Stakeholder Advisory Group on ELF EMFs (SAGE)

Precautionary approaches to ELF EMFs

Supporting Papers to the

First Interim Assessment: Power Lines & Property, Wiring in Homes and Electrical Equipment in Homes

Date of issue: 27/04/2007

R K Partnership Ltd
Ellsdone
Torbay Road
Castle Cary
BA7 7DW

phone/fax: 0845 4561813
email: sage@rkpartnership.co.uk

The SAGE process was initiated by National Grid but is now under the lead of the Department of Health. It is funded equally by the Department of Health, the Electricity Industry, and the charity CHILDREN with LEUKAEMIA.

The process was designed and facilitated by Rob Angell of RK Partnership Ltd and by Brendan Hickling of TW Welch & Partners. The facilitators hold no formal position on any of the substantive issues that have been or might be considered. It is for the participants to decide what issues are raised, how they might be addressed and how any observations, conclusions and recommendations might be recorded and communicated.

The R K Partnership website www.rkpartnership.co.uk has a full description of the process, as well as papers considered by the participants and reports produced from the process.

PLEASE NOTE

The remit of SAGE is to provide advice to Government. It is for Government to take decisions on policy relating to EMFs and health, based on this advice and whatever other inputs it deems necessary.

This document is the supporting papers to SAGE's first interim assessment.

The Assessment represents a record and a distillation of the discussions that have taken place within SAGE. It is not a single definitive set of universally agreed conclusions and recommendations, but rather captures the point our evolving discussions have reached. We are aware of places where particular issues need further consideration, and intend to progress our work. Merely by having participated in the process, no stakeholder is thereby bound to agree with every statement in the Assessment, or deemed to agree with every recommendation.

Government officials form a part of the process to inform the debate and to supply factual input to the Assessment. The Government supports the production of the Assessment and welcomes the material and the contribution it makes to consideration of the EMF issue. However, this does not necessarily imply that Government is aligned with the views expressed or the conclusions stated in the Assessment and Government representatives will not be formally supporting any particular conclusions and options outlined in the Assessment as that is a matter for Government as a whole to consider once it has received the Assessment.

Recognising that the Assessment reflects some degree of agreement but not total agreement, each stakeholder has been given the opportunity to make a statement of their view of the point the SAGE discussions have reached. These are contained in the appendix to the Interim Assessment.

Stakeholders (individuals and organisations) are not bound by this Assessment in their future activities or commercial decisions.

Contents

Supporting Paper S1

S1 Participants in SAGE

The following stakeholders have been involved in the SAGE process.

Everyone has been a member of the Main Group. Participation in other groups is indicated as follows:

Power lines and property	PLP
Internal wiring and electrical equipment:	EIE
Coordinating group:	C
Funders' group:	F
Review and Completion group:	RC
Public Opinion:	PO

Person	Organisational Affiliation	Participation in groups (additional to Main Group)
Academics		
Roger Coghill	Coghill Research Laboratories	EIE
Denis Henshaw	University of Bristol	PLP, C, RC
Alan Preece	University of Bristol	EIE
Electricity Industry		
Tony Glover	Energy Networks Association	
Ross Hayman	National Grid	
Gareth Llewellyn	National Grid	
Keith Maclean	Scottish and Southern Energy (since December 2005 until March 2007)	PO
Hector Pearson	National Grid	PLP
David Renew	National Grid	
John Swanson	National Grid & Energy Networks Association	PLP, EIE, C, F, RC, PO
Individuals		
Ingrid Dickinson	MastSanity until November 2005, thereafter Individual	PLP
Mike O'Carroll	University of Sunderland & Revolt	PLP, C, RC
Geoffrey Stokes	Institution of Engineering and Technology (IET) Wiring Regulations Policy Committee	EIE
Local campaign groups		
Maureen Asbury	Trentham Environmental Action Group	
Caroline Paterson	Stirling Before Pylons	

Person	Organisational Affiliation	Participation in groups (additional to Main Group)
National campaign groups		
Edward Copisarow	CHILDREN with LEUKAEMIA	F, PO
Katie Martin	CHILDREN with LEUKAEMIA (until March 2007)	
Alasdair Philips	Powerwatch	EIE
Chantelle Roberts	CHILDREN with LEUKAEMIA (since March 2007)	
Brenda Short	Powerwatch	
National government departments		
Katy Collins	Office of the Deputy Prime Minister (up to July 2006)	PLP
Alison Edwards	DCLG (since September 2006)	
David Gray	DTI	PLP
George Hooker	Department of Health	PLP, EIE, C, F, RC, PO
Arthur Johnston	Scottish Executive Health Department	
Richard Mellish	DTI	
Nigel McMahon	Department of Health, Social Services & Public Safety (NI)	
Rod Robson	Energy Division of the Department of Enterprise, Trade and Investment, Northern Ireland	
John Steed	DTI (up July 2006, subsequently HSE)	EIE
Hilary Walker	Department of Health	C, F
Stephen Wall	Welsh Assembly Government	
Other Industry		
Mike Dolan	Mobile Operators' Association	PLP
David Dossett	BEAMA (The Association for the British Electrotechnical Industry) (since November 2006)	
Richard Hughes	AMDEA (Association of Manufacturers of Domestic Appliances)	EIE
Professional bodies.		
Tony Barker	Institution of Engineering and Technology (IET) (formerly Institution of Electrical Engineers (IEE))	PLP, RC
John Ware	Institution of Engineering and Technology (IET) (formerly Institution of Electrical Engineers (IEE))	EIE
Property		
Barry Hall	Council of Mortgage Lenders	PLP
Michael Jayne	Nottingham Trent University & Royal Institution of Chartered Surveyors	PLP, RC

Person	Organisational Affiliation	Participation in groups (additional to Main Group)
Sally Sims	Oxford Brookes University	PLP
Regulators		
John Benson	Office for Gas and Electricity Markets (Ofgem) (until February 2007)	PLP, EIE, C, RC
Statutory Advisory Bodies		
Jill Meara	Health Protection Agency (formerly NRPB)	PLP, EIE, RC

Supporting paper S2

S2 EMF Metrics

1 Background

The doubling of childhood leukaemia risk associated with magnetic field exposures above 0.4 µT refers to the so-called time-weighted average exposure. In fact, there are a variety of ways to characterise exposure to power-frequency magnetic fields, for example the average night-time exposure or the maximum day-time exposure, and the issue of which exposure metric or metrics are most relevant to health risk has been discussed for some time.

In 1998 the then NRPB (now the HPA-RPD) held an International Workshop on "*Exposure metrics and dosimetry for EMF epidemiology*", the proceedings of which were published in a special issue of Radiation Protection Dosimetry[1]. In the UK nothing of substance appears to have happened since this workshop was held, although a recent Department of Health/HPA research tender document on "Health effects of ionising radiation and electromagnetic fields (excluding telecommunication)" lists "*Development of exposure metrics...."* as one of the Programme's research priorities.

2 Choice of EMF exposure metric

It is clear that from the point of view of the scientific debate and the epidemiological findings in relation to health and EMF exposure, there is considerable current interest in metrics. For example, some recent studies of miscarriage have suggested a stronger link with magnetic field exposure when the maximum or peak exposure is taken into account. There are also suggestions that night-time exposure may be particularly relevant in relation to the hypothesis that this may suppress or otherwise disrupt the nocturnal production of natural anti-oxidant melatonin in the pineal gland.

Accordingly, a sub-group of SAGE has considered which of the many possible metrics of EMF exposure should be considered from the point of view of precaution. A full list of possible metrics is attached, but it is clear that from the point of view of precaution there would be major practical difficulties in adopting metrics involving anything other than a relatively simple measurement.

We therefore agreed:

- That we note that we are aware that there are several possible metrics, but for the purposes of precaution only a limited number of these should be considered at present.
- That of the more simple metrics, we adopt TWA (24), a time-weighted-average magnetic field exposure over 24 hours, as an exposure metric on which to base precautionary measures against public exposure.

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[1] Vol. 83, Nos. 1-2, 1999

3 Magnetic Field Assessment Methods and Metrics

At present, this is a list, not in any particular order, compiled by various stakeholders, of different metrics and assessment methods that have been used in EMF work to date. It is not presented as a rigorous scientific analysis or as a definitive list.

Metric	Description
Average MF strength	Arithmetic mean of MF strength A/m, though often given in Tesla.
Average magnetic flux density	Arithmetic mean of flux density, Tesla, though MF strength is most frequently used
Time weighted average – TWA (unless otherwise stated, for 24 hours: TWA(24)	$B_{TWA} = \frac{1}{T}\int_0^T B_{res}\,dt$, B_{res} is $\sqrt{B_x^2 + B_y^2 + B_z^2}$
12 h day TWA	B_{TWA} but only for 12 hrs of the day
12 night TWA	B_{TWA} but only for 12 hrs of the night
Geometric mean	Measure of 'central tendency' $G = \sqrt{AH}$ Where A is arithmetic mean and H is harmonic mean value
Median MF	The midpoint in a series of MFs; half the values are above the median, and half are below
Fixed-location long term	A long term measurement of MF strength in one place
Spot measurement	Single (or very few) measurement of MF strength at one point
Personal exposure	A MF meter is worn to gauge an individual's exposure
Rate of change of field	dB/dt
Frequency/ Total harmonic distortion - THD	Mean of the broadband and/or 50 Hz and/or harmonics; harmonic/ broadband ratio
Rate of change - RCM	Root mean square of the Δ MF between successive sequential samples $RCM = \sqrt{\left[\sum_{j=1}^{N-1} \frac{(B_{i+1} - B_i)^2}{N-1}\right]}$

Metric	Description
Standardised RCM - RCMS	$RCM = \sqrt{2}SD(B_t)\sqrt{(1-\gamma_1)}$ $RCMS = \sqrt{2}\sqrt{(1-\gamma_1)}$ Where y is first lag autocorrelation[1]
Polarisation/ Ellipticity	% minor/major axis of the ellipse traced out by the field vector
95th percentile value	Highest remaining value of MF strength after the top 5% of measured values have been discarded
Cumulative exposure	µT.years or µT.hours
Percentage time over X µT	% time that the MF > threshold value X (NB compare with effect function below)
Constant field metric	Estimates field stability - total length of time in MF > 0.2 µT, when variation in orthagonality < 10%, and these conditions are met for $\geq$12 seconds
Effect functions E_1, E_2, E_3 (Threshold, T)	E_1 α N^o 5 min sequences/hr when 80% field exposure is > T E_2 α N^o counts/hr when Δ field strength $\geq$T E_3 α N^o 5 min sequences /hr when 20% Δ field strength $\geq$T
Calculated MF	Historical calculations/ situation models to estimate MF strength
Field combinations	Is risk of CHL related to combinations of static and power-frequency MF?
Frequency domain analysis	Variation in time periods of measurements
Wire-code	Wiring design of homes
Powerline proximity	Proximity of homes/ places of work to power distribution lines
Appliance usage	Frequency of usage of appliances in the home and work place; Positioning of the user in relation to the appliance MF

Supporting Paper S3

S3 Extension of precaution outside the home

1 Introduction

The epidemiological evidence on magnetic fields and childhood leukaemia relates primarily to exposure in the home. Most of our work has accordingly concerned homes. We consider here whether and how to extend this to other locations, principally schools. We consider first whether there is a justification for considering schools and other locations, then, if so, how this can best be done.

This discussion is mainly in the context of childhood leukaemia. For other possible adverse health effects, we agreed there was too much uncertainty in the scientific evidence to allow the sorts of judgements necessary.

2 Is there a scientific basis for considering precaution outside the home?

The Ahlbom pooled analysis of magnetic fields and childhood leukaemia, which has been highly influential on scientific opinion and on which we have based much of our work, extracted from the exposure assessments used in each of the constituent studies just the 24-hour (or longer) average field in the home. Therefore, the epidemiological evidence on magnetic fields and childhood leukaemia, as summarised by Ahlbom, relates only to fields in homes.

We therefore recognise the case that, since the home is the only exposure situation for which we have evidence, this is the only exposure situation we can or should take precaution on. On this argument, we have no knowledge whatever about what the risks are in schools. We can only take precaution about the risk that is suggested; we can take precaution about homes because that's what we have studies on, we cannot take precaution about schools because we have no evidence.

However, there are two scientific counter-arguments.

One is that the obvious interpretation of the epidemiological results is that they implicate time-weighted average exposure, or at least long-term exposure if not strictly time-weighted average fields. There is no reason to suppose such fields, in the home, have any different biophysical effect to fields elsewhere (though if the time of day at which exposure occurred were relevant, this could change this argument). If fields in the home cause cancer, we would expect similar exposures elsewhere to do the same. There may be debate about how to transfer the concept of “24 hour average greater than 0.4 µT” to other settings, but the principle is that the evidence implicates magnetic fields, and therefore implicates magnetic fields in the school (and elsewhere) as well as in the home.

The other counter-argument is that it is only in the Ahlbom pooled analysis that exposure is limited to the home and exposure in schools is excluded. Some of the constituent studies either did include exposure in schools or sought to. The decision to exclude such exposures from the pooled analysis was in the interests of consistency between studies, not on any principle of which exposures are relevant. Specifically, the UKCCS did include exposure in schools, investing some effort in measuring fields in schools, and the McBride study in Canada measured personal exposure and therefore automatically included exposure in schools. The Linet study in America started out with the principle that exposure in schools was relevant and did considerable exploratory work. They decided not to measure in schools, not because it was wrong in principle, but because they decided the difference it would make to the exposure estimates in practice did not justify the cost involved. Thus the three largest single studies actually did consider exposure in schools to be relevant, and two of them actually included it, and therefore, to some extent, the epidemiological evidence is relevant to schools as well as homes.

We conclude that, scientifically, it is legitimate to argue this issue either way. However, looking beyond the science, we recognise that society is unlikely to regard exposure in schools as acceptable when the same exposure in the home is not. This is because exposure in schools is largely involuntary, involving many children at once, and in a setting where we commit our children to society's safe-keeping for their benefit,

This consideration of issues broader than just the science therefore influences us to opt for the view that the epidemiological studies implicate exposure to magnetic fields in general rather than only in homes, and therefore it is correct to consider precautionary measures in schools as well as homes. The age range of relevance would be up to 15, matching the usual definition of childhood leukaemia, thus including most schools but excluding sixth-form colleges.

3 Where outside the home should be considered?

We have chosen to formalise the buildings in which any precautionary policies should apply in terms of the Use Classes defined in Planning legislation, as listed in Section 5.5. The aim is to include buildings where people spend long periods of time, using overnight stays as an indicator of this. For children, where there is the greatest priority for protection, the net is cast wider, and hence schools and nurseries and other childcare settings where an individual child might spend a significant fraction of the week are included. For adults, the restrictions are more relaxed, hence workplaces are not included. The Use Classes used in planning law do not correspond exactly to the uses we would ideally define, but we consider that using these existing definitions is nonetheless the best approach.

We suggest that precautionary policies should apply to buildings and not to the associated gardens, playgrounds or grounds. This is on the basis:

- that the epidemiological evidence relates to buildings
- that definition of the exact extent on the ground is easier (and hence ambiguity and disputes less likely) for buildings than for gardens
- that people spend more time, perhaps an order of magnitude more, in buildings, particularly homes and schools, than in gardens or school playgrounds.
- That when people are outside, they tend to move around more, making a definition of exposure harder

4 How should schools be included in precautionary considerations?

We identify three main approaches to considering schools (and, by extension, other locations): a separate quantitative treatment; a half-way house; and simply treating them the same as homes.

Approach 1: separate quantitative treatment

This assumes that a magnetic field has the same effect wherever it is experienced: all microtesla-person-hours are equally effective at increasing the risk of leukaemia wherever accumulated.

Assume a child spends a quarter as long at school as at home. This is derived by assuming 7 hours per day for 190 days per year at school, compared to 16 hours per day for 340 days per year at home; but infants and young children probably spend longer at home and certainly don't spend time at school. So the average child's exposure at school carries a quarter of the risk of their exposure at home. Compare a home (with the 0.45 average number of children occupying it) with a school of say 1000 pupils. The value of removing the school from >0.4 µT to <0.4 µT would be 1/0.45 x 1000 x 1/4 = 550 times greater than for the home (which we round to 500 times).

This calculation assumes that the whole school is either exposed >0.4 µT or is not, which is probably almost never true (and becomes less true the larger the school is). Suppose 10% of the occupied volume of a school is in >0.4 µT. Then the value of removing the school (or the bit of it that is exposed) becomes 50 times greater than for the home. This calculation can be made specific to any particular school; there will be some which are entirely above 0.4 µT, but there are certainly secondary schools where the power line goes across the playing fields and not the buildings at all.

It also takes no account of the varying risk for leukaemia over age - a secondary school, for instance, has a lower risk than a primary school, and both are lower than for a nursery, on the assumption of a constant risk ratio (and no-one knows if the risk, if there is one, is a constant excess risk or a constant risk ratio). The rates (for childhood leukaemia) would in fact be roughly halved for secondary ages and roughly doubled for nursery. So we might say:

- a 50 child nursery, entirely above 0.4 µT: 1/0.45 x 50 x 2 = 50 times the value of a home
- a 2000 pupil comprehensive, 10% above 0.4 µT: 1/0.45 x 2000 x 0.1 x 0.5 = 50 times also.

We recognise a number of problems with this approach:

- The epidemiological evidence does not suggest that all microtesla-person-hours are equivalent; it suggests that it is fields >0.4 µT that matter. Indeed, it could be argued it is not just fields above 0.4 µT, it is homes where the average field over 24 hours or more is >0.4 µT. How do we translate that concept to schools? Is spending 7 hours in a field >0.4 µT sufficient to trigger whatever effect it is that is produced by spending longer periods in >0.4 µT in the home? Should it be hours above 0.4 µT that we pro-rata rather than cumulative exposure or is there a threshold number of hours?

- We have little good evidence as to whether day-time exposure is equivalent to night-time exposure or not. Indeed, there are hypotheses as to why it is night-time exposures that matter, in which case presumably daytime exposure in schools would not be relevant at all.

- We do not know about the ages of children that are relevant. When Draper et al was published, looking at address at birth, some people saw that as evidence that it is exposure earlier in life or even prenatally rather than at diagnosis that matters. In that case, presumably schools would be irrelevant. Milham argues that the appearance of the peak of childhood acute lymphocytic leukaemia (ALL) in the early 20th century is caused by magnetic fields; again, if it is the childhood peak in particular, affecting younger children, that is caused by magnetic fields, most exposure in schools is not relevant.

Approach 2: simple scaling of the epidemiological results for homes.

The epidemiological results implicate a field of 0.4 µT in the home. Exposure in schools is for a quarter of the time; therefore precautionary action should be taken in schools if the field is four times higher, 1.6 µT.

Approach 3: just do whatever we do for homes

Suppose we decide there should be no new homes built within 60 m of power lines. Then decide no new schools should be built either. Suppose we decide to buy up and demolish all existing homes within 60 m. Then demolish the existing schools as well.

This is pragmatic, and probably the easiest to apply in practice.

Overall, we recognise that the attractiveness of apparent quantitative rigour in the first approach is probably illusory, as there are so many uncertainties and assumptions. There are likewise conceptual problems with the second approach. Accordingly, we have, on balance, opted for the third approach.

Supporting Paper S4

S4 Key assumptions and facts and figures about health risks

This paper sets out the key facts and figures about EMFs and possible adverse health effects. Some are data from the literature, some stem from assumptions we have chosen to make.

1 Childhood leukaemia

This table considers two scenarios, labelled in shorthand "Ahlbom" and "Draper". The former is what is normally regarded as the epidemiological evidence on magnetic fields in homes and childhood leukaemia. The latter is specific to the one particular study, Draper et al, on power lines. As discussed in Sections 2 and 5, we draw our conclusions for childhood leukaemia mainly on the basis of "Ahlbom"; we include the "Draper" figures here for completeness.

