbeds; there was no association with prenatal or childhood use of electric blankets (Preston-Martin et al. 1996b). A large population-based case-control study in west-coast States found no association between childhood brain tumours and maternal prenatal or childhood use of electric blankets or heated waterbeds (Preston-Martin et al. 1996a). Similarly, a case-control study in Washington State (based on a subset of the subjects in the previous study) found no associations between childhood brain tumours and maternal prenatal or childhood use of electric blankets or heated waterbeds (Gurney et al. 1996). A small case-control study in New Zealand found no association between childhood CNS tumours and prenatal or childhood use of electric blankets, heated

waterbeds or VDTs; there was an association with electric heating in children's day room but not with such heating in their bedroom (Dockerty et al. 1998). A population-based case-control study in Germany found an association between medulloblastoma but not total CNS tumours and maternal prenatal electric blanket use (Schuz et al. 2001b).

*Power-frequency electric fields*

A population-based case-control study in the UK found no overall association between childhood CNS tumours and spot electric field levels in the children's bedrooms; there was a borderline association with spot electric fields in the subset of subjects with verified electric field measurements (Skinner et al. 2002).

### 8. Childhood lymphomas: meta-analyses and recent literature reviews and original studies

Reference, location	Design	Exposure	Results	Association <sup>11</sup>	DR <sup>12</sup>	Covariates
(Washburn et al. 1994), USA	Meta-analysis of 5 studies of childhood lymphomas, 1979-1993	Residential proximity to electric power transmission and distribution equipment	Borderline association between childhood lymphoma and proximity to transmission and distribution lines (pooled odds ratio)	1.6 (0.9-2.8)		
(Meinert and Michaelis 1996), Germany	Meta-analysis of 5 studies of childhood lymphomas and EMF, 1979-1994	60 Hz magnetic field exposure based on wire code, proximity to high-voltage wires and magnetic field measures	Non-significant association between childhood lymphoma and measured or calculated residential average magnetic field levels (pooled odds ratio for avg fields >0.2 µT)	2.2 (0.7-6.8)		
(National Institute of Environmental Health Sciences 1999), USA	Expert group review of health effects from power frequency EMF		Inadequate evidence of an association between childhood lymphomas and magnetic field exposure			
(Feychting et al. 2000), Sweden	Cohort study, 235,635 children born during 1976-77 and 1981-82; linked to national cancer registry records up to 1993; 40 lymphoma cases during follow-up	Parental occupation, industry and SES from census records close to children's date of birth; estimated avg parental occupational magnetic field exposure using a job-exposure matrix and survey data on avg exposure levels in various	Lymphoma not associated with maternal occupational magnetic field exposure (relative risks, 0.12-0.18, ≥0.19 vs <0.12 µT)	0.4 (0.1-1.3) 0.4 (0.1-2.0)		Sex, census year

<sup>11</sup> Entries in this column include odds ratios, relative risks and certain other statistical measures of association as published in original epidemiologic studies; an entry of '+' means the measure of association was not an odds ratio or relative risk and was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

<sup>12</sup> 'DR' refers to a dose-response relationship in an epidemiologic study; an entry of '+' means the measure of dose-response relationship used in the citation was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

Reference, location	Design	Exposure	Results	Association <sup>11</sup>	DR <sup>12</sup>	Covariates
		occupations				
			Lymphoma not associated with paternal occupational magnetic field exposure (relative risks, 0.13-0.29, $\geq 0.30$ vs $< 0.13 \mu\text{T}$ )	1.3 (0.6-3.1) 0.9 (0.2-3.4)		As above
(Ahlbom et al. 2001), International Commission for Non-Ionizing Radiation Protection	Review of epidemiologic literature on EMF and health		Available studies show little evidence of an association between childhood lymphomas and residential EMF exposure but are limited by small numbers of highly exposed cases			

#### Childhood lymphomas: summary

A meta-analysis of 5 epidemiologic studies of childhood lymphomas found a borderline association with residential proximity to electric power transmission and distribution equipment (Washburn et al. 1994). A subsequent meta-analysis of 5 epidemiologic studies (including 4 studies also assessed by Washburn et al. 1994) found a non-significant association between childhood lymphomas and average residential magnetic fields (Meinert and Michaelis (1996). A census-based birth cohort study (Feychting et al. 2000) found no association between childhood lymphomas (there were only 40 cases) and maternal or paternal occupational magnetic field exposure; exposure was inferred from census-based information on occupation and industry and survey data on average magnetic fields in various occupations. Two recent reviews both concluded that there is inadequate epidemiologic evidence for an association between childhood lymphomas and residential magnetic field indices (National Institute of Environmental Health Sciences 1999, Ahlbom et al. 2001).