Science based on Ahlbom et al 2000	**Science based on Draper et al 2005**
Mechanism is magnetic fields	Mechanism is unknown but not (or not solely) magnetic fields; distance is a suitable surrogate
The threshold is 0.4 µT (and above) which for typical National Grid power lines equates to an average of 60 m, less for lower voltage lines (this is a working assumption made by SAGE)	The threshold is 600 m (and below)
The relative risk is: 2 (this is a working assumption made by SAGE which includes several unresolved debates about the shape of the dose-response curve)	The relative risk is: 1.23 for 200-600 m 1.69 for 0-200 m 1.28 for 0-600 m (assumes risk does not extend beyond 600 m)
Annual risk of childhood leukaemia: 1 in 24,000 per year (this is the average over childhood; at the peak at age 1-4 the risk is 1 in 13,000 per year) Lifetime risk of childhood leukaemia 1 in 1600 Number of cases per year: 420 (E&W), 480 (UK)	
The number of attributable cases is: 2 per year for all sources of field 1 per year for all power lines 0.5 per year for National Grid power lines (fractions attributable to the different sources derived from the HPA "residential sources" study)	The number of attributable cases is: 5 per year for National Grid power lines 5-25 per year for 132 kV power lines as well (derived from 5 per year from Draper et al and recognising that the extension to 132 kV lines could multiply by between 1 and 5)
The exposed fraction of the population is All sources 0.4%=90,000 homes=40,000 children All power lines 0.2%=45,000 homes=20,000 children National Grid power lines 0.1%=23,000 homes=10,000 children	The exposed fraction of the population is 4%=900,000 homes=400,000 children (figures for 0-600 m for National Grid lines only – multiply by 1-5 to get figures including 132 kV lines)

2 Other adverse health effects

For other adverse health effects, we list here the national incidence or prevalence. New cases are expressed as cases per year; ongoing prevalence of a condition is expressed as a percentage. We recognise that these figures could be refined and expressed in better ways.

adult leukaemia	7,000 cases per year
adult brain cancer	4,500 cases per year
Alzheimer's disease	50,000 cases per year
amyotrophic lateral sclerosis	1,000 [? Check] cases per year
breast cancer	42,000 per year cases per year
other childhood cancers	1,000 cases per year
depression: mixed anxiety and depression	(7 per cent for men, 11 per cent for women)
depression: anxiety	(4 per cent for men, 5 per cent for women)
depression	(2 per cent for men, 3 per cent for women)
electrical sensitivity	unknown
certain types of heart disease	Prevalence of coronary heart disease (England, 2003): Males 7.4%, Females 4.5%
miscarriage	Approx. 1 in 4 pregnancies. ~250,000 per year in the UK
suicide	6,000 per year

Supporting paper S5

S5 Comparison of risks from different activities and agents

This Supporting Paper compares the possible risks from exposure to power frequency electric and magnetic fields (EMFs) with other hazards from environmental factors.

Attributable deaths per year

UK annual attributable deaths and relative incidence risk for a number of environmental and lifestyle hazards including the Ahlbom and Draper powerlines/power frequency electric and magnetic fields (EMFs) and childhood leukaemia scenarios[2].

Attributable deaths per year					
Hazard	Reference	Mechanism of harm/disease	Strength of evidence of causality	Timing of effect	Attributable deaths per year (UK unless otherwise stated)[3]
EMFs Ahlbom hypothesis, childhood leukaemia (Age 0-14)	1	Childhood leukaemia	Statistical association and hypothesised mechanism	Within 15 years, but many before age 5	Less than 1[4]
Lightening strike all ages Britain	14	Cardiac arrest/neurological damage	Causal	Immediate	3-5
Residential proximity to power lines within 600 m Draper hypothesis, childhood leukaemia (Age 0-14)	8	Childhood leukaemia	Statistical association and hypothesised mechanism	Within 15 years, but many before age 5	1-5 [3]
Carbon monoxide	10	Hypoxia	Causal	Immediate	30
Drowning, choking, suffocation (Age 0-14,2004)	13	Hypoxia	Causal	Immediate	72
Childhood transport accidents (Age 0-14, 2004)	13	Traffic accident	Causal	Usually immediate	139

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[2] Quantitative estimates have not been agreed for other medical conditions that have been linked to EMFs in some published studies. However in this case the number of attributable cases and deaths would be considerably greater and the relative risks would apply to a larger selection of diseases.

[3] Some of these numbers are exact values, as from death certificates and coroners reports; others are model dependent (generally a linear-no-threshold model for many environmental hazards, but a threshold is assumed for EMFs)

[4] SAGE has used the results of the Ahlbom and Draper studies as two models of the possible numbers of childhood leukaemia cases attributable to EMFs (see S4) The figures here also use those models, but with the additional assumption that attributable deaths are 20% of attributable cases (2 cases per year for Ahlbom and 5-25 cases per year for the Draper model). These figures (as with others in the table) make no assumption about the health detriment of non-fatal cases and deaths occurring after age 14, although that detriment is taken into account in our cost-benefit calculations.

Attributable deaths per year					
Hazard	Reference	Mechanism of harm/disease	Strength of evidence of causality	Timing of effect	Attributable deaths per year (UK unless otherwise stated)[3]
Radon gas, all ages, all levels of exposure	6	Lung cancer	Causal	Within 30 years	1000 - 2000
Attributable deaths per year					
Hazard	Reference	Mechanism of harm/disease	Strength of evidence of causality	Timing of effect	Attributable deaths per year (UK unless otherwise stated)
Ultraviolet radiation from the Sun and artificial sources, all ages	9	Malignant melanoma	Causal	Within 30 years	2000
Exposure to second-hand smoke at home (passive smoking) Age 20-64	11	Various, especially cancer and heart disease	Some epidemiological evidence, biological evidence at higher exposures	Within 30 years	2700
Air pollution PM10[5] and sulphur dioxide SO_2[6] in urban areas of Great Britain, all ages	3,4,5	Respiratory diseases	Causal [7]	Within 30 years	8,100
Active smoking, all ages, 2000,	12	Lung cancer	Causal	Within 30 years	30,000
Active smoking, all ages 2000	12	Lung cancer, heart disease and other causes	Causal	Within 30 years	115,000

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[5] PM_{10}: particulate matter generally less than 10 µm in diameter. Sources include road transport (especially diesel), combustion and industrial processes. These emissions have more than halved since 1970. http://www.naei.org.uk/pollutantdetail.php?poll_id=24&issue_id=1
Estimated total deaths occurring in urban areas of GB per year = c430,000 from all causes

[6] SO_2 is produced from combustion of solid fuel and some petroleum products. Levels have fallen by more than 5-fold since 1970 http://www.naei.org.uk/pollutantdetail.php

[7] Advised likely to be causal (COMEAP)

Relative risk of disease incidence

Relative risk of disease incidence					
Hazard	Reference	Disease	Strength of evidence of causality	Timing of effect	Relative risk compared to people without the risk factor
Eating vegetables (upper quartile of consumption v lower quartile)	2	Lung cancer	Established epidemiological association	Within 30 years	0.7[8]
Air pollution: living in a large city	2	Lung cancer	Some epidemiological and biological evidence	Within 30 years	1.2
Residential distance from power lines Draper hypothesis, childhood leukaemia Living 200-600 m from a power line	8	Childhood leukaemia	Statistical association and hypothesised mechanism	Within 15 years	1.2
Exposure to second-hand smoke (passive smoking) all ages	7	Lung cancer	Causal	Within 30 years	1.2
Smoking 25 or more cigarettes per day	2	Leukaemia (adult)	Some epidemiological evidence	Within 30 years	1.3
Female alcohol consumption, more than one drink per day vs none	2	Breast cancer	Some epidemiological and biological evidence	Within 30 years	1.4
Exposure to second-hand smoke (passive smoking) in children aged 0-6	7	Serious lower respiratory tract infections	Some epidemiological evidence, biological evidence at higher exposures	Short term	1.6
Residential distance from power lines Draper hypothesis, childhood leukaemia living within 200m of a power line	8	Childhood leukaemia	Statistical association and hypothesised mechanism	Within 15 years, but many before age 5	1.7
EMFs Ahlbom hypothesis, childhood leukaemia from exposures above 0.4 uT at home	1	Childhood leukaemia	Statistical association and hypothesised mechanism	Within 15 years, but many before age 5	2.0
Domestic radon above 800 Bq/m³	6	Lung cancer	Causal	Within 30 years	2.0
UV exposure of the skin, repeated sun burns	2	Malignant melanoma	Causal	Within 30 years	3.7
Smoking 25 or more cigarettes per day	2	Lung cancer	Causal	Within 30 years	10.0

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[8] Note that this means vegetables could be protective against lung cancer

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Supporting paper S6

S6 Analysis of costs and benefits

1 Introduction

We have explained our use of cost-benefit analysis in Section 2, describing how we see it as a tool to help us understand some of the issues and to guide society towards the best use of its resources, without being prescriptive. Here, we give more detail on the calculations we have done, to arrive at figures for the benefit of reducing fields. We then apply these results, first to the options for house wiring in Supporting Paper S10, then to the options for power lines in Supporting Paper S19.

Our full quantitative analysis is confined to childhood leukaemia, because it is here that the data give a reasonable basis for the calculations necessary. For other possible adverse health effects, we do not perform a separate calculation. Instead, we take the methodology and the calculations we have performed for childhood leukaemia, and assume that if EMFs are a cause of many of these other possible effects, then the impact on society could be a hundred or so times larger. We explain the justification for this approach in Section 2.4.

For this purpose, we have assumed that magnetic fields do cause childhood leukaemia; there is no allowance in our analyses for the uncertainty in whether this is true. Similarly, in several places our valuation of benefits is deliberately higher than current normal Government practice. Therefore, if our analysis concludes that an option is not justified, this is likely to be a fairly safe conclusion in conventional cost-benefit terms, though the number of uncertainties means nothing can be certain.

We stress that in this section, our aim is to explain our methodology and reasoning. The conclusions we draw are to be found in Section 5 and not here.

2 Consideration of costs

2.1 General issues

Many of the options we consider do not have a single, unambiguously identifiable cost; instead, they produce a chain of transfers of value from one section of society to another, with some people gaining and others losing. We have not fully explored who within society would pay the cost. We have simply aimed to identify what the total cost would be, regardless of where it falls.

As an example, consider a ban on any new development of homes on land within x metres of a power line. This would set in train a sequence of changes to land and property values:

1. Owners of undeveloped land near power lines in areas allocated in Local Plans for development suffer a loss of value (the amount depends on whether they are allowed to develop commercial property instead, or no development at all)
2. Some fraction of those landowners claim and are paid compensation by the electricity company
3. The electricity company may or may not pass that cost on to the electricity consumers, depending on various legal and political factors
4. In some parts of the country (eg Thames Gateway) the number of new homes that Government/Regional/Local authorities want built are not built because there is no alternative land (or perhaps the same number is built but smaller homes)
5. In other parts of the country, the same number of homes get built, by using land that would otherwise not have been developed (in some cases this may involve allowing development on current greenbelt)
6. Owners of land available for development but not within the x metres of the power line gain an increase in value (a small increase if the land was already allocated for development, a large one if it was previously unavailable for development)

7. The homes that are built are correspondingly more expensive than they would have been
8. Existing homes within and possibly beyond x metres of power lines in general become less attractive because of the message that homes near power lines are unsafe/undesirable, and suffer a price drop
9. People owning/selling those homes suffer a loss; some recover that loss from the electricity company, some don't
10. People buying those homes buy a less attractive property for a lower price
11. Existing homes not near power lines become proportionately more attractive and hence, possibly, more expensive; their owners gain a windfall; people buying them pay a larger price for the property
12. A few homes near-ish power lines may become more valuable if the ban on development prevents development that would otherwise have reduced their value

Faced with this chain of transfers of value, we have been guided by the Cabinet Office Better Regulation Executive[1]. They say, in part (emphases in original):

- *In general, the analysis of costs and benefits will need to quantify only at the first-round, or impact effects of proposed measures. …*
- *In most cases, you should note any macroeconomic or second-round effects but it will not normally be necessary to try to quantify or forecast them…. Such effects are difficult to estimate and are likely to be speculative, and, in most cases represent simply a re-distribution of resources within the economy, without any net overall economic effect. ….*
- *Most proposals will not have significant* ***macroeconomic*** *effects. Therefore, effects on jobs or foreign trade are not normally relevant, since displaced workers will find other jobs and trade will be brought back into balance by changes in domestic or foreign demand or prices.*
- *If there are likely to be significant* ***transitional*** *or* ***regional*** *effects, these should be mentioned (e.g. if a large industry will close down in an isolated area and there is likely to be prolonged local unemployment) …*
- *There may be cases where* ***second-round*** *effects could add to costs or benefits. This would normally be where the initial proposal had significant spillover or demonstration effects. For example, if a proposal to restrict storage of goods on industrial premises resulted in increased freight movements, the extra road congestion could have negative spillover effects on the rest of the economy. Or if a proposal led to increased use of ICT in one sector, there might be positive demonstration effects reducing costs in other sectors.*
- *However,* ***it will seldom be the case that mere changes in the direction of an industry's expenditure lead to a significant overall second-round effect****. For example, if an industry has to buy new safety equipment, this will improve the revenues of the suppliers of that equipment. But the industry will have to reduce its expenditure in some other area, and so there will be other suppliers who will lose out, with no overall effect on the economy.*

Following these principles, we have therefore attempted to quantify "first-round" effects of each option, that is, the immediate costs it imposes. We similarly attempt to note but not to quantify "second-round" effects and distributional effects, which would fall unevenly on house-holders, property owners and businesses. Where there is ambiguity as to these definitions, we consider the answer under different definitions, eg "first-round" being just the impact on industry, or on industry plus consumers, or on industry plus consumers plus home-owners.

2.2 Deferring costs and benefits

In general, if an option is deferred, both the present costs but also the present benefit can be reduced. This, in itself, is unlikely to affect the cost-benefit comparison greatly.

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[1] http://www.cabinetoffice.gov.uk/regulation/ria/ria_guidance/index.asp

3 Value to society of preventing childhood leukaemia

We assumed the value to society of preventing a fatal case of childhood leukaemia is £4M.

To arrive at this figure, we have taken one clear steer from the HSE[1]. They say to use £1M for a fatality, which is also in line with the official highways figure of £1.3M. They also say that this should be increased in certain circumstances. The only specific example they give is for cancer, which they say as a dread disease is given greater priority, and they give a factor of 2, making £2M per fatality. This multiplier clearly applies in our situation.

They are mainly thinking about occupational safety issues and therefore mainly adults. We consider it is reasonable that another of the factors which they suggest could increase the value is when children are affected, particularly when the exposure is involuntary. We can justify this in two ways: one is that a child killed at age 5 probably loses twice the expected life years of an adult killed at age 40. The other is simply that society recoils more from children dying than adults. Either way, a further factor of 2 seems reasonable, giving £4M per fatality.

Another relevant figure we are aware of is from the National Institute for Health and Clinical Excellence (NICE), who for some purposes use £30,000 per QALY (Quality Adjusted Life Year). For a child dying age 5 and losing 70 years life, this is 70 x £30,000 = £2.1M, though not allowing for discounting of the benefits in later years, so this is at least comparable to (though clearly not the same as) the HSE figure.

We also assumed the value to society of preventing a non-fatal case of childhood leukaemia is £0.5M.

To derive this, suppose we say that when a child gets leukaemia, they have three years of extremely unpleasant treatment at a quality-of-life factor of 0.5; 60 years of impaired life at 0.9; and that (little more than a guess on our part) their life expectancy is reduced by 10 years. That adds up to 1.5+6+10=17.5 QALYs lost. Using the NICE £30,000 figure (but with no discounting) that has value £0.53M which we round to £0.5M (discounting would reduce this considerably).

Thus the values we have used are related to values used by HSE and in Government but are deliberately on the high side, though not by any means as high as they could be, compared to theirs.

Now assume 70% of children contracting leukaemia survive and 30% do not (it is usual to quote more like 80% but that is a five-year figure and we recognise that some still die after 5 years). That gives a value per case of 0.7x0.5 + 0.3x4=£1.6M.

Thus the value to society of preventing a single case of childhood leukaemia is £1.6M.

To obtain the value of preventing one case per year going forward in time, we used the HSE and Treasury Green Book procedures on discounting future benefits.

If we accept the principle of discounting, the value to society today of achieving a health benefit in a future year is different from the value of achieving the same health benefit here and now. It increases because evidence suggests society will progressively attach greater value to health benefits; it decreases, because society will pay more for a benefit which it gets now than for a benefit deferred to the future. If the latter decrease is larger than the former increase, as it usually is, the value now of future benefits decreases for each year the benefits are deferred; this decreasing series of values can be summed to a finite value without having to assume an arbitrary number of years that the benefits accrue over. All these values are expressed in real terms; discounting is separate from allowing for inflation.

HSE[2] originally gave a discount rate of 6% combined with a real increase in the values society places on health and safety of 4% per year, giving a net 2% reduction per year, which gives a multiplier to the

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[1] HSE "Reducing Risk, Protecting People" http://www.hse.gov.uk/risk/theory/r2p2.htm

[2] HSE "Reducing Risk, Protecting People" http://www.hse.gov.uk/risk/theory/r2p2.htm

annual value to get the net present value of 50 times. Subsequently[1], they say the discount rate should be 3.5% (reducing to 3% after 30 years) and the real increase 2% giving an effective or net discount rate of 1.5%. These figures are the same as given in the Treasury Green Book2 and can therefore be taken to represent current Government policy.

Using a real increase in society's willingness to pay of 2% pa and a discount rate of 3.5% pa, and for a period of fifty years, we obtain a value of preventing one case per year going forward of £50M.

We recognise that alternative approaches are possible. Some of us feel that society is, in practice, unwilling to invest in safety measures where the payback is 50 or more years into the future as implied by these figures. As the net discount rate gets smaller, the amount of the sum-to-infinity that accrues long distances, perhaps unreasonably long distances, into the future increases. At 1.5%, as an example, accruing benefits indefinitely gives a multiplier to the annual benefit of 67, accruing just for the first 50 years gives a multiplier of 35; so almost half the "infinite" benefit occurs after 50 years. In work relating to energy efficiency, for example, all the evidence is that both business and the general public will not invest in energy efficiency measures which produce real financial benefits to them and very important benefits to society (reducing global warming etc) unless there is a very short payback. This implies that they are discounting (albeit of economic rather than health benefits) at rates in the range 20 - 60% rather than 3.5%. In other areas, a discount rate of 10% (a multiplier of 10 to get the net present value) is a rule of thumb.

Others feel the real increase in future years may be higher or lower than the Treasury's 2% pa.

Others have reservations about the principle of discounting of health benefits. An alternative approach is to take account of the finite life, perhaps of order 50 years, of a power line or of house wiring. A simple multiplier of 50 with no discounting at all could reflect the likely life of a power line.

All these variations, however, are fortuitously likely to result in similar answers to the Treasury approach, at least to within a factor of two or so, and we proceed on this basis.

4 Value to society of reducing exposure

To relate this benefit to the options for precautionary measures we are considering, we assume that removing a home from a field of greater than 0.4 µT to a field of less than 0.4 removes any child living there from a relative risk of 2 for childhood leukaemia. That is, we are assuming a step function, with zero excess risk from magnetic fields below 0.4 µT and a doubled risk above 0.4 µT. Nationally, therefore, on the basis of the figures in Supporting Paper S4, removing all homes from fields of >0.4 µT from all power lines has a value to society of £50M (one case prevented per year); removing them just for National Grid power lines, a value of £25M (one case prevented per two years).

For each single home that is moved from above to below 0.4 µT (regardless of the source of the field) the value is £1,000, calculated as follows:

Suppose we agree a figure for the health benefit of preventing a case of leukaemia of £50M.

Start with the Ahlbom scenario.
Suppose we remove one home from a field of >0.4 into a field of <0.4 µT. We have therefore removed that home from a relative risk of 2 according to our assumptions.

Annual average risk of childhood leukaemia for a child in that home = 1 in 24,000

Therefore risk removed from a child living in that home = 1 in 24,000 per year

Average number of children living in that home = 0.45 (10M children, 22M homes)

The 4% and 6% figures come from para 17 of appendix 3 on printed page p66/Adobe page 74 - 6% as a real rate of return and therefore discount rate, 4% as an annual increase in the value society places on preventing a fatality.

[1] HSE http://www.hse.gov.uk/risk/theory/alarpcba.htm

[2] http://greenbook.treasury.gov.uk/

Therefore, on average, value to society of removing that home from the field
= £50M x 0.45 x (1/24,000) = £1k (near enough)

On the Draper scenario instead:
Suppose we remove a home from somewhere in the 200-600 m band to the >600 m; on our assumptions let's say we remove it from a relative risk of 1.23
Benefit to society = £50M x 0.45 x (1/24,000) x 0.23 = £215
Suppose we remove it from the 0-200 m band, a relative risk of 1.69
Benefit to society = £50M x 0.45 x (1/24,000) x 0.69 = £650

If we are dealing with a home where we know children are living (rather than just a random home) we don't need to include the 0.45 factor.

If we were prepared to assume that risk applied only to certain years (at birth, for example, or during the peak years for leukaemia, 3-4) we could adjust these figures: lower if the risk applies only in certain years, higher if the risk applies in a year when the risk of leukaemia is higher

We consider how to extend these calculations from homes to schools in Supporting Paper S3.

5 Uncertainties

To derive all these figures, we have made many assumptions, as set out in this Paper. The details of these assumptions could undoubtedly be challenged, but we believe the results we obtain, whilst not intended to be precise, provide a realistic estimate of the relevant quantities. We emphasise again that this calculation is of what the cost-benefit would be if magnetic fields do in fact cause childhood leukaemia and makes no allowance for the uncertainty in that or judgement on how likely that is.

More generally, there are a number of places where we made assumptions, but where alternative assumptions would be possible. Clearly, there are alternative assumptions which would make the cost-benefit ratio larger and other which would make it smaller. For the sake of transparency, we summarise those alternatives here.

Alternatives which would make the value assigned to the benefits larger:

- Applying further multipliers to the value to society of preventing a fatality from childhood leukaemia, beyond the factor of 4 we have used
- Rejecting the concept of discounting for health benefits deferred into the future
- Assuming a significant rise in the incidence rate of childhood leukaemia or in the population of children over future years
- Assuming that the value society places on preventing a fatality rises by more than the 2% per year suggested by the Treasury and HSE

Alternatives which would make the value assigned to the benefits smaller:

- Using only the single factor of 2 multiplier to the value to society of preventing a fatality from childhood leukaemia explicitly suggested by HSE, rather than the factor of 4 we used
- Using a lower value of preventing non-fatal cases, for example by discounting the estimate of reduced life expectancy or by revising it
- Assuming that the fatality rate for childhood leukaemia continues to fall, rather than stays constant as we have assumed
- Discounting future health benefits by larger amounts than the net 1.5% we used, for example using a multiplier of 10 to obtain the net present value which could be argued to be more in line with societal behaviour in other areas
- Applying discounting to the benefits for options, such as ceasing to allow development near lines, where the benefits accrue only over extended periods of time

Alternatives which would make the value assigned to the costs change:

- Assuming that reductions in land or property value close to power lines are countered by increases elsewhere, reducing the net cost to society of options where this is the significant cost

Supporting Paper S7

S7 Surveys of Public Opinion

This Supporting Paper contains details of the following research papers/surveys:

Add web links for all studies

1 **Scottish Executive Environment Group** publication 'Public Attitudes and Environmental Justice in Scotland' (2005) John Curtice, Anne Ellaway, Chris Robertson, George Morris, Gwen Allardice and Ruth Robertson. The full report is available at …
(Please note copyright approval to use this summary in the SAGE report has not yet been sought – the SAGE representative of the Scottish Executive needs to be made aware of this)
Available from…

2 **MORI Opinion Polling work commissioned by National Grid** (5 surveys between 1997 and 2006).

3 **Centre for Environmental Risk publication funded by the Department of Health**, 'Public Risk Perceptions of the Health Effects of Ionising Radiation and Power Frequency Electromagnetic Fields' reference RRX89 (2005) Patrick Cox, Nick Pidgeon, Iain Lake and Wouter Poortinga.
The full report is available at www.rkpartnership.co.uk/documents/emf%20projects.pdf.

4 **University of Bristol research, funded by the Department of Health** 'Non-ionising radiation risk perception in exposed and non-exposed subjects and their response to information on the nature of the risk' reference RRX67 (1999) AW Preece, B Stollery and A Smith.
Available from…

5 **Opinion Leader research, commissioned by the charity CHILDREN with LEUKAEMIA**, 'The public's view on an appropriate response to the relationship between EMFs and childhood leukaemia' (2005).
The full report is available at …

6 **An Opinion Leader Research summary of a UK quantitative survey by TNS, commissioned by the charity CHILDREN with LEUKAEMIA**, 'The public's view on an appropriate response to the relationship between EMFs and childhood leukaemia' (2006).
The full report is available at …

7 **An Opinion Leader Research summary of a quantitative survey in Scotland by TNS, commissioned by the charity CHILDREN with LEUKAEMIA**, 'Scottish Attitudes on an appropriate response to the relationship between EMFs and childhood leukaemia' (2006).
The full report is available at …

Supporting Paper S8

S8 International EMF exposure limits

This paper summarises international practice on policies, limits or guidelines relating to ELF EMFs.

1 Countries adopting ICNIRP:

- EU, Austria, Croatia, Czech Republic, Estonia, Finland, France, Ireland, Malta, Portugal, Singapore, South Africa, South Korea, Taiwan, UK

2 Countries adopting limits similar to ICNIRP but differing in detail:

- Bulgaria, Germany, Hungary

3 Countries adopting non-quantitative precautionary measures:

- Australia: up to 4% of project cost to be spent on field mitigation (ICNIRP applies elsewhere)
- California: up to 4% of project cost to be spent on field mitigation provided 15% field reduction can be achieved

- Denmark: new homes should not be built “near” existing lines and visa versa
- Luxembourg: new homes should not be built near existing line
- Sweden: measures to “reduce fields radically deviating from what would be considered normal” where this is at “reasonable expense and with reasonable consequences in all other aspects”.

4 Countries adopting quantitative limits lower than ICNIRP

	Country	Year	Status	Limit	How calculated	Applies to			Qualifications
						Source of field	Type of exposure	New/old	
10 -100 µT	China	?		0.5 mA m^{-2}		?	?	?	?
	Poland	2003	Law	48 µT		?	?	?	?
1-10 µT	Italy[*+]	2003	Law	10 µT	24 hour median	Power lines	Exposure >4 hours/day	Existing	?
				3 µT				New lines and new buildings	
	Slovenia[+]	?	Law	10 µT		Power facilities >1 kV	Homes, schools, public areas	New facilities	?
<1 µT	Switzerland	2000	Law	1 µT (each source)		Fixed installations	Homes, schools, playgrounds	New	Exemptions on technical or cost grounds
								Existing	Does not apply if phases optimised
	Israel	2001	Environmental Guideline	1 µT	24 hour average	?	?	?	?
	Netherlands[+]	2005	Recommendation from Government	0.4 µT (from power line only)	Annual average	Power lines	Children: homes, schools	New lines and new buildings	Where reasonably possible

[*] Three Italian regions have limits of 0.2 for schools, hospitals and homes [+] ICNIRP or something similar applies where lower limits do not

Supporting Paper S9

S9 Wiring in homes: background information and options

This paper provides background information on EMFs from house wiring.

1 Levels of fields in homes

1.1 Magnetic fields

In homes close enough to power lines, the dominant field in the home is produced by the power line. In the majority of homes, which are not near power lines, the field generally comes either from net currents in distribution wiring and other services outside the home, or from wiring in the home. Fields from distribution wiring outside the home will be considered by a subsequent SAGE Working Group. There are also localised fields inside the home produced by equipment; these are considered in Supporting Paper S13.

Table 1 – A guide to typical AC magnetic field levels (50 Hz) (with a comparison of different units)

μT	*nT*	*mG*	Comments
0.05	*50*	*0.5*	The average in UK homes and therefore a level that can be regarded as “normal”
0.2	*200*	*2*	The high end of what could be regarded as the normal range of fields in homes not near power lines
0.4	*400*	*4*	The magnetic field level (when present as a 24-hour average) implicated by the epidemiology of childhood leukaemia.

In the majority of UK homes, levels of less than 0.05 microteslas from internal house sources should be reasonably achievable in most of the house living areas, with maybe double these levels in blocks of flats especially near to the “rising main”. Ground-floor rooms in cities usually have the highest magnetic fields from external underground cables and pipes and, in some cases, it will be difficult to achieve levels as low as 0.05 microteslas.

As explained in Section 1, all these figures are for ELF magnetic fields arising from human activity; the earth’s natural field is about 50 µT but is a static field, and natural ELF fields are many orders of magnitude lower.

1.2 Electric fields

Table 2 – A guide to typical alternating current (a.c.) electric field levels (50 Hz)

Electric field	Comments
< 10 V/m	With good design it would be easy to ensure AC electric field levels in homes were below this level
5 – 25 V/m	The average in UK homes and therefore a level that can be regarded as “normal” in the middle of rooms away from wiring and electrical equipment
>25 V/m	30 to 75 V/m can be regarded as the higher end of general background AC electric fields in homes. Near wiring and Class II electrical equipment electric field levels can reach several hundreds of volts per metre.

Electric fields are produced by voltage differences between conductors, one of which may be "earthed" and may even be the natural ground surface. The electric field is measured in volts per metre (V/m). A difference of 230 volts between two parallel conductors one metre apart results in a field of 230 V/m. In practice, however, nearby conductive objects and people distort the electric field which will usually result in higher personal exposure to electric fields than would be expected from a simple calculation.

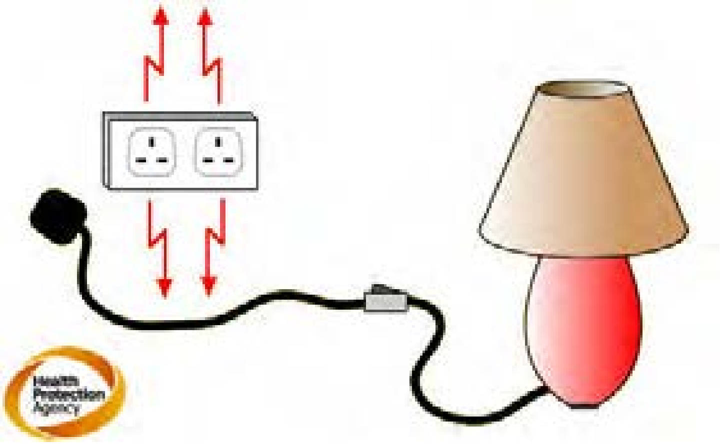


Figure 2 – Electric fields from sockets and installation wiring

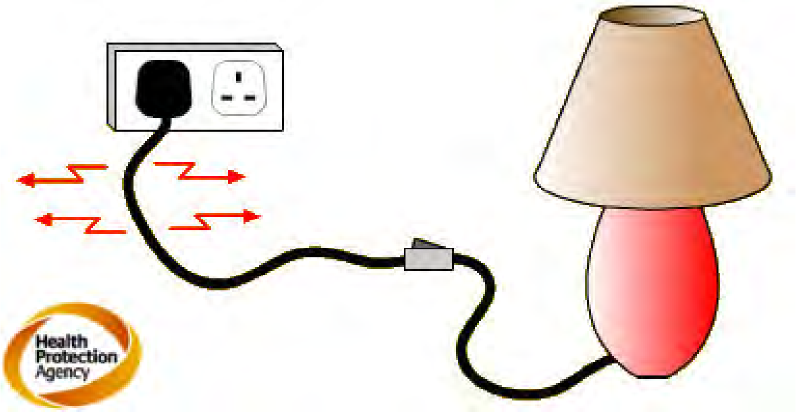


Figure 3 – Electric fields from appliance cables

In the majority of homes, levels of electric fields less than 10 V/m from internal house sources should be reasonably achievable in most of the house living areas. Electric fields inside houses are almost completely due to internal wiring and equipment. They are present all the time the mains is on. Apart from windows, building structures using traditional building materials generally provide fairly effective screening against externally generated electric fields from high-voltage overhead power lines.

2 House electrical installations and EMFs

2.1 Magnetic fields

A magnetic field is produced whenever an electric current flows. The larger the current, the higher the magnetic field produced. A mains powered electrical circuit effectively starts and ends at the local electricity substation transformer. The supply from the substation feeds the building's electricity meter, main switch, consumer unit ("fuse box") and final circuits. The outward and return currents in the phase and neutral conductors should be equal. As long as this is true and the two currents are close to each other, the magnetic fields produced are small. Significant magnetic fields arise either when the two currents are not equal – there is a "net current" – or when they are separated.

In most cases, a cable supplying 230 volts single-phase power will have three conductors; phase and neutral conductors providing the outward and return paths for the current and a safety (protective) earth conductor. The protective conductor usually carries virtually no current except under fault conditions, although some small currents are to be expected from filters and certain capacitive circuit devices. The protective earth conductor provides an alternative path back to the source for the electricity if a fault to earth occurs. This conductor is often uninsulated in circuit cables but fitted with green-and-yellow (or just green on older cables) plastic sleeving at its connection points.

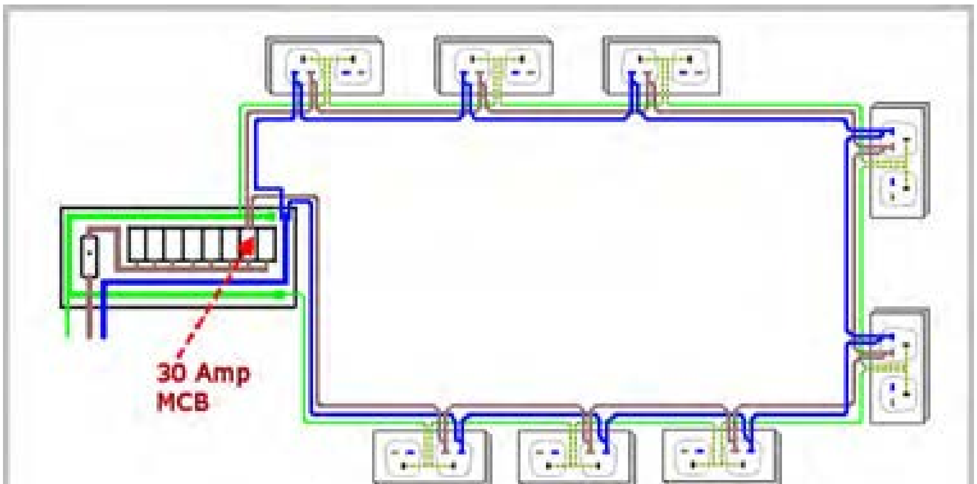
The ‘neutral’ conductor is connected to Earth at the local electricity substation (and sometimes elsewhere, too, under ‘protective multiple earthing’ [PME] schemes) and is used to carry the returning current. This wire is now coloured blue in the UK (compulsory by April 2006 for new installations). It used to be black, which is the colour that will be still be found in most building wiring (installed in 2005 and earlier).

The third conductor is the ‘phase’ conductor (colloquially often called the “live” conductor) and this has the electric pressure (ie the voltage) on it and it is the source of the current used to power electrical equipment. This conductor now has brown insulation in the UK (compulsory by April 2006 for new installations). It used to be red, which is the colour that will still be found in most building wiring (installed in 2005 and earlier).

The easiest way for an electrician to check the circuits for any net current is by using a clamp-ammeter around the cable. Although this is best done around the phase and neutral conductors only, this is not always easy to do. However, in practice, a very good indication is usually obtained by using the clamp-meter around the whole (twin & earth) cable. This is because discontinuities in phase or neutral will still show up and also any leakage to earth rarely stays in that specific protective conductor. The clamp-meter reading should rarely show more than 0.01 A (10 mA), even when the circuit is loaded using a high load such as an electric kettle or a 3 kW fan heater. If it does, then there is a wiring fault causing high magnetic fields.

Final “ring” circuits usually feed the socket-outlets in UK homes. These ‘rings’ of cable can give rise to higher magnetic fields than simple ‘radial’ or ‘tree and branch’ wiring. A ‘ring’ final circuit is not required, but is recognised, in BS 7671 (IET Wiring Regulations) and is what most electricians traditionally install. They were originally introduced after the second World War in order to minimise the use of copper wire while at the same time allowing for a number of electrical heaters, etc, to be used at the same time.

A tree or radial circuit forces the return current to travel back down the same piece of cable. However, in a ‘ring’ final circuit, the wires are laid out in a circle (more or less), starting and finishing at the consumer unit (fusebox). This means that current used from a socket-outlet has two possible ways to flow to and from the consumer unit. Currents may not flow equally both ways around the ring, so the magnetic fields produced may not cancel, and the cables then radiate these higher magnetic fields into the room and the adjacent rooms.



Traditional "ring" final circuit

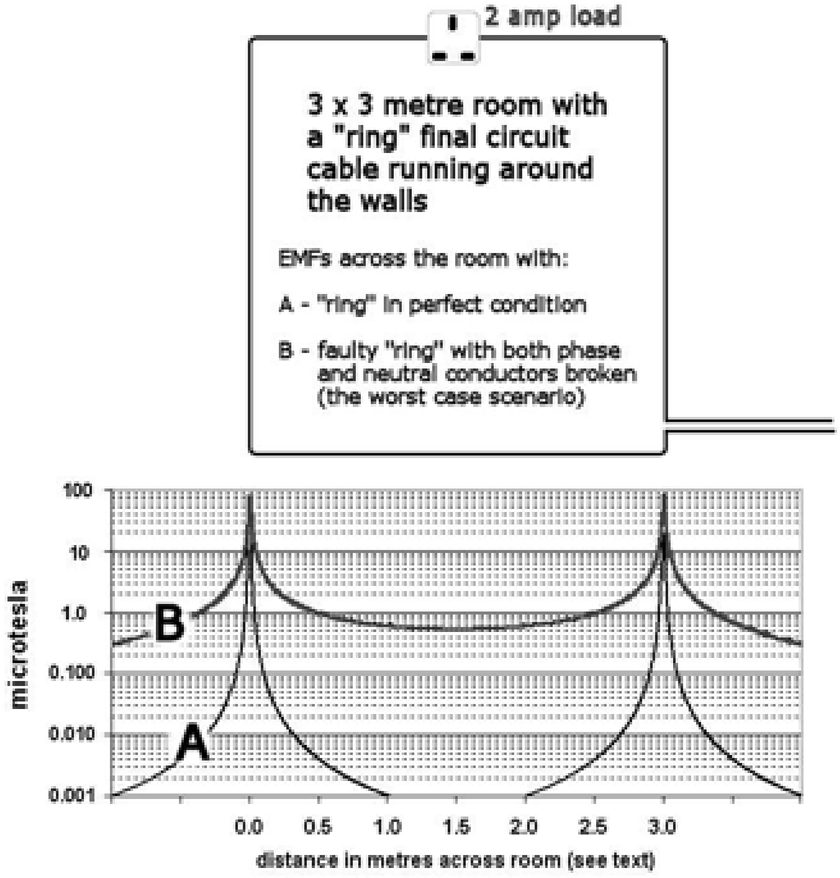
At every socket-outlet two cables are joined. A small difference in the impedance back each way to the consumer unit around the loop will cause a problem almost as bad as a poor connection.