### 9. Other childhood cancers

Reference, location	Design	Exposure	Results	Association <sup>13</sup>	DR <sup>14</sup>	Covariates
(Tynes and Haldorsen 1997), Norway	Case-control study nested within census-based cohorts totaling 168,450 children age 0-14 yr living in census wards crossed by a high-voltage power line in Norway; cancer cases identified by linking cohort to national cancer registry for 1965-1989; 532 cancer cases, 2112 matched controls	Estimated lifetime residential magnetic fields based on proximity to power lines, distance between phases, line load; a substudy of children monitored by personal dosimetry for 24-hr found that children living within 50 m of power lines were exposed to 0.4-1.6 $\mu$ T for 75% of the 24-hr; those living at least 150 m from power lines were exposed to less than 0.1 $\mu$ T for 83% of the 24-hr; correlation between geometric mean 24-hr measured and estimated magnetic fields was 0.86 (Spearman's)	Borderline dose-response relationship between childhood cancers other than brain, leukemia and lymphoma and lifetime time-weighted avg magnetic field exposure in residences near power lines (odds ratios for 0.05-0.13 and $\geq$ 0.14 vs $<$ 0.05 $\mu$ T)(there were, respectively, 7 and 5 cases in these exposure categories – these included osteosarcoma, Wilm's tumour and testicular cancer)	2.9 (1.0-8.4) 1.9 (0.6-6.0) p-trend=0.07	(+)	Matched for sex, YOB, municipality
			Dose-response relationship between childhood cancers other than brain, leukemia and lymphoma and proximity of residence to power lines (odds ratios for 51-100 and $\leq$ 50 vs $\geq$ 101 m)(8 and 23 cases, respectively, in these exposure categories)	0.6 (0.2-1.2) 2.8 (1.5-5.0) p-trend=0.01	+	As above

<sup>13</sup> Entries in this column include odds ratios, relative risks and certain other statistical measures of association as published in original epidemiologic studies; an entry of '+' means the measure of association was not an odds ratio or relative risk and was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

<sup>14</sup> 'DR' refers to a dose-response relationship in an epidemiologic study; an entry of '+' means the measure of dose-response relationship used in the citation was statistically significant at the 0.05 level; an entry of '(+)' means the association was almost statistically significant.

Reference, location	Design	Exposure	Results	Association <sup>13</sup>	DR <sup>14</sup>	Covariates
(Feychting et al. 2000), Sweden	Cohort study, 235,635 children born during 1976-77 and 1981-82; linked to national cancer registry records up to 1993; 522 cancer cases (161 leukemia, 162 CNS, 40 lymphoma, 25 neuroblastoma, 134 other)	Parental occupation, industry and SES from census records close to children's date of birth; estimated avg parental occupational magnetic field exposure using a job-exposure matrix and survey data on avg exposure levels in various occupations	Kidney cancer not associated with maternal occupational magnetic field exposure (relative risks, 0.12-0.18, $\geq 0.19$ vs $< 0.12$ $\mu\text{T}$ )(there were only 28 cases)	1.7 (0.5-5.6)	As above	Sex, census year
			Kidney cancer not associated with paternal occupational magnetic field exposure (relative risks, 0.13-0.29, $\geq 0.30$ vs $< 0.13$ $\mu\text{T}$ )(there were only 28 cases)	1.4 (0.3-6.4)		
			Neuroblastoma not associated with maternal occupational magnetic field exposure (relative risks, 0.12-0.18, $\geq 0.19$ vs $< 0.12$ $\mu\text{T}$ )(there were only 25 cases)	1.1 (0.4-2.7) 1.7 (0.5-5.7)		
			Neuroblastoma not associated with paternal occupational magnetic field exposure (relative risks, 0.13-0.29, $\geq 0.30$ vs $< 0.13$ $\mu\text{T}$ )(there were only 25 cases)	2.6 (0.5-13) 3.9 (0.7-21)		
(De Roos et al. 2001), Children's Cancer Group and Pediatric Oncology Group, USA	Hospital-based case-control study, 538 cases neuroblastoma, age 0-17 yr, 1992-1994, 504 matched controls	Self-reported information from both parents on occupational exposure to electrical equipment and radiation sources during 2 yr before child's birth; used a job-exposure matrix and published	Neuroblastoma not associated with maternal occupational ELF-EMF exposure (odds ratios for self- and hygienist-rated probable exposure)	1.5 (0.5-4.6) 1.0 (0.2-5.7)	As above	Matched for DOB; adjusted for child's age, maternal race, age and education
				0.7 (0.3-1.3) 0.9 (0.2-3.7)		