A ring final circuit is usually protected against overload current above 30 or 32 Amps, while the cable is nominally rated at only 20 Amps. Multiple 'plug-in' electric heaters and other 'plug-in' high-current loads are now rarely used and it is now most unlikely for the total load on a ring circuit in a house to exceed 20 Amps, meaning that a radial circuit with a 20 Amp circuit-breaker can be used instead in most areas, except in a kitchen where higher loads are more often used. However, if there are a number of items of IT equipment on the circuit, the inrush current when these are switched on may sometimes trip a 20 A circuit breaker.

A circuit may pass the required safety tests required by BS 7671 but can still have a poor ratio of resistance between different sections of the circuit, leading to unnecessarily high magnetic fields. BS 7671 requires ring circuits to be tested by cross-connecting phase and neutral to form a figure-of-8 loop, and then resistance readings are taken between phase and neutral at each socket-outlet and these readings should be substantially the same (this test should be performed by qualified electricians only).

In the worst case, which is surprisingly common, a phase or neutral actually gets disconnected (often as a result of incompetent DIY-type work) and this effectively results in a large single-turn loop. When a significant load is applied, the magnetic field in rooms throughout the inside of the ring can rise to many microteslas.

Figure 4.017



3 x 3 metre room with a "ring" final circuit cable running around the walls

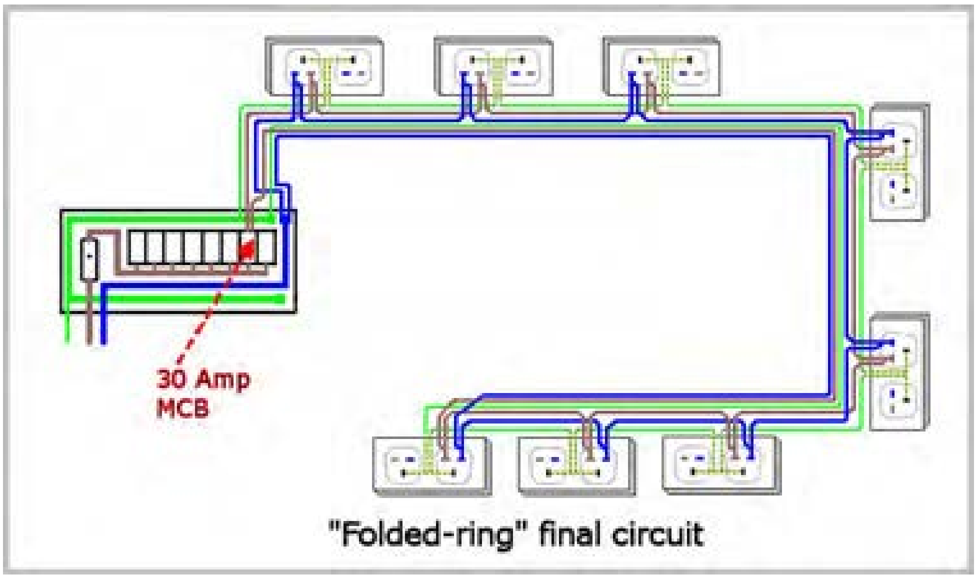
EMFs across the room with:

A - "ring" in perfect condition

B - faulty "ring" with both phase and neutral conductors broken (the worst case scenario)

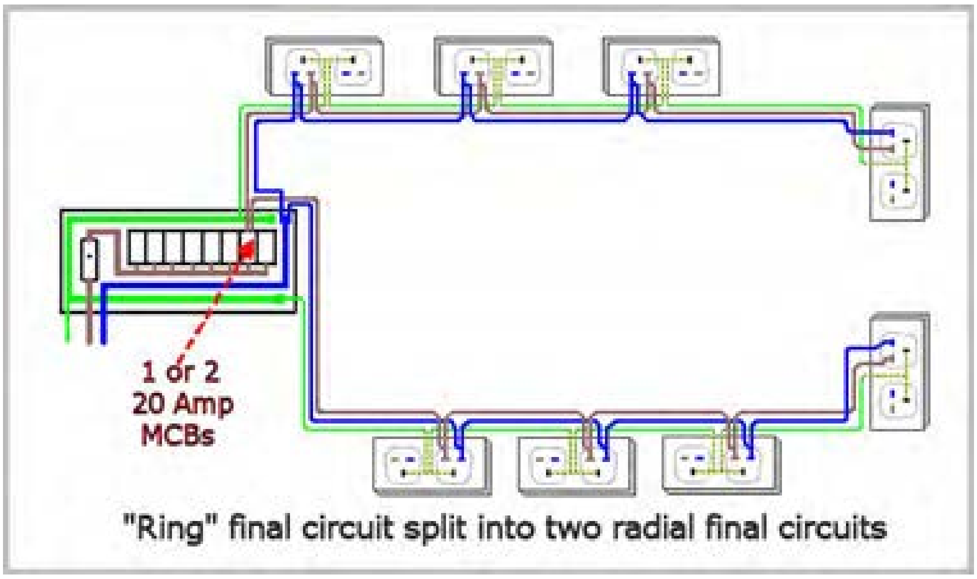
Comment: for situation 'B' ~ This is with phase and neutral broken towards opposite ends of the ring. For only one broken ring conductor, which is the situation more often encountered in practice, the EMF levels will between the levels shown as A and B. This diagram illustrates the principles rather than attempting to show exactly what would be found in practice.

An alternative for electrical designers and electricians who wish to employ a traditional ring final circuits is the 'folded ring'. Two cables are taken together around the rooms, one connecting to the socket-outlets and the other connecting to the final socket-outlet to complete the loop. This uses more cable but avoids the problems described above as the return current path is always close to the outward current path. In this case it may be marginally better to cluster the sockets in two groups, one group at each end of the folded ring.



"Folded-ring" final circuit

Radial circuits have low emission of magnetic fields. It is often possible to convert an existing 'ring' final circuit into one long radial circuit without major rewiring by removing one end connection and lowering the value of the protective device to 20 Amps. In other cases it is possible to break the 'ring' near its middle and, likewise, protect the two new circuits with one or two 20 Amp circuit-breakers depending on the expected electrical loading. In both cases, whilst electrically functional, such circuits will often no longer conform to the standard circuits recommended by the IET in the On Site Guide.



"Ring" final circuit split into two radial final circuits

We assume here that if radial circuits were adopted instead of ring mains, they would continue to use the existing UK BS1363 three-rectangular-pin plugs and sockets. However, these BS1363 plugs and sockets are optimised for use with ring circuits. In some people's eyes, changing to radial circuits reduces the case for retaining BS1363 plugs and sockets, and makes a change in the UK to using European-style unfused plugs and sockets more likely. This perception could lead to opposition to such a change from ring circuits to radial circuits. However, logically, the two issues are separate, and any recommendation by SAGE to adopt radial circuits should not be taken as implying a view either way on the desirability of BS1363 plugs and sockets.

An undetected neutral-to-earth short–circuit can cause a high magnetic field within a building. Insulation tests on the live and neutral conductors of each circuit will detect such a fault. Insulation tests must be performed when any wiring changes are made and, ideally, at suitable periodic intervals when the building wiring is checked. A neutral-to-earth short-circuit contravenes the requirements of the IET Wiring Regulations. If a Residual Current protective Device (RCD) is used, any significant imbalance in live and neutral currents (ie any net currents, which will almost always raise magnetic field levels) will cause the circuit to trip out and indicate a fault. RCDs are usually double-pole devices that switch both the phase and neutral conductors. They can cause unnecessary circuit trips when some high loads are suddenly applied to the circuit, especially if these are highly inductive or capacitive loads. An RCD can be combined with an over-current protective device (MCB) in one unit and it is then known as an RCBO.

An earthed metal conduit system (with cables or insulated wires in metal pipes), with radial final circuits will always produce the lowest electric and magnetic fields. The earthed metal pipes completely screen the electric field but, generally, have little effect on the magnetic field.

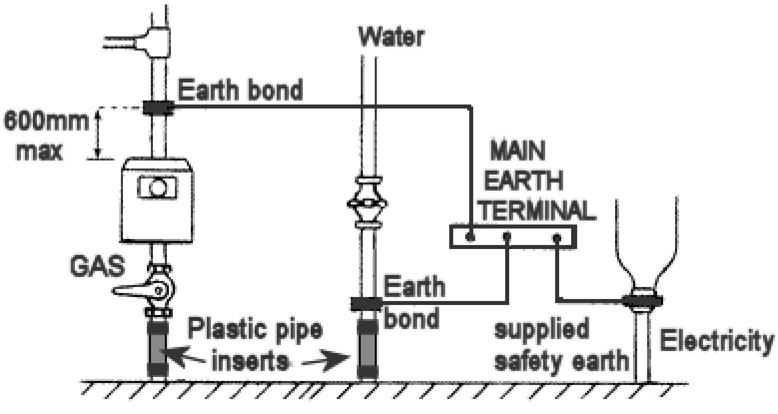
Another common cause of high magnetic fields comes from poorly laid-out lighting wiring. When possible, phase and neutral conductors should always be run together. To minimise magnetic fields, both phase and neutral should be taken to each luminaire (light) and then the phase taken to-and-from each switch as a twin-and-earth cable. The live and neutral conductors should always be connected to the same circuit from the consumer unit and should never be connected between different circuits as a borrowed-neutral situation would exist, creating a dangerous ‘trap’ for an electrician working on the installation in the future. It is not uncommon to find two-way switched lighting circuits that, incorrectly, interconnect different circuits. This is against the requirements of BS 7671. Such circuits must be fed from only one phase and kept with their own neutral; special 3 core and earth cable is required to do this satisfactorily.

The neutral conductor is connected to earth at the local electricity substation and, with Protective Multiple Earthing (PME), at regular intervals along the low-voltage electricity distribution system in the locality. This can give rise to elevated magnetic field levels, but will be dealt with in another SAGE Working Group. In newly connected UK buildings an earthed safety protective conductor is provided by the local electricity distribution network operator (DNO). Generally, if a means of earthing is provided by the DNO, the consumer’s earthing conductor is either connected to the neutral or the cable sheath/armour. Neutral and earth must not be connected together anywhere else in the building.

If the means of earthing is not provided by the electricity distributor, it is necessary to use a local safety earthing point (usually a copper rod or mat under the earth) and a Residual Current Device (RCD) that will automatically disconnect the supply to the installation in the event of an imbalance in the phase and neutral currents (usually due to a fault current flowing to earth). This arrangement will prevent earth fault currents causing high magnetic fields.

One problem that causes high magnetic fields due to external distribution problems, but one that can be dealt with by the building owner, are “stray” net currents flowing on incoming metal gas and water pipes. These “stray” currents enter, or leave, the building and then transfer via the required electrical safety bonding to the electrical safety earth. The currents are easily detected by either holding a magnetic-field meter next to the pipes where they enter the building (the fields will rise as you get closer to the pipe) or by using a clamp-ammeter around the pipe. Zero current should be flowing in the pipe. If there is more than about 10 or 20 mA (and it can be as high as several amps), then a short section of suitable plastic pipe could be inserted into the metal pipe, with due concern for the safety implications. This will break the circuit and stop the current flowing.

NOTE : Internal metal pipework must still be correctly main-bonded as per BS 7671. Also, the incoming pipe should be isolated as near the ground as possible and any exposed pipe covered with insulating tape or sleeving as, under fault conditions, it would be possible for a significant voltage to exist between the house Electrical Safety Earth and the incoming pipe tail that could give rise to a voltage shock hazard.



Reducing Net Currents by isolating incoming metal pipes

2.2 Electric Fields

The electric field from ‘twin-and-earth flat cable’ and normal three-core cable falls away fairly rapidly with distance and, by careful routing, fields in areas such as beds, where people regularly spend a long time, can be kept fairly low even using normal unscreened cable. For the mains wiring in a building, a system where the wires are contained in a screened cable or metal conduit (pipe) effectively provides an electrical screen around all such wires and reduces the external electric field from them to near zero. Electric fields from unscreened cables will always be higher than where screened (or enclosed by metal conduit) wiring is used because, if not screened, there is a potential gradient between the live conductor and nearby earthed bodies. Some of the voltage always couples into the building structure and alters electric field levels slightly.

Electric fields are present all the time the home circuits are connected to the mains and not just when current flows. A common cause of elevated electric fields is from the wiring of lighting circuits. It is not always obvious that these are the source, and care needs to be taken interpreting electric-field readings taken with hand-held meters. To track down the source it is worth referencing the meter to a known good electrical earth - it can then easily be used to pinpoint the live sources. Otherwise it is easy to become confused as electric fields can travel through conducting bodies (including people) and then return to a nearby earth - such as a radiator. It is not uncommon to obtain apparently high electric-field readings from a radiator, when the source of the field is actually below the floor and the radiator is acting as the return earth, with the circuit connection being supplied by the person holding the meter.

Electric fields are produced by a conductor having a potential (voltage) on it with respect to earth, and here an earthed metal conduit system, or using cable with an outer screen or armour, effectively provides an electrical screen around all such conductors. However, the electric field from a three-core (twin & earth) cable falls off fairly rapidly and, by careful routing, fields in areas (such as beds) can be kept fairly low even with normal unscreened cable. They will always be higher than when screened (or metal conduited) wiring is used because, if not screened, some of the voltage always leaks into the building structure (usually capacitively coupled).

[insert suggested lighting wiring diagrams here]

There are also screened low-halogen fire-retardant (eg ‘fire-safe’ TW950) cables available – mainly intended for critical safety applications, but also suitable for general wiring as they are available in standard 1, 1.5 and 2.5 mm^2 conductor sizes. They are easy to terminate but do have a larger bending radius requirement than ordinary PVC cable.

There is suitable, reasonably priced, screened flexible cable now available (types CY and SY), intended for eliminating electrical interference in industrial and commercial use, which can be used instead of conduited cables provided the screens are carefully and effectively terminated. This is most suitable for rewiring an existing non-conduited house when electric fields are to be minimised.

’Demand switches’ can be used to minimise electric fields from circuits which are not actually supplying power. A Demand Switch is an electronically controlled mechanical circuit breaker (MCB) that replaces the 230 volts AC with a low voltage that is then used to sense when a switch is closed, when the 230 volts automatically re-connected to the circuit. These can be fitted in consumer units and wired in series with the circuit over-current device (circuit-breaker or fuse). They are not needed if metal conduited or screened cables are used in the installation, but can be useful for remedial electric field reduction.

3 Options for reducing fields

The following table lists the options we considered. Our conclusions about these options are described in Section 3.

Table 3: Initial list of options that were considered – (not in order of priority)

Reduce magnetic fields	Reduce electric fields
For new installations, do not employ ring final circuits to supply socket-outlets and accessories. Use radial or ‘tree and branch’ final circuits	Install a wiring system employing screened cables, armoured cables, mineral insulated cables, metal conduit or metal trunking
Replace existing ring final circuits supplying socket-outlets with radial circuits	Use string pull light switches
Insert short sections of plastic pipe in metallic gas, oil and water pipes to negate stray neutral and earth leakage currents	Consider the use of low voltage (possibly d.c.) circuits for lighting etc
Make the user’s installation an independently earthed system with a local earth electrode and protection by a residual current device.	Fit demand switches. (A demand switch is device that only applies mains voltage to a circuit when there is a demand for power on that circuit – use of such a device on a lighting circuit in a dwelling would mean that when not in use the lighting circuits are not energized)
Select discharge luminaires (such as fluorescent lights) with electronic control gear as opposed to chokes or transformers	Employ screening using earthed metallic tape or earthed foil backed plasterboard. Such measures used in building construction would screen electric fields from the wiring and from any external influences such as nearby high voltage lines
Select equipment with an earthed metallic case (Class I equipment).	Disconnect or remove unused or redundant wiring
Reduce both magnetic and electric fields	
Ensure phase, neutral and earth conductors for each circuit are kept together at all times. (For example switch drops from looped ceiling roses should include an earth or neutral conductor)	
Inspection and testing of electrical installations both on completion (new build) and during periodic inspection should include results of field measurements. (Electricians would need to have the necessary equipment and be experienced in measurement techniques.)	
Minimise time spent exposed to fields, for example, by minimizing electrical equipment at the bedhead, not using electric blankets while in bed, siting washing machines in utility rooms, positioning the mains incomer and meter away from parts of the home subject to high occupancy.	
Manufacturers of equipment to provide figures for field levels	
Improve availability of test instrumentation	
Improve availability of instruction/training on the use of test instrumentation	

Supporting Paper S10

S10 Wiring in homes: applying cost-benefit methodology

1 Introduction

This paper considers the application of the cost-benefit methodology to the options for reducing fields from house wiring. As previously, the quantitative argument is developed for childhood leukaemia, with other possible health effects dealt with by means of a multiplier.

2 Basis of cost-benefit considerations

The principles adopted in SAGE for considering costs and benefits were summarised in Section 2.4 and described in more detail in Supporting Paper S6.

In summary, we made the following key assumptions:
- We assumed magnetic fields actually do cause childhood leukaemia, including no allowance for the uncertainty in this.
- We made the assumption that there is a relative risk of 2 above 0.4 µT which is removed by moving the home to below 0.4 µT. That is, we assumed a step-function dose-response relationship.
- We assumed £4M as the value to society of preventing a fatality from childhood leukaemia and £0.5M per non-fatal case

From these assumptions, we derived the following results:
- £1.6M as the value to society per case prevented, multiplied up to £50M for preventing one case per year going forward into the future.
- This equates to a value of £1k per home removed from above to below 0.4 µT.
- If the home is known to have a child resident (as opposed to homes in general, and if we are prepared to assume a child will be resident there for the next 50 years too) the value doubles to £2k

3 Applying these principles to house wiring

Consider first a home where we know the field is greater than 0.4 µT.

We can justify (in cost-benefit terms) spending £1k (£2k if we know a child is resident) on reducing the field.
On any reasonable assessment, this is more than enough to do a test to identify the reason for the high field, and, if the reason is something to do with the house wiring, fixing it.
So a decision to offer a menu of options to householders to apply if they want to reduce their fields is cost-benefit justified.

Consider now building a new home.

We know that only 0.4% of homes in general in the UK have fields greater than 0.4 µT (from UKCCS data). Of those homes, we know that roughly half come from high-voltage power lines (data from HPA “residential sources” study). Of the remaining homes >0.4 µT, we do not know exactly what fraction are due to house wiring and what fraction net currents in services. But a reasonable guess from the data in the “residential sources” study is that it is about half.

So, of the new homes we build, about 0.1% will have, or will go on to develop, fields greater than 0.4 µT as a result of wiring. It is in this 0.1% of homes that we deliver the benefit of moving them from above to below 0.4 µT, a benefit valued at £1k (assuming that our package of options is effective at removing all house-wiring sources of high fields).

We intend to apply our options to all new homes. Therefore, the average value per home is £1k x 0.1% = £1.

4 Costs of options for house wiring

The cost of applying our package of options depends on what fraction of homes it involves doing something different and therefore incurring costs. Suppose we assume:

Option	Cost (in those new homes where it is not already done)	Fraction of homes incurring this extra cost	Average cost per home
Radial power circuits	£15	100%	£15
Go and return together	£3	10%	£0.3
Relocate meter/consumer unit	£25	10%	£2.5
Electronic meters	£10	5% (the few where it doesn't happen anyway)	£0.5
RCD for whole installation	£31	5% (the diminishing fraction where it doesn't happen anyway)	£1.5
Tails tied together	£0		£0
Total			Approx £20

The detailed derivations of the costs in this table are included at the end of this paper. They are intended to be the cost to a large developer of applying these options routinely on new developments; the cost to an individual private householder seeking to have these options done as a one-off would be higher.

In this instance, we believe these costs, the immediate "first-round" costs, are the correct costs to consider, and there are no significant consequential costs that we need to include.

We therefore have:

- cost (average per new home) approximately £20
- benefit (average per new home) £1.

An alternative way of expressing this is:

- cost per home removed from a field of 0.4 µT £20k
- benefit per home removed £1k.

Clearly, on this analysis, applying our package of options to all new homes is not cost-benefit justified in terms of childhood leukaemia.

The key figure which affects this analysis is the fact that only 0.4% of homes are greater than 0.4 µT (and only 0.1% greater than 0.4 µT because of house wiring). So, because we assumed the benefit comes only from reducing fields above 0.4 µT, and we do not know which ones they are when we are wiring them up, we have to do our options to 999 "wasted" homes for every home where we get a benefit.

5 Detailed derivation of the costs of the options

We have estimated the costs of the main options we are considering. Material costs come from the current Screwfix catalogue except where indicated. For labour we have assumed £20/hour, as an estimate of the cost to a developer building many homes. The cost to a private householder employing an electrician to do the work would be higher.

5.1 Option: radials instead of rings

Assume the average new build has two 32 A ring mains.

Assume these are replaced by four 20A radials wired in 2.5 mm^2 routed in exactly the same way so labour costs and cable costs are unchanged (note: theoretically there is also a saving of the length of cable that joined up the ring).

Cost:

Incremental extra cost of a consumer unit two ways larger (£5) plus two extra MCBs (£5ea)	£15

Note: there is also theoretically a reduced functionality this way, ie reduced flexibility in connecting heavy loads and increased likelihood of nuisance trips on surge currents; but there is a theoretical reduced fire risk as the ability to overload one arm of the ring or a spur is eliminated.

Note: an alternative is to use the same number of circuits. This reduces functionality (the maximum load is reduced) and in some homes requires a change to the On Site Guide and possibly the Wiring Regulations (to deal with floor areas, voltage drop etc).

5.2 Option: go and return currents together

Assume in most new build this option makes no difference as the wiring of a two-way switch is already done in triple-and-earth (or two pieces of twin-and-earth routed next to each other).

Assume in a fraction of homes, where two-way switching would currently involve a large loop, this option would require an average of 10 m extra cable (either triple-and-earth or twin-and-earth to double back) to eliminate the loop.

Assume that for new-build the labour cost is no different (for a rewire of an existing home it could conceivably require an extra chase which would have a labour cost).

Cost (for those homes where it is not done already):

10 m triple-and-earth (25 p/m)	£3

Note: some instances of a loop involve a “borrowed neutral” from a different circuit; these are contrary to the wiring regulations and should not be done, so rectifying these should not be regarded as an extra cost.

5.3 Option: RCD or RCBO

All new installations are supposed to have at least one RCD already (for the circuit that would be used for outdoors). Many new installations already have two RCDs, one (100 mA time delayed) protecting the whole installation. This option requires that all new installations are done this way, with at least one RCD protecting the entire installation.

Cost (for those homes where it is not done already, which is probably a dwindling minority of homes)

80 or 100 A RCD (£28) plus enclosure (£3) or larger consumer unit to accommodate it	£31

5.4 Option: screened cables

Assume this would be done using the cheapest form of cable possible; so it would not be done with armoured cable, it would be done with a variant of twin-and-earth with a thin screen under the outer sheath. It was suggested that FP200 is one such existing cable; but that is a specialist fire-resistant cable that probably has a higher specification than needed. Assume that if the required cable does not exist already it would be developed in response to mass demand, at a cost more than present twin-and-earth but less than eg FP200.

Assume similarly a method of terminating the screen would be developed that is less time-consuming than armoured cable but still longer than existing twin-and-earth. (If a cable was developed where the screen was in contact with the CPC along the length, could the need for terminations be avoided altogether?)

Costs:

Incremental cost of using more expensive cable, applied to materials cost for cables only of typical new-build installation. (assume 300 m cable @ 20% increment on 20p/m (average over 2.5 and 1 TE) now)	£12 To use existing FP TW950 cable it would cost £210 to £300 depending on the cable ratings
Labour cost of extra time for terminations (one possible approach: typical new-build contains 30 socket outlets with two cables to each, and 15 lights and 10 light switches with one cable each = 85 terminations at 30 seconds extra each = 45 minutes extra labour cost)	£15
Total	£27

5.5 Option: siting/screening of meters/consumer units

Assume in many homes this would make no difference as the meter/consumer unit are already placed suitably. Where it does make a difference, assume the changed positioning of the consumer unit results in average 2 m extra length on each of 4 radials plus two light plus one cooker circuit plus the service cable = 15 m extra cable (this may be overestimate – some circuits might be shorter)

Costs (for those homes where it makes a difference)

20 m extra cable inside home (assume 2.5 mm^2 twin-and-earth) (assume 25 p/m)	£5
2 m extra service cable (assume £5/m – complete guess)	£10
Extra labour cost of routing cables further (30 mins? complete guess)	£10
Total	£25

Supporting Paper S11

S11 ELF EMFs testing procedures

There are currently international standards being developed on EMF measuring procedures. Any procedures that were incorporated into, for instance, house-wiring testing procedures or building surveys would need to be developed in the light of those standards. We offer here, in the interim, some informal guidance on the issues involved.

1 Introduction:

Basic ELF magnetic fields are relatively easy to measure and are not affected by the person carrying out the measurements. Relatively few instruments measure ELF electric fields and they do this with varying degrees of accuracy, especially due to the presence of the person taking the readings significantly perturbing the electric field. Please read the section on "instrument selection and use" towards the end of this document.

Whilst high electric and, especially, high magnetic fields in buildings can be due to external sources such as substations and power lines, the majority of elevated field levels are due to the building's installation wiring and electrical equipment. It is possible to install wiring systems and electrical equipment in buildings that produce virtually zero electrical and magnetic fields.

For an analysis of the causes of high magnetic fields, it is worth seeing the "High Homes" study report based on the homes in the UK Childhood Cancer Study that had the highest recorded magnetic field levels.[1]

The electric field is the hardest to reduce due to the way many houses have been wired. Electric fields can be high, in the order of a few hundred volts per metre in places, unless metal conduit or screened cables are used.

IMPORTANT NOTE: It is safe to use an EMF meter to measure the fields in a building. However, remember that electricity can be lethal, and all wiring installations should be periodically checked by a competent person with suitable test equipment to ensure that they are safe and that they comply with the UK BS 7671 Requirements for Electrical Installations (also known as the IET Wiring Regulations). Although compliance is not intended to keep electric and magnetic field levels down it usually helps to ensure low field levels. It is now illegal for unqualified people to undertake major electrical work without formal independent third-party inspection and test. The Building Regulations (Part P) set out the latest applicable requirements. There are other regulations that apply to commercial and public buildings such as schools. It is not worth taking any risks with electrical safety in the course of trying to reduce EMFs. In the UK, about 20 people are killed by accidental electrocution each year.

2 Taking initial ELF EMF readings:

Electric and magnetic field readings should be taken at the four inside corners of the building, on all floors. Measurements should be taken about one metre away from the walls and in the middle of the rooms. The readings represent the ambient background levels. If these levels are low enough for the desired level of precaution (*say 0.05 microteslas and 15 volts/metre*) then there is no need to do any more other than to record them. If the levels are higher than desired, then further investigation is required to determine the cause.

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[1] Maslanyi M P, Mee T J, Allen S G, Investigation and Identification of Sources of Residential Magnetic Field Exposures in the United Kingdom Childhood Cancer Study (UKCCS), HPA-RPD-005, August 2005. http://www.hpa.org.uk/radiation/publications/hpa_rpd_reports/2005/hpa_rpd_005.htm

3 Further investigations:

Switch off the Main Switch. Turn off all the electricity supply to the home (or other building) at the Main Switch that can usually be found on the main consumer unit ("fuse box"). This may mean that some electric clocks (eg on a cooker, microwave oven, etc) will have to be reset after power is turned back on. Some smoke alarms may also emit beeps when the power is off

Again, electric and magnetic field readings should be taken at the four inside corners of the building, on all floors. The readings now represent the ambient background due to external wiring and currents flowing in external power-lines and street distribution cables and, possibly, in metal water and gas pipes.

With the building power turned off, *ideally*, magnetic fields should be less than 0.02 μT and electric fields should now be less than 2 V/m at distances greater than two metres from the electricity meter. However it is fairly likely that the magnetic field will be nearer to 0.04 μT and the electric field to 5 V/m. The fields will almost certainly be higher than this in a block of flats, close to overhead power cables and in buildings with frontage directly on to the pavement.

In urban areas there can be considerable magnetic fields from electricity distribution cables that usually run under the pavement. If the magnetic fields exceed 0.10 μT from external sources then, in the absence of overhead power lines, the underground electricity supply cables belonging to the local electricity distributor are likely to be the source. The distribution cables should not produce high magnetic fields in houses, but they often do, due to the way they are commonly interconnected and also, sometimes, undetected faults. Details of what to do next if higher than desired EMF levels are found from underground cables will be explained in a separate SAGE document 'EMFs from electricity distribution wiring'.

In towns and blocks of flats, the ambient levels may well be higher due to electricity use in the other apartments. Typically the electric field may be around 10 V/m, and the background magnetic reading 0.05 to 0.10 μT. If the levels significantly exceed these, then it may be worth investigating the causes of the higher than normal field levels as it may be easily possible to do some simple, cost effective, remedial work.

Switch on the Main Switch. The magnetic and electric fields will usually rise.

Next, place the meter, set to read magnetic fields, on the floor in the centre of each room in turn. Note the reading. Now plug in a high electrical load (an electric kettle, hair drier or fan heater is suggested) as far away as possible in the room and turn it on. The reading should either not rise, or only rise slightly.

If it increases significantly, say from 0.04 to 0.1 μT or more then there is a problem with the wiring causing separated 'go' and 'return' currents. The causes and cures for such problems are discussed in Section 3.

Lighting circuits are often a significant cause of magnetic fields due to wiring and poor connections. Lights with two on/off switches, such as those found on stairs, quite often cause high magnetic fields due to incorrect wiring. Measure the magnetic fields with individual lights switched off then with them switched on. There should be little, if any, change in the magnetic field reading. If there is, then that indicates a wiring problem causing separated 'go' and 'return' currents.

Set the meter to read electric fields. As before for electric fields, take measurements at the four corners of the rooms, on all floors. They should be taken about 1 metre away from walls, or 0.5 metre if much time will be spent there – eg at chair or bed locations. The room lights should be switched on and off by an assistant, as readings are taken at each measurement location, because lighting circuits often have a significant effect on electric field strength.

Electric fields in most areas should still be under 10 V/m, certainly under 30 V/m. The field will rise in the vicinity of any wiring, and often towards the ceiling. Even in new houses the field can be 50-100 volts/metre at head height, especially near light fittings. The causes and cures are discussed in the main SAGE document.

Where higher than expected electric and magnetic field readings are found, the readings should be repeated with each circuit in the house turned, one at a time, on so that problem circuits may be identified.

4 Selection and use of ELF EMF meters:

There are a considerable number of ELF EMF meters now available. The frequency response (±3dB) of the meter should at least cover the range 30 to 300 Hz and a range of 10 to 2000 Hz is quite common. Some meters can be set to just measure 50 or 60 Hz. All of these should be acceptable for general precautionary measurements but do need to be selected with care for scientific research. The basic time weighed average (TWA) metric recommended by SAGE would be best measured by a frequency corrected meter with a response that extended up to, at least, 300 Hz. To get a TWA(24) value the readings would need to be data-logged every few minutes over a 24 hour period, preferably in winter when electricity use is higher, and then averaged.

Relatively few instruments measure ELF electric fields and they do this with varying degrees of accuracy, especially because the presence of the person taking the readings usually significantly increases the readings.

(N*ote: Techniques and protocols for measuring electric fields in homes need further work and discussion.)*

Supporting Paper S12

S12 ELF Electric field mitigation in homes

In Section 3 of the Report we discuss options for reducing fields from house wiring. For electric fields, we suggest that the best option is to wire the house in a form of cable which has an earthed screen inside the outer sheath but enclosing the conductors.

We are aware of only one practical example of such a cable available today, FP400. This is a specialist cable for use in connection with fire protection. It therefore has other properties besides the screen, and these other properties make it quite expensive.

The existence of FP400 does, however, prove the practicality of such cables. For instance, it shows that issues of fault current flowing through the screen have been adequately dealt with.

We therefore recommend that a simpler cable should be developed, basically just existing twin-and-earth cable but with the extra screen. This would be more expensive than existing cable, but, produced in bulk, not much so, and certainly cheaper than FP400.

Unless and until such a cable is developed, however, the following are existing options for reducing electric fields in homes:

- Place wiring in metal conduit or trunking
- Use armoured cable
- Use FP400 despite the cost
- Use metal accessories (eg socket outlets, light switches) and mounting boxes
- Use remote light switches (ceiling-mounted cord-pull switches or remote control) rather than run loops of wire to eg bedside light switches
- Cover wiring with 50 mm conducting tape suitably earthed
- Use plasterboard with earthed aluminium foil as a constructional material
- Demand switches (principally on circuits supplying bedrooms). A Demand Switch is an electronically controlled mechanical circuit breaker (MCB) that replaces the 230 volts AC with a low voltage that is then used to sense when a switch is closed, when the 230 volts automatically re-connected to the circuit. These can be fitted in consumer units and wired in series with the circuit over-current device (circuit-breaker or fuse).

In principle the following could also result in lower electric fields, but would require more development and are not immediately practical options:

- Extra-low-voltage circuits
- DC circuits

Supporting paper S13

S13 Electrical equipment in the home

1 Fields from electrical equipment

All items of electrical equipment produce EMFs.

EMFs from equipment are linked to use and also tend to decrease rapidly with distance. The decrease is somewhere between the inverse square and the inverse cube of distance, ie for a doubling of distance from the appliance the magnetic field will fall by a factor of between 4 and 8. Factors influencing exposure therefore include the exposure time and the distance between the user of the equipment and the equipment in its normal operation (eg most people sit closer to a computer screen than they do a TV). At one metre the fields from most sources are at background and it is only at 0.5 metre or less that significant exposure usually results. Because of this variation with distance, the equipment producing the highest fields may not necessarily produce the highest exposure.

The average background in UK homes from all sources is about 0.05 microteslas, as measured in a number of studies as 24 hour TWA. The personal exposure TWA for someone spending a lot of time in the home is about 0.07 microteslas because of contributions from working with electrical equipment (Preece et al, 1996, 1997, and 1999; Swanson et al, 1999).

The strongest sources of magnetic field exposure due to the combination of current-consumption and proximity, such as shavers, hairdryers and vacuum cleaners are not the major factors for cumulative personal TWA exposure because either distance or time mitigates accumulated exposure. Potentially the biggest source of accumulated TWA exposure is an electric blanket (McElroy et al, 2001), if used as an over blanket and particularly if the devices is of the low-voltage type operating off a transformer connected to the mains (this design is often intended for use when the person is in bed, not just as a pre-warmer). However, in studies in the UK, electric blankets are very uncommon, and modern design minimizes magnetic fields. Also, the potential risks of being exposed to higher values of magnetic fields from low-voltage/high-current have to be offset against the much larger risk of electrocution inherent in a blanket that operates at mains-voltage/lower-current.

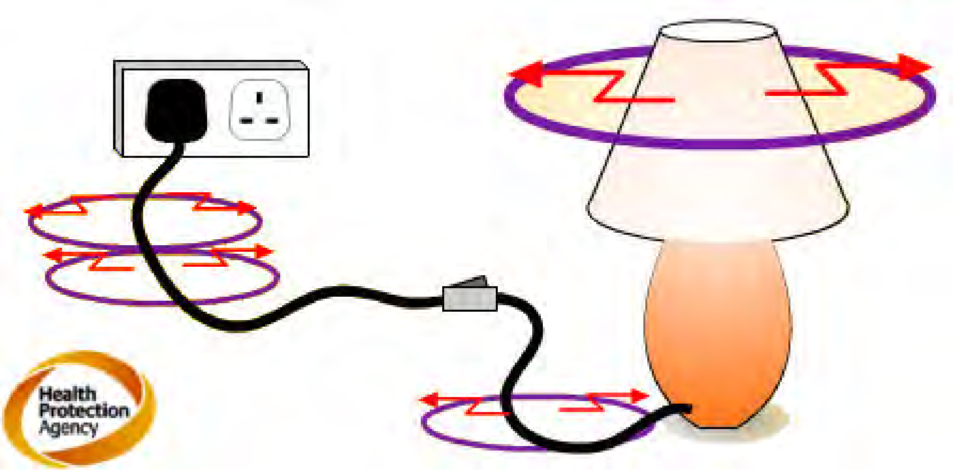


Figure 1 – Electric and Magnetic fields from an appliance in use

The greatest contributors to personal exposure are dishwashers, microwave cookers, bedside clock radios, electric clocks, washing machines and TVs (in that order) (Preece et al 1999). Since that research, another strong source identified in many houses is the transformer supplying halogen lights – particularly if the transformer is placed in the ceiling space, which ends up below a bed in the room above. Also mains-frequency plug-in transformers supplying video and other electronic games can be significant exposure sources for children. There have been changes in people's use of electrical equipment. For example, fewer people now arguably have or use mains powered clock radios. Increasingly, plug-in adaptors/chargers for MP3 players, laptops etc use switched-mode power supplies operating at hundreds of kHz. Low-voltage halogen lamps are being replaced by mains voltage halogen lamps and in the future are set to be replaced by white LED technology which uses far lower power levels than halogen lamps.

2 Reducing EMFs from electrical equipment

Three major factors contribute to a person's exposure: firstly, the intrinsic design of the appliance, secondly the distance to the subject and, lastly, the length of time the person is near a source. Hence washing machines tend to be a lower contributor to TWA than a bedside clock, for example. This is markedly affected by the placement of the device and to an extent design can affect this. For example, a transformer supplying halogen lights could be integral with the light, or on an extended lead, which may determine whether the transformer ends up in a ceiling, effectively exposing a bedroom above, or whether it is fitted low down in a cupboard. Since fields vary inversely with distance – between a power of 2 and 3 for distance – placement of continuously operating equipment is important.

Electrical design features to minimize magnetic field include:

1. In transformers, better quality design and components (such as thinner laminations or more iron in the core) will reduce the flux leakage resulting in a lower stray field.

2. The use of C core or toroidal transformers greatly helps to confine the field.

3. Equipment can be designed so that transformers (including plug-top 'mains adapters' and battery/mains radios and music players running from the mains) can be located at least 1 metre away from places where people sleep or sit for long periods.

4. Use of a switched-mode power supply can avoid the use of a 50 Hz transformer.

5. Using an electronic ballast in a fluorescent luminaire avoids the use of a choke. The latest high-frequency fluorescent luminaires emit minimal EMFs.

6. Microwave ovens can be located in the corner of the kitchen at least one metre away from where people stand and work when preparing food.

7. In an electric blanket, the use of a PTC parallel wired heating element will reduce fields. Low-voltage electric over-blankets that remain turned on all night should be avoided.

8. Consideration can be given to using equipment operating at a higher voltage. Magnetic fields result from current and for a given power consumption the current is inversely proportional to voltage. Therefore a mains-operated device produces lower magnetic field. Electric fields could be minimized by ensuring a protective earth conductor is employed in conjunction with careful internal design.

9. Where underfloor heating is to be installed, it should be ensured that live and neutral lines of the element run together and in parallel.

The use of DC power is sometimes an option.

Supporting paper S14

S14 Power lines: facts on EMFs

1 Terminology

This paper (and all SAGE work) distinguishes “overhead line” and “underground cable”. “Line” and “cable” used on their own should usually be understood as “overhead” and “underground” respectively and a “power line” should similarly be understood to be overhead.

An overhead line is hung from “wooden poles” or “pylons”. “Pole” used on its own would mean a wooden pole. A “pylon” is a lattice steel structure. The electricity industry uses the term “tower” synonymously for what is commonly referred to as a “pylon”; this paper uses the better understood term “pylon” but occasionally a “tower” may be encountered in existing literature.

The length of line between two adjacent poles or pylons is a “span”. The height of the lowest part of the span (ie the lowest conductors at the lowest point of their sag) is the “clearance” or “ground clearance”.

Distinctions such as “high voltage” v. “low voltage” and “transmission” v. “distribution” are always difficult and have no universal definition, despite what some people will insist. Broadly, in the context of this paper, in the UK, 400 kV and 275 kV overhead lines and underground cables are clearly “transmission” or “high voltage”. 400 V, 11 kV, 33 kV (and the less common voltages 22 kV and 66 kV) are almost always “distribution” and are usually “low voltage”. 132 kV, unfortunately, can be either.

A “grantor” is a person (or company or public authority) who owns land over which an overhead line passes (the overhead line “oversails” the land) including land where a pole or pylon is. The line is present by means of a legal agreement (wayleave or easement, explained in Supporting Paper S16). Therefore, the landowner who grants this agreement for the line is the “grantor”.

2 Lengths of power lines in the UK

The last year for which statistics collated across the UK are readily available is 1989, the last year of the nationalised industry. For that year, Table 5.1 gives the figures:

Voltage	Circuit km		Route km	
	Overhead	Underground	Overhead	Underground
400 kV	9520	303	5258	160
275 kV	3626	444	1584	433
132 kV	16927	2558		
66 kV	3289	1137		
33 kV	22213	13137		
22 kV	5576	2541		
11 kV	131913	95170		
other over 650 V	2059	16442		
under 650 V (ie mainly 400 V distribution)	63278	245541		

Table 5.1: lengths of electricity lines and underground cables in 1989 in England and Wales

These figures are for England and Wales. Figures for Scotland are available but have not been included here.

The majority of these figures are for "circuit km". As many lines, particularly at the higher voltages, comprise two circuits on the same pylons or poles, the "route km" are smaller, but the more useful "route km" figures are, unfortunately, not so readily available. The ratio of (circuit km)/(route km) for the National Grid is 1.9 and is assumed to be less at lower voltages.

Pictures of some of the main types of pylon, as a guide to interpreting what these different voltages look like in practice, are available at: http://www.emfs.info/Source_overhead_index.asp

3 Fields produced by overhead power lines

3.1 Fields produced at various distances

Electric fields are produced wherever there is a voltage; magnetic fields wherever there is a current. Thus, overhead lines produce both electric and magnetic fields, and underground cables produce magnetic fields (the electric field produced by an underground cable does not escape from it as the cable is enclosed in a metal sheath).

The size of field produced depends on the separation of the individual conductors (ie, broadly, how big the pylon or pole is), the loads and voltages, and other detailed factors as well. Higher voltage lines generally produce the highest fields. Further, fields in normal operations are usually lower than the theoretical maximum field, as loads are normally lower and ground clearances higher.

All these factors can be quantified and the fields calculated for any desired scenario. The web site www.emfs.info (maintained by National Grid) contains numerous calculations presented both as graphs and tables at http://www.emfs.info/Source_overhead_index.asp. The following graphs are taken from that web site.

Figure 1 shows the maximum magnetic fields produced by overhead lines of various voltages.

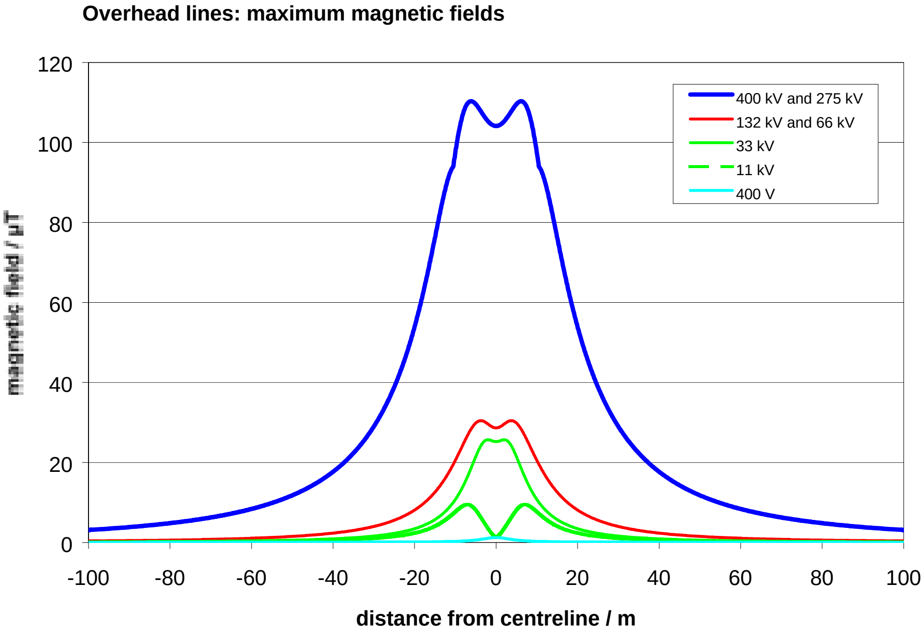


Figure 1 Maximum magnetic field produced by overhead lines at different voltages

Figure 2 shows the maximum electric fields produced by overhead lines of various voltages.

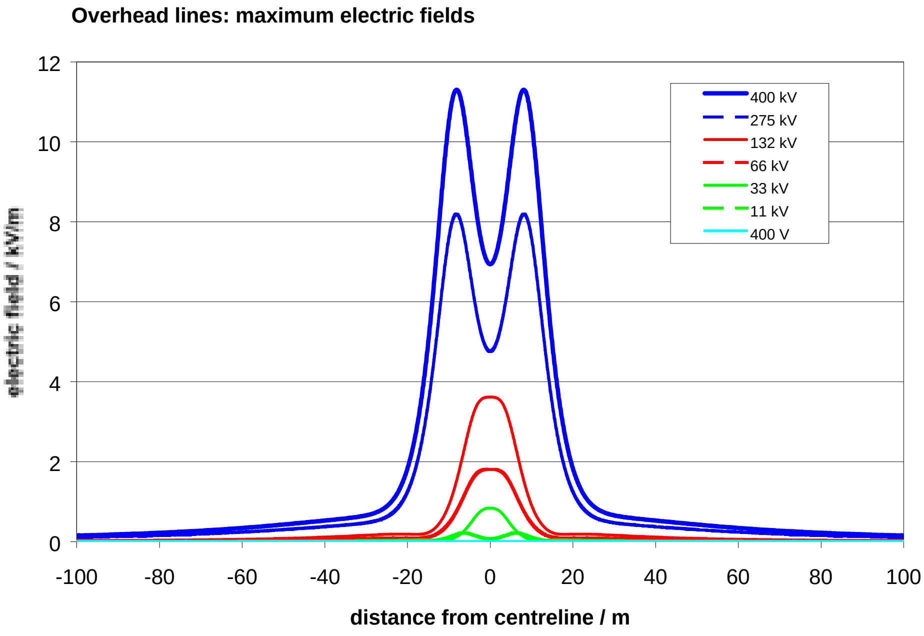
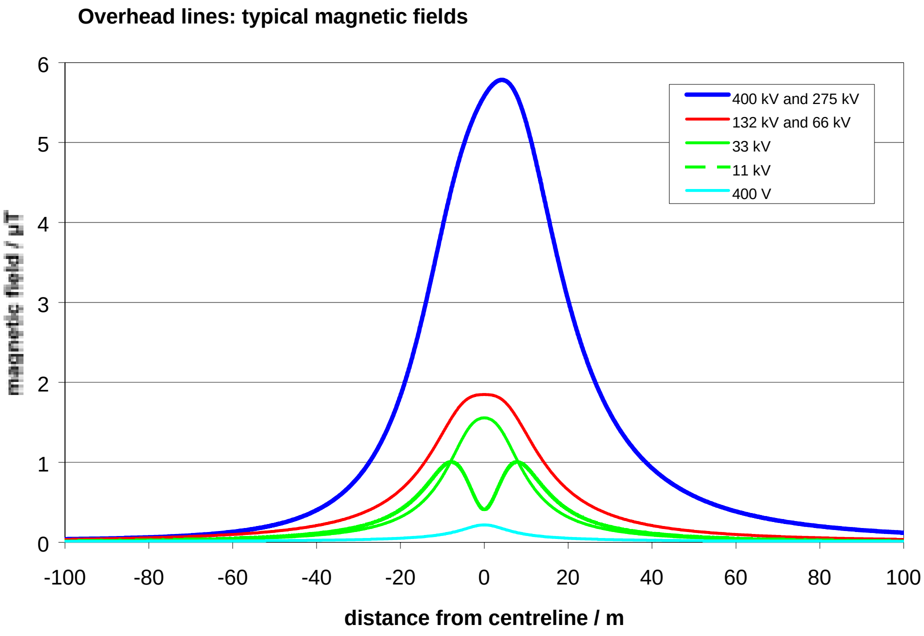


Figure 2 Maximum electric fields produced by overhead lines at different voltages

Typical fields are lower than maximum fields because loads are usually lower than the maximum and clearances are usually higher than the minimum. Figure 3 shows typical magnetic fields. These are calculated by choosing specific values of clearance and load that our experience leads us to regard as typical.

Figure 3 Typical magnetic fields from overhead lines



Note, however, that knowledge of “typical” conditions on 11 kV and 33 kV circuits is limited. The study conducted by HPA into sources of fields greater than 0.4 µT in homes did not find any instances attributable to 11 kV and 33 kV lines. This suggests that the values chosen for the calculations in Figure 3 may overestimate the field.

Figure 4 shows the same information for typical electric fields. With electric fields, as with magnetic fields, typical fields are lower than maximum fields because the typical clearance is higher than the minimum clearance. However, the voltage does not vary between these two conditions in the way the load does, so the margin between typical and maximum field is less for electric fields than for magnetic.

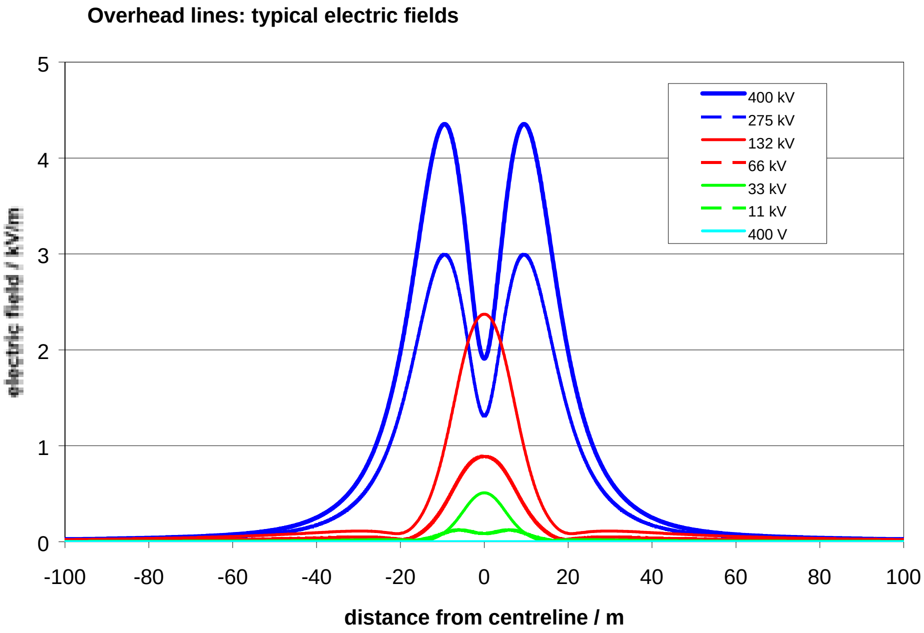


Figure 4 Typical electric fields from overhead lines

Two factors in particular which affect the magnetic field are the degree of balance between the loads in the two circuits, and the degree of balance between the loads on the three phases in each circuit. The degree of balance between the two circuits is taken account of in the calculations of typical magnetic fields for 275 kV and 400 kV lines by choosing as the “typical” conditions a situation where the loads are unequal (400 A and 600 A in the two circuits). The calculations do not take account of imbalance within each circuit (in electrical engineering jargon this is referred to as “zero-sequence current”). This becomes significant only at large distances where the field is small anyway. It may make a few percent difference to fields of say 0.1-1 µT but could double fields below 0.01 µT.

An alternative to choosing specific “typical” conditions is to average actual fields over a number of routes and over time. This has been done for a sample of National Grid lines. Table 1 gives fields calculated from one year’s worth of recorded load data and are the average for a representative sample of 43 different lines. This calculation uses actual load data and therefore automatically takes account of imbalance between circuits, but once again does not take account of imbalance within a circuit (zero-sequence current).

{PRIVATE}Distance m	0	50	100	200	300
Average Field µT	4.005	0.520	0.136	0.034	0.015

Table 1: Average fields calculated for a sample of National Grid overhead lines.

Clearly, if the “typical” conditions were chosen correctly, the two approaches should give the same answer: and they do, roughly anyway.

A similar exercise has not been done for lower voltage lines to our knowledge.

3.2 Distance for field to fall to various values

Instead of expressing the field at various distances, it may sometimes be more helpful to express the distance for the field to fall to certain values. Table 2 presents this information. The data here are derived from the data on fields presented above, ie there is no new content in this table. The distance given is for the typical field to fall to that value; roughly, therefore, half of lines will be producing that field at greater distances, and half less.

Voltage	Distance (m) for typical field to fall to:				
	10 µT	1 µT	0.4 µT	0.1 µT	0.01 µT
400/275 kV	*	30-40	50-60	90-110	200+
132 kV	*	0-10	10-30	30-60	90+
33/11 kV	*	0-5	0-20	10-40	50+
400 V	*	*	*	10	20+

* typical fields from this line do not reach this value anywhere

Table 2 Distance for magnetic fields from overhead lines to fall to various values of field

Tables 1 and 2 suggest that the average distance for the field from a National Grid (275 and 400 kV) line to fall to 0.4 µT is 60 m. This is, however, the average; the field from some lines falls below 0.4 µT closer, and others farther from the line. This is shown in Figure 5

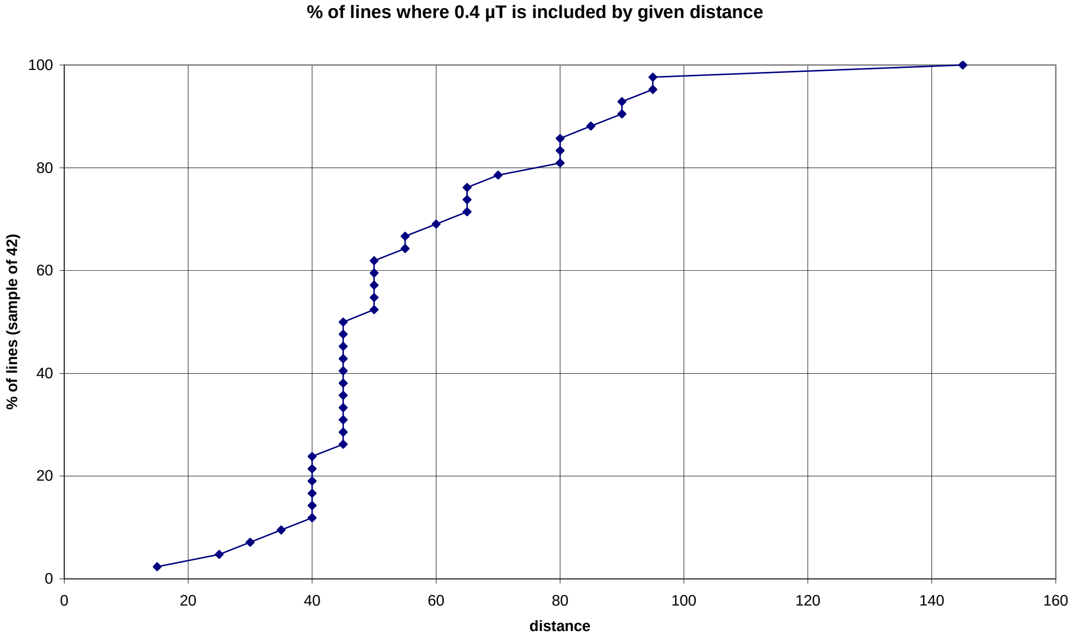


Figure 5 Distance for field to fall to 0.4 µT for different 275 and 400 kV overhead lines

3.3 Comparison with fields from other sources

In most homes, which are not near high-voltage power lines, fields come from low-voltage distribution wiring outside the home and house wiring and appliances inside the home.

The average magnetic field in UK homes is about 0.05 µT. This is the “background” field, ie the field present over the general volume of the home, not the higher fields from appliances which are present only in very localised volumes close to the source. There is, however, a range around this value; 2% of homes have background fields greater than 0.2 µT and 0.4% greater than 0.4 µT.

The average electric field is probably between 5 and 10 V/m.

Because of the way electric and magnetic fields add vectorially, when there are fields from two sources present, the higher tends to dominate. Thus, at distances where the field from the power line is greater than the background field from other sources, the field is roughly equal to the power line field. At larger distances, where the field from the power line is lower than the background field, the field in the home is roughly equal to the field from the other sources.

4 Factors which can change the field from an overhead power line

4.1 Clearance of line above ground

Higher lines are further from where people are and therefore produce lower fields. The extent of this can be seen from Figure 6, which shows the variation of field with clearance of the conductors above ground.

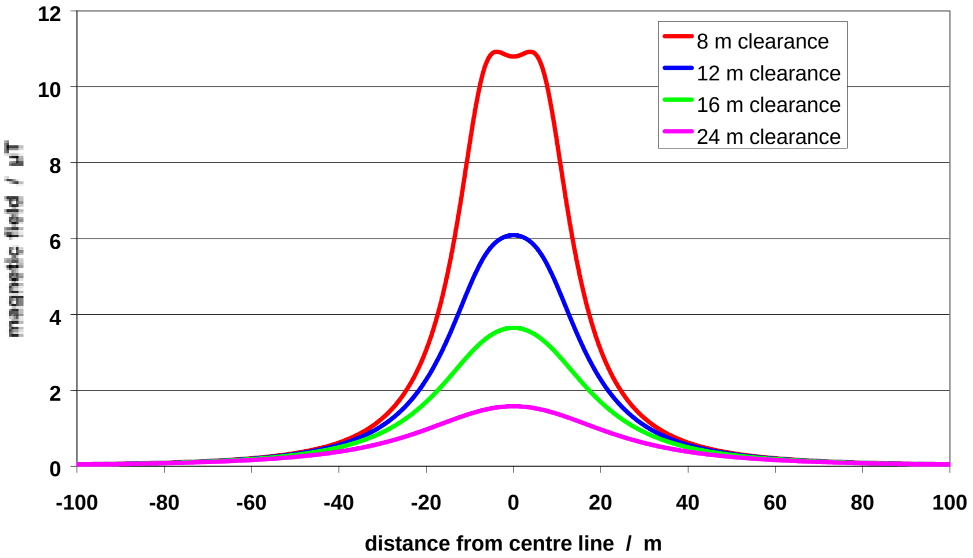


Figure 6 Variation of magnetic field with height of lowest conductors above ground for typical National Grid lines

Increasing the clearance over the whole range illustrated, from 8 m to 24 m, decreases the range of 1 µT from roughly 30-40 m to 20 m, and decreases the distance for 0.4 µT from roughly 50-60 m to 40 m.

4.2 Phasing of double-circuit lines

Many overhead line have two circuits, each of three conductor bundles or “phases”, carried on the same pylons. Each circuit produces a magnetic field, and the resultant field depends on the relative order of the three phases of each circuit. This is referred to as the “phasing” and the lowest magnetic fields to the sides of the line are produced by an arrangement called “transposed phasing”. Changing a line from untransposed to transposed phasing reduces the magnetic field to the sides of the line. The effect of this is shown for National Grid lines in Figure 7.

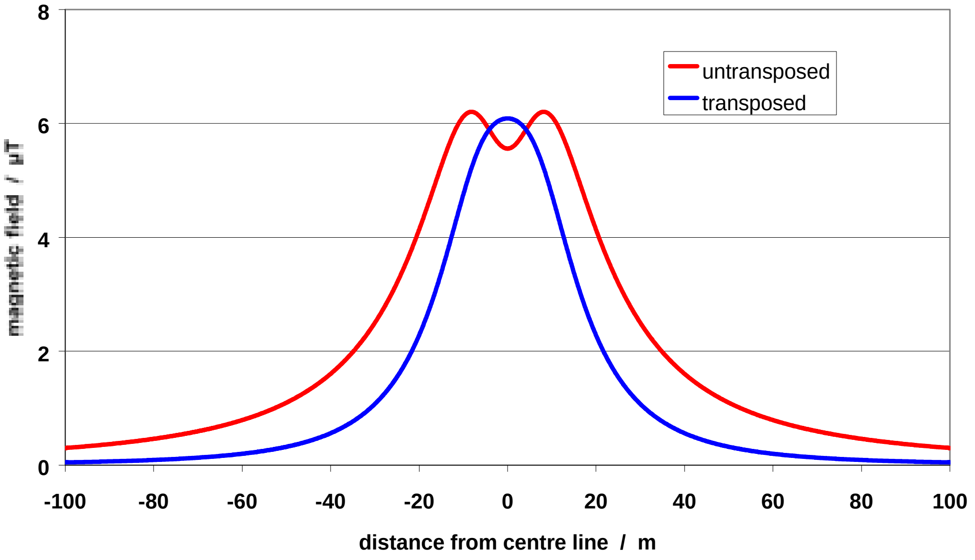


Figure 7 Effect of relative phasing of the two circuits on magnetic field from overhead lines

The effect of this is clearly quite large. The distance for the field to fall to 1 µT changes from roughly 50 m to 30 m, and the distance for 0.4 µT changes from roughly 90 m to 45 m. For 132 kV lines, there is a similar approximate halving of the distance for the field to fall to 0.4 µT, from say 30 m to 15 m.

The full reduction of the field with transposed phasing occurs only when the loads in the two circuits are equal and in the same direction. The extent to which this applies varies from line to line, so in practice, transposing a line may not produce the full reduction in field expected. If it is known that the direction of load flow in the two circuits is opposite, untransposed becomes the phasing producing the lowest fields instead of transposed.

National Grid policy is to use transposed phasing where possible (and has been since the 1950s when construction of the National Grid started). Roughly 90% of the system has transposed phasing. The rest is mainly either single-circuit or where three lines join at a “T” point, where completely transposed phasing is impossible without introducing a separate phase-transposition tower. The 132 kV system was not systematically designed with transposed phasing; much is now transposed, but we estimate there is 12% - about 2000 km – that is not transposed but could be considered for conversion.

5 Fields from underground cables

5.1 Magnetic fields

Magnetic fields produced by various voltages of underground cable are harder to characterise succinctly than those produced by overhead lines as they are more sensitive to height above ground, and also ratings (and hence the meaning of “maximum” field) are less standardised. Figure 8 shows the typical field for the highest voltage of underground cable, 400 kV. Maximum fields could be three times higher.

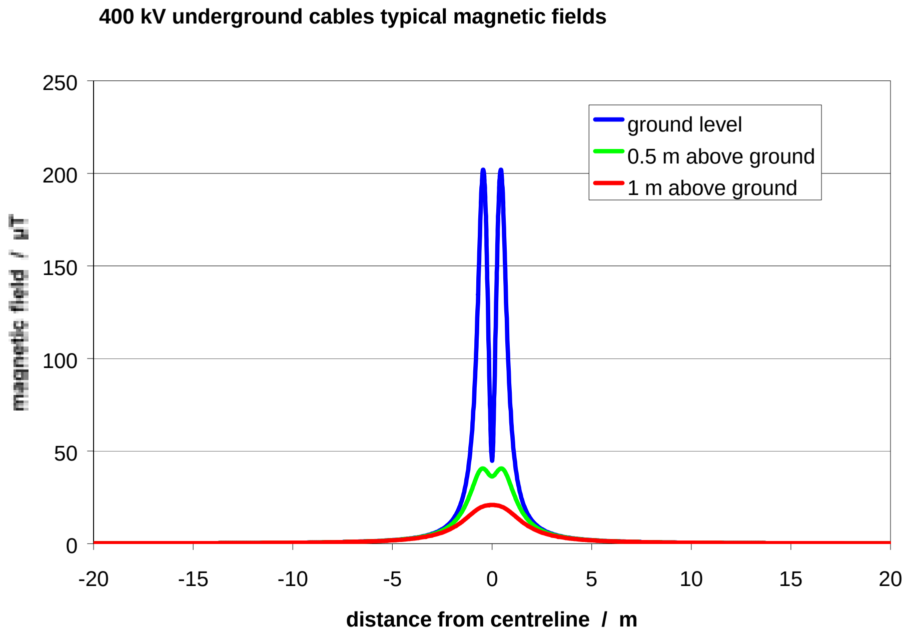
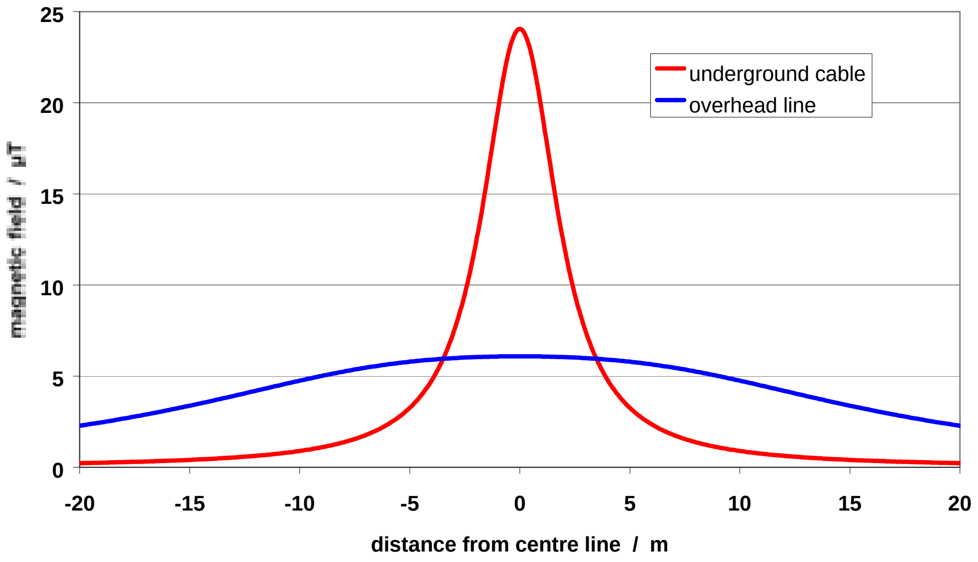


Figure 8 Magnetic fields from underground transmission cable



Comparison with the field values in Section 4 of this paper shows that an underground cable produces higher magnetic fields immediately above the route centre but lower fields to the side. This is shown expressly by the comparison of typical fields for equivalent 400 kV overhead and underground cables in Figure 9.

Figure 9 Typical magnetic fields from equivalent 400 kV overhead line and underground cable

This suggests that placing a 400 kV line underground confines exposures of 1 µT to within about 10 m (down from 30-40 m), and exposures of 0.4 µT to within about 15 m (down from 50-60 m). However, it is likely that fields at these distances are influenced proportionately more by imbalances in the loads which are not allowed for in the calculation, so some caution should be exercised.

Note that, for a directly buried cable, buildings are not permitted immediately above the cable, and for a certain distance to the side to allow for maintenance access.

5.2 Electric fields

Underground cables produce no external electric field as they are invariably enclosed in a metal sheath which screens the electric field.

5.3 Depth of burial of underground cables

The standard depth of burial of a high-voltage underground cable is 1 m. The calculations shown above are for that depth.

It is possible to bury cables more deeply by digging a deeper trench. This reduces the field (primarily the field directly above the cable, with less effect on the field to the sides). This has never been done in the UK because of the increased cost.

The alternative is to place the cable in a tunnel. This is done in several places where the difficulty of digging up roads or finding another route for a trench is too great. Tunnels can be bored at any depth required but are usually 20-40 m below ground. This greatly reduces the magnetic field at the surface.

At the other extreme, cables are sometimes laid in concrete troughs immediately below the surface, with the cable itself 0.3 m below ground. This produces higher fields but requires less land area than direct burial.

5.4 Conductor spacing for underground cables

The closer together the individual conductors of an underground cable can be placed, the better the cancellation and the lower the resultant field.

The limit on how close the conductors can be is the need to remove the heat that is generated. Direct buried cables normally have a conductor spacing of about 0.5 m; this can be varied slightly depending on the load and hence heat generated, and also on what the space around the conductors is filled with, which affects how well the heat is removed.

Heat can be removed more efficiently, and hence the conductors placed closer together, with forced cooling. Basically, water pipes are laid alongside the conductors, and water pumped through to remove the heat. This can and has been done in the UK, albeit at the penalty of one or more cooling stations, which are significant and potentially noisy buildings at intervals along the cable route where the water is pumped and cooled.

However, forced cooling of underground cables has fallen out of favour because of reliability problems.

5.5 Screening of magnetic fields from underground cables

It is possible to screen magnetic fields either by ferromagnetic screening or by eddy current screening.

Ferromagnetic screening requires the three phases of conductors that make up a typical underground cable to be completely enclosed in a ferromagnetic screen. The exact shape of the screen is unimportant as long as it is continuous around the conductors. A trial installation in Italy involves placing the three conductors inside a circular steel pipe. The pipe is laid first, then the conductors are drawn into it, then the remaining space inside the pipe is filled with sand to ensure the necessary thermal conductivity.

Eddy current screening is usually done with aluminium but copper has been used as well. It does not require the conductors to be completely enclosed; the screen basically just has to be between the conductors and the area where screening is required. This makes it more suitable for retro-fitting; existing cables can be uncovered and aluminium sheets laid over them (and probably, for improved efficiency, wrapping round the sides as well).

Both techniques involve increased losses, due to heating within the screen, and both involve de-rating the cable, because of reduced thermal efficiency. Both bring worries about corrosion and induced voltages during faults, and both reduce reliability and increase repair time.

Both techniques are frequently employed at low voltages. At higher voltages, eg on transmission cables, there are trial installations of both methods in Italy and possibly elsewhere. No installation of either has been attempted on transmission cables in the UK and substantial development work would be required before they could be contemplated.

Supporting Paper S15

S15 Power lines: facts on nearby homes and land use

This Supporting Paper sets out the facts, as best we have been able to assess them, relating to the numbers of homes and the amount of land allocated for development near power lines, including estimates of the value. The possible effect of any precautionary measures on those values is considered separately, in Supporting Paper S17.

1 The present situation: siting of power lines

In the UK, electricity companies very rarely own the land their overhead lines are built on. The lines normally exist on land owned by other people by means of either a “wayleave” or an “easement”. All new overhead lines over 20 kV also require consent under the Electricity Act 1989, with the application for consent determined by the Department of Trade and Industry.

Wayleaves are akin to a rental agreement. The landowner receives an annual payment for the presence of the overhead line. The wayleave can be terminated by the landowner, in which case the electricity company can apply for a Necessary Wayleave, and an Inspector appointed by the Secretary of State for Trade and Industry adjudicates the matter at a Hearing.

With an easement, the landowner receives a one-off payment in return for a permanent right for the line to be there. The landowner still owns the land.

Either a wayleave or an easement is needed for any land “oversailed” (crossed) by conductors. No such agreement is needed for land not crossed by the conductors, no matter how close to them it is.

More detail on wayleaves and easements is in Supporting Paper S16.

Underground cables are either on public land (eg under streets) or are on private land, either through an easement or where the land has been purchased by the electricity company.

Any electricity company will usually make some effort to route new power lines away from existing residential properties on grounds of general amenity. Obviously, lower voltage lines that are supplying properties have to go close to them, but generally, the higher the voltage of the line, the more effort is put into routing them away from properties. These efforts to keep away from existing properties are, however, subjects to limits. In part these limits are set by what is physically possible; in part, they represent a judgement made by the electricity company, which will often be disputed by citizens, as to what represents a reasonable effort or a reasonable extra expense.

For a new transmission line in a basically rural area (a recent completed example is National Grid’s second Yorkshire line, and a forthcoming example is the Scottish companies’ Stirling – Inverness line) it is exceptional for there to be any property within 50 m of the proposed route; there may be a few properties within 100 m; but increasing numbers of properties beyond that.

It seems highly unlikely that National Grid would ever seek to build a new line over an existing residential building, save perhaps specifically at the request of the landowner as preferable to the alternatives. It is not possible to use compulsory powers to place a line over someone’s house or garden, though they can be used to retain one there. However, in the past, lines have been constructed close to or over existing properties.

Further, new properties have been built (and continue to be built) close to and even under existing power lines. This is legally entirely permitted, providing statutory safety clearances are maintained. It is believed that the majority and probably the large majority of homes which are now underneath or very close to high-voltage overhead lines were built after the line was already there. There is no statutory obligation on the developer or planning authority to consult with electricity companies in determining planning applications.

One area of contention in the past has been attempts by local authorities to prevent development close to lines, on EMF grounds, by means of policies in Development Plans. National Grid or other electricity companies have sometimes opposed such attempts, including through the use of legal representation at Inquiries (where, in turn, the local authorities themselves are usually legally represented). Whilst the ultimate responsibility for the resulting rulings that have been made preventing local authorities from introducing such policies lies with the Inspector at the Inquiry, it is fairly clear that if National Grid had not intervened, no such rulings would have been made, and the local authorities concerned would have introduced such policies.

One consequence of this present regime is that even when a new line is built away from existing properties, new properties may well subsequently be built closer to the line.

National Grid for several years has sought to influence developers on how land should be developed in the vicinity of overhead lines. It published guidance ‘Sense of Place – Design Guidelines for Development near High Voltage Overhead Lines’, National Grid, 2003 showing how, by using careful design and planning, residential development could take place in the vicinity of overhead lines, retaining housing densities and values, and without destroying amenity. This guidance has been well received, and endorsed by a number of bodies, but an example of development built to its guidance has not yet appeared.

2 Numbers of homes near power lines

2.1 Homes near National Grid lines: overall numbers

Information on numbers of homes near National Grid overhead lines is available from a number of sources. National Grid has performed analyses for all England and Wales homes based on postcodes and augmented by data on individual addresses and from aerial photography for the closer properties. Specifically, National Grid has bought AddressPoint data on all homes within, approximately, 200 m of power lines. AddressPoint gives a grid reference that lies at an arbitrary point within the footprint of the building concerned. These data were purchased in the late 1990s so are out of date to the extent of further building since then. The UKCCS has published data on its subjects and estimates have appeared as part of other epidemiological studies. Fortunately, all the answers seem fairly similar whether based on postcodes, addresses, or children, and as the number presumably increases over time, approximate answers are all that can be expected anyway. The best estimates available (from National Grid’s grid-reference data) are given in Figure 1 and Table 1. Table 1 goes all the way out to 70 km, the largest distance from a National Grid line anywhere in England and Wales, for completeness, but it is not suggested that these larger distances are relevant for the present purposes.

Distance (rom centreline)	Thousands of domestic delivery points	% of total domestic delivery points
10 m	1.8	0.008
20 m	4.8	0.02
30 m	8.7	0.04
40 m	12.6	0.06
50 m	17.0	0.08
100 m	46	0.21
200 m	139	0.63
300 m	264	1.20
400 m	416	1.89
500 m	599	2.72
1 km	1,759	7.99
2 km	4,591	20.86
5 km	11,658	52.96
10 km	17,694	80.38
20 km	20,938	95.11
50 km	21,946	99.69
70 km	22,013	100.00

Table 1: Numbers of homes at various distances from National Grid overhead lines

These figures are, strictly speaking, for “domestic delivery points”. For practical purposes this equals “homes”. There are 22 million homes in England and Wales, 10 million children, and 53 million total population. Therefore, within acceptable accuracy, to get the number of children multiply these figures by 0.45, and to get the number of people multiply by 2.4. This assumes the three distributions (homes, children, people) are the same, which is probably not true in practice, but we have no good data to make any other assumption.

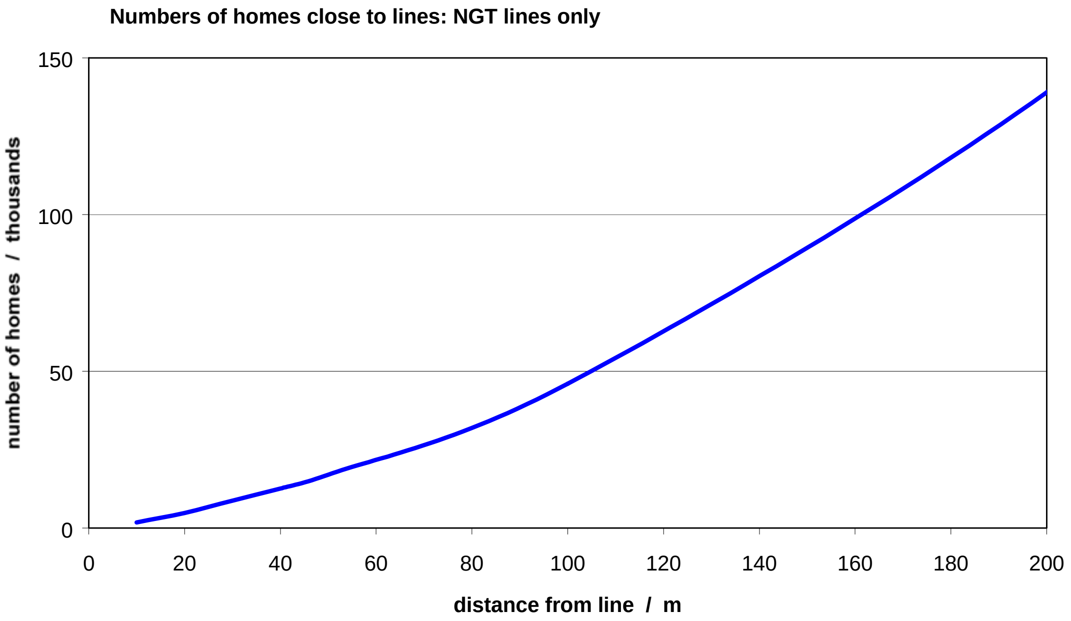


Figure 1 Numbers of homes near National Grid overhead lines in England and Wales

2.2 Homes near National Grid lines: particular spans

A “span” is the length of wires between two adjacent poles or pylons. Homes are, of course, clustered around certain spans of line only. The following table estimates numbers of spans with at least one home, based on the AddressPoint grid reference, within the specified distance.

At least one home within:	Number of spans	% of total spans
100 m	2923	14
50 m	1337	6
40 m	1006	5
30 m	730	3.5
20 m	489	2.3
10 m	275	1.3

Table 2: Numbers of spans with at least one home at various distances

Yet another way of thinking about the same data is the number of homes that are close to each span. Table 3 considers homes within 50 m (an arbitrarily chosen distance – the calculation could be repeated for any other distance) and enumerates the spans with various numbers of homes within this distance.

Number of homes within 50 m	Number of spans	% of the 1337 spans which have at least one home within 50 m	% of the 21,000 total spans
≥100	12	0.9	0.06
≥50	94	7	0.4
≥20	265	20	1.3
≥10	386	29	1.8
≥5	521	39	2.5
≥1	1337	100	6.4

Table 3: Spans with varying numbers of homes within 50 m

The figures in both these tables suffer from potential ambiguity where homes are at the ends of spans and therefore could be classified as close to either of two adjacent spans.

2.3 Homes near other overhead electricity lines

No comparably reliable statistics exist on numbers of homes near electricity lines at lower voltages.

Two different pieces of work (a pilot study for the CCRG/DH epidemiological study conducted in area of Southern Electricity; estimates made by East Midlands Electricity) have estimated that there is somewhere between three and five times the fraction of homes near 132 kV lines as near 275 kV and 400 kV lines. We assume a ratio of 4 here but recognise considerable uncertainty in the resulting figures. That factor of 4 in the fraction of homes is made up roughly of a factor of 2 because there is twice the length of lines, and a second factor of 2 because the average housing density around those lines is twice as great.

Little if anything is known about homes near even lower-voltage lines (eg 33 kV, 11 kV) and the quantitative treatment in this paper is limited to lines of 132 kV and above.

On this basis, the estimated numbers of homes in proximity to overhead lines of 132 kV and greater is shown in Figure 2.

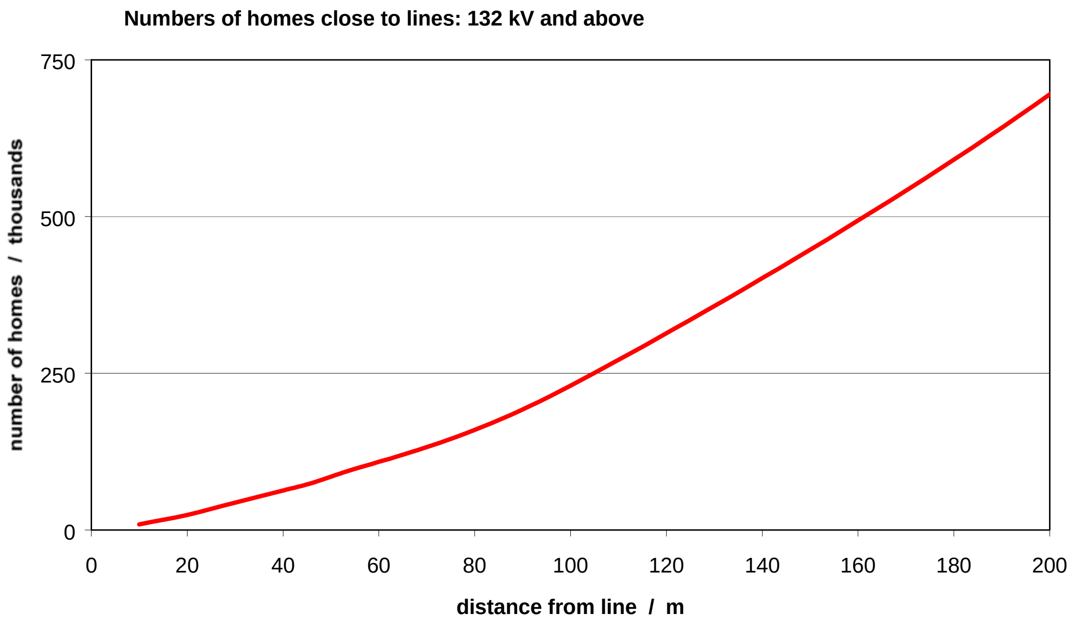


Figure 2 Estimated numbers of residential properties near overhead power lines 132 kV and above in England and Wales

3 Value of homes near power lines

The value of homes near power lines could differ from the national average for two reasons: if the homes that are built there are devalued because of the presence of the power line, or if different types of homes are built there in the first place. For example: on the one hand, a three bedroom house is built, that anywhere else would be worth £200k, but because of the effect of the power line is only worth £190k. On the other hand, instead of building three bedroom houses, the presence of the line means the builder builds smaller and less valuable two-bedroom houses instead.

The impact of the power line on the value of a property very much depends on the type of property. For individual homes in a rural location within 50m of National Grid lines, an average diminution in value of up to 15% (compared to what the same property would be worth without the power line) has been experienced. Larger devaluations are quite possible where the visual setting is a large part of the attractiveness of the property. However, on large housing estates, where the visual setting is less important, the average devaluation per house for properties close to the overhead line is probably less than 5%.

Where there is devaluation, it is almost impossible to identify whether any of that is due to EMFs as opposed to the purely visual factors.

In addition to evidence on specific devaluation near lines, there is also some evidence that homes near lines may be less valuable than the average for the country as a whole. National Grid used the Hometrack postcode-level data on house values and took a random sample of homes within 50 m of National Grid lines in summer 2003. On that basis the average value was £115k per home, 85% of the then national average of £135k. The national average is now £167k (January 2005) so it is assumed the average value of property within 50 m of National Grid lines is now £142k. On this basis, the value of residential property in proximity to National Grid lines is shown in Figure 3.

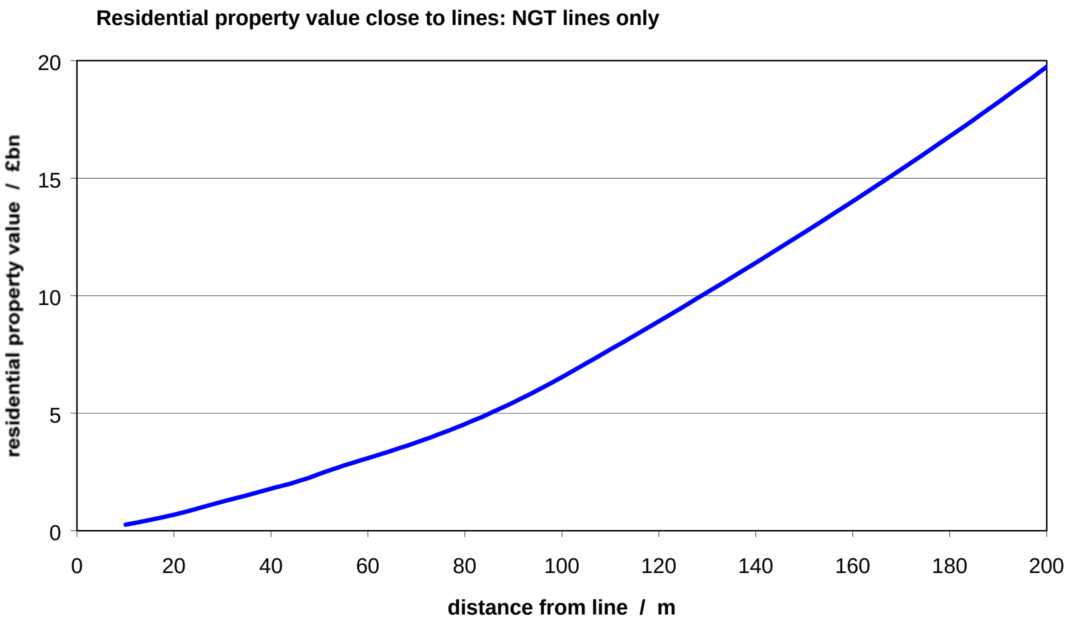


Figure 3 Estimated value of residential property near National Grid overhead power lines in England and Wales

Assuming the average value of a house near 132 kV lines is the same as for near National Grid lines, Figure 4 gives the value of homes at various distances from 132 kV and above lines.

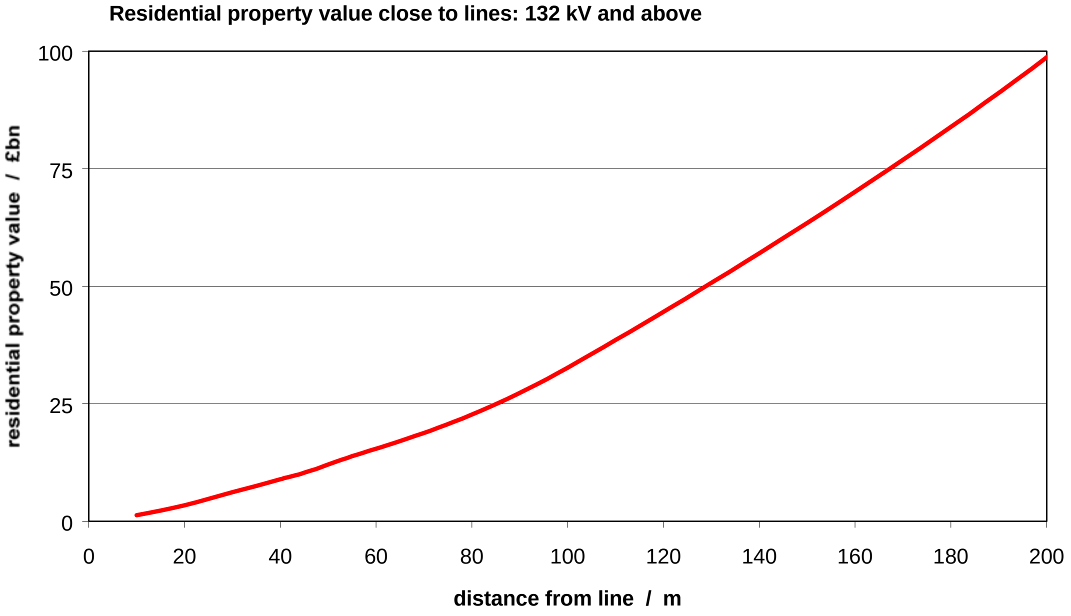


Figure 4 Value of homes near lines of 132 kV and above

4 *Other existing development near power lines*

4.1 Schools

Three sources of information on schools near power lines are available:

- a list of schools created by asking National Grid linesmen and wayleave officers
- a list of schools created by searching the “name” field of the AddressPoint data for terms such as “school”, “academy”, “college”
- a database of all educational establishments in England supplied by DfES analysed by National Grid for proximity to lines.

In all three cases, the data available relate only to proximity to National Grid lines (275 kV and 400 kV) and not to 132 kV or below lines.

In all three cases, a major difficulty is establishing the extent of the school’s grounds.

The analysis of the DfES database shows that there are 41 within 100 m and 193 within 200 m. Perhaps slightly under half of these are nurseries or other childcare facilities. It must be emphasised that this distance relates to an arbitrary point within the school buildings and not necessarily to either the closest point of the school buildings or the closest point of the grounds.

Based on the first two sources of information

- It is known that there are at least 25 schools with their grounds or playing fields oversailed by a National Grid power line.
- There are believed to be approximately 100 schools where part of the buildings is within 200 m of an overhead power line. For these, and possibly for others even more distant, it is possible that the grounds could extend underneath the line, but this has not been directly verified.

It is clearly possible to reconcile all three sources but this is not a trivial exercise. However, it appears that the two sets of figures presented here are broadly compatible.

4.2 Other land uses

- Recreation areas

As one example of recreation areas, it is believed that there are at least 100 golf courses extending under a National Grid overhead power line.

- Footpaths, bridleways etc

It is estimated that at least 2000 pylons have a footpath, bridleway, pavement etc passing close to them. The corresponding estimate for paths underneath spans must be considerably higher.

5 Land with development potential near National Grid lines

All areas in England and Wales are covered by a local Development Plan. These allocate areas of land for development on a 10-15 year timeframe. There is no guarantee that all these sites will be developed, and there is no guarantee that development will not occur on other sites not allocated for development. However, there is a presumption that these are the sites where development will take place in the next 10-15 years.

As far as National Grid can discover, as of 2003, there were 158 sites allocated in development plans for development which were crossed by a National Grid overhead line. 48 of these were allocated for residential development (including 4 mixed use sites). They involve about 13 km and 130 spans of overhead line (this is an approximate figure partly because of the ambiguity of defining whether the span which starts at a pylon on the land but finishes off the land is included or not).

There is no known information on development sites under lower-voltage lines.

These sites vary in size and in the nature of the likely development. National Grid has experience of negotiating compensation for loss of development potential caused by the presence of an overhead line. On the basis of existing experience, including mitigating factors such as optimum planning for a site so as to use land directly under conductors for non-built development, it estimates it would expect to be liable for approximately £125-175m across all these sites, in respect of a strip of land 30 m wide, ie extending just the actual extent of the conductors plus a small margin. This is the total amount payable; each affected landowner would receive a one-off payment and this total therefore represents a one-off amount, albeit probably in practice spread over a number of years.

Extrapolating to larger distances is difficult because it is not something electricity companies have hitherto had to do. This paper uses a simple linear extrapolation, which has been verified as reasonably appropriate on the basis of a detailed analysis of land affected and possible compensation for one particular distance, ±50 m.

In the absence of specific information, 132 kV lines are included simply in proportion to their length (making an estimate that there are twice the 132 kV route km as National Grid route km), trebling the figures for National Grid lines alone, but these figures can only be approximate.

The 2004 Planning and Compensation Act introduced a new system of Development Plans called Development Frameworks. These are to be updated more regularly than their predecessors and will include site specific ‘Action Plans’ for defined areas, together with a myriad of documents covering different development topics. It is too early to understand the impact this will have on the number and frequency of sites coming forward for development. National Grid and others will monitor the new system to understand further the impact of development on the transmission network.

Supporting paper S16

S16 Power lines: contractual, legal and compensation issues

This paper describes some of the legal issues that arise in connection with the options considered for power lines and property and their consequences: the legal framework under which power lines exist, compensation, compulsory powers, and the law related to nuisance and pollution.

1 Legal framework for the existence of power lines

In England and Wales electricity companies usually own the land occupied by their substations, but only exceptionally do they own the land on which their electricity lines are installed. Unlike many other countries there is no defined “right of way strip” where overhead lines are installed. Instead of acquiring land, rights to place electricity lines and cables on third party land known as wayleave agreements and deeds of grant of easement are entered into with landowners. Landowners are paid compensation for the grant of these rights, either as an annual sum under a wayleave or one off capital payment under a deed. These payments are made by the electricity company that installs the apparatus. Landowners with apparatus on their land are known generally as “grantors”.

Under the Electricity Act 1989 only those with electricity equipment, be it towers, poles or overhead line conductors on or over their property are entitled to compensation.

Such situation requiring easements or wayleaves plus compensation payments include temporary situations arising from lateral movement of line conductors between supports due to high winds

The agreements to place equipment on grantors’ land, and payments made to them, are discussed in more detail below.

1.1 Wayleave Agreements

In England and Wales the bulk of electricity lines are held on voluntary wayleaves. A wayleave agreement is defined as a terminable licence for which annual rent and compensation is payable. A wayleave agreement gives the electricity company the right to install and keep installed an electric line on, under or over land for the purpose of inspecting, maintaining, adjusting, repairing, altering, replacing or removing the electric line.

Where a wayleave agreement is entered into by a grantor an annual payment is made. In England and Wales wayleave payment rates for electricity transmission and distribution lines are the subject of an agreement between the electricity companies, the Country Land and Business Association (CLA), the National Farmers’ Union (NFU) and the Farmers’ Union of Wales (FUW). Annual payment rates are reviewed periodically and are based upon the type and size of the structure or apparatus and typically include two elements:

- rent – payable to the landowner
- compensation – payable to the occupier (unless the tenancy terms provide otherwise) for interference with agricultural activities. The compensation element is based upon DEFRA figures using a formula devised by ADAS, using average farm input prices.

Special rates apply to various forms of intensive cultivation and additional payments are made for multiple lines.

Where an electricity line is held on a wayleave and the landowner believes that his property or a development that he proposes has been diminished by the existence of the apparatus then the landowner makes a claim to the electricity company. In these instances the electricity company may make a compensation payment equal to the diminution in value to the property and agreed between the parties. Where such a payment is made this is done as a “one off payment” in exchange for the

landowner entering into a deed of grant of easement to allow the electricity company to retain its equipment permanently.
If agreement on the sum of compensation payable is not reached between parties then it may be determined upon the reference of either party to the Lands Tribunal under the Lands Tribunal Act 1949 the Land Compensation Act 1961 and the Land Compensation Act.

1.2 Deed of Grant of Easement

This is a legal right in perpetuity granting the electricity company the right to install, and keep installed, an electric line on, under or over land for the purpose of inspecting, maintaining, adjusting, repairing, altering, replacing or removing electric lines. This legal right is granted by formal documentation. In exchange for the deed of grant of easement the electricity company will pay a capital sum which is based on twenty times the yearly wayleave payment. Where there is 'injurious affection' due to the presence of the overhead line on the property, then an additional sum of compensation agreed between the company and the landowner or their agent may be paid. The principle of compensation in these instances is based upon the difference of the value of the property without the "scheme" ie the overhead line and the value of the property with the "scheme".

Electricity Companies recommend that landowners employ suitably qualified professional land agents and valuers to negotiate claims on their behalf. Landowners will also require a solicitor to complete the Deed of Grant of Easement. Reasonable solicitors' and agents' fees are paid upon completion of the legal deed.

Where an electricity line is held on an easement no further compensation is payable to a landowner unless the easement contains what is known as a "development clause". This specific clause can allow a landowner to receive more compensation, subject to conditions which may include planning permission being granted, where the proposed development is affected by the presence of the overhead line.

In the event of a failure to agree on compensation for a deed of grant of easement then the matter can be referred to the Lands Tribunal.

2 Compensation issues

This section summarises the present situation. It obviously does not preclude any change to the present compensation regime as part of an overall change in policy.

2.1 Entitlement to receive compensation

It is only fair to preface the following information with a recognition that some of the legal issues have not yet been thoroughly tested. What follows is largely National Grid's and DTI's opinion on the contractual and legal situation, but there is always the possibility that a court could disagree.

If a property experiences devaluation, the ability of the owner to claim compensation depends on the nature of their contractual relationship, if any, with National Grid or other electricity company.

If they (or a previous owner of the land) have granted a standard permanent easement to National Grid:	then	They can claim no further compensation, even if there is in fact further devaluation
If they have granted a permanent easement which explicitly allows for further compensation through a development clause:	then	They could claim compensation for any devaluation, the amount to be settled by negotiation or by the Lands Tribunal if negotiation fails
If the line is present through a terminable wayleave	then	They could negotiate compensation for devaluation in the course of converting the wayleave to an easement. If agreement could not be reached, they could terminate the wayleave, the electricity company could apply for a necessary wayleave, and if granted, compensation could either be negotiated or settled by the Lands Tribunal.
If the line does not cross their land	then	No legal liability for compensation from the electricity company or from anyone else under present law, no matter how close the line nor how large the actual devaluation

These arrangements apply equally to any devaluation of existing properties as to loss of development potential for undeveloped land. The key legal issue is whether devaluation has, as a matter of fact, taken place. For the purposes of compensation, it is irrelevant whether the devaluation occurred as a result of any particular actions or not, who took that action, or whether it is reasonable or not.

National Grid has roughly 20,000 grantors, similar to the number of residential properties within 50 m of National Grid lines. There is not a simple correspondence between these two groups but there is obviously considerable overlap (many, but not all, residential properties within 50 m have the line crossing them and are therefore grantors; many, but not all, pieces of land crossed by a line are part of a residential property). The further the distance from the line considered, the greater the fraction of homeowners who would not be grantors and would have no entitlement to compensation. The same principle applies to lower-voltage lines.

The majority of grantors are on terminable wayleaves.

2.2 Who pays the compensation?

Where an electricity company is faced with additional costs it could absorb them itself or it could seek to pass them through to its customers, and hence ultimately to electricity consumers.

Charges for use of electricity transmission and distribution networks are regulated by Ofgem. Ofgem’s corporate body, The Gas and Electricity Markets Authority, has a principal objective to protect the interests of consumers, as does the Secretary of State. They also have responsibilities to promote efficiency and economy, and protect the public from dangers, subject to the need to ensure that reasonable demands for electricity are met and companies are able to finance their activities (Utilities Act 2000, Section 13).

If Government were to introduce regulations or planning policy that made it mandatory for the companies to apply a particular level of precaution, the companies would have no choice but to comply. Ofgem would have little choice but to treat such costs as unavoidable and, providing they were incurred in an efficient way, take them into account in setting use of system price controls. However, any such change in regulations or planning policy would be preceded by a consultation and regulatory impact assessment, which would inevitably focus on costs and benefits.

If, in the absence of mandatory measures, transmission companies were asked voluntarily to apply precautionary measures, funding would be more problematic. Ofgem