Reference, location	Design	Exposure	Results	Association <sup>13</sup>	DR <sup>14</sup>	Covariates
and Canada		estimates of avg occupational magnetic field exposures				
			Neuroblastoma not associated with paternal occupational ELF-EMF exposure (odds ratios for self- and hygienist-rated probable exposure)	0.8 (0.6-1.2) 1.2 (0.8-1.9)		As above
			Borderline association between neuroblastoma and paternal occupational high magnetic field exposure (odds ratio, >0.4 vs ≤0.4 μT)	1.6 (0.9-2.8)		
			No association between neuroblastoma and maternal occupational high magnetic field exposure (odds ratio, >0.3 vs ≤0.3 μT)	0.8 (0.5-1.3)		

### **Other childhood and young adult cancers: summary**

#### *Mixed types of cancer*

A case-control study nested within census cohorts of children living in regions crossed by high-voltage power lines in Norway found a dose-response relationship between childhood cancers other than leukemia or brain and residential proximity to high-voltage power lines; this study also found a borderline association between such cancers and estimated lifetime average residential magnetic fields (Tynes and Haldorsen 1997).

#### *Kidney cancer*

A Swedish census-based birth cohort study (Feychting et al. 2000) found no association between childhood kidney cancer (there were only 28 cases) and maternal or paternal occupational magnetic field exposure; exposure was inferred from census-based information on occupation and industry and survey data on average magnetic fields in various occupations.

#### *Neuroblastoma*

A Swedish census-based birth cohort study (Feychting et al. 2000) found no association between childhood neuroblastoma (there were only 25 cases) and maternal or paternal occupational magnetic field exposure; exposure was inferred from census-based information on occupation and industry and survey data on

average magnetic fields in various occupations. A large case-control study of childhood neuroblastoma in United States and Canada found no overall association with maternal or paternal occupational magnetic field exposure but did find a borderline association with paternal occupational exposure to magnetic fields above  $0.4 \mu\text{T}$ ; magnetic field exposure was estimated from self-reported occupational history and published estimates of average occupation-specific exposures (De Roos et al. 2001).

**10. General considerations**

Reference, location	Design	Exposure	Results
(National Academy of Sciences 1997), USA	Expert panel review of potential health effects of residential 60-Hz electric and magnetic fields	There is no widely accepted understanding of how 60 Hz EMF could cause a disease or if it could cause a disease	At levels 3 to 5 orders of magnitude higher than those in homes, EMF can produce biologic effects, e.g., accelerated bone healing, changes in cellular signal transduction pathways and gene expression and behavioural change (but not adverse neurobehavioural effects); no reproducible genotoxic effects at any level
			There is no convincing evidence that 60-Hz EMF can cause cancer in animals
		The most appropriate EMF exposure metric for human health studies is unknown; wire codes are only weakly correlated with measured residential magnetic field levels and are associated with housing age and density and neighbourhood traffic density	Several epidemiologic studies have shown associations between childhood leukemia and residential wire codes but not with contemporary measured magnetic fields; the significance of the association with wire codes remains uncertain
			There is inadequate epidemiologic evidence for an association between adverse pregnancy outcome and 60 Hz EMF
			Current evidence from studies of power-frequency EMF on cells, tissues and humans does not indicate a human health hazard at residential exposure levels
(Boorman et al. 2000), USA	Review of mammary gland carcinogenicity studies of 50-60 Hz magnetic fields in rodents	3 large-scale chronic bioassays of carcinogenicity in rodents exposed to 50-60 Hz magnetic fields of up to 5000 $\mu$ T for 2 yr found no increased incidence of mammary cancer	12 studies of 50-60 Hz magnetic field and DMBA-induced mammary cancer in rodents found no consistent pattern; none of the studies that included histological examination found a significant increase in total mammary cancer incidence in groups exposed to EMF

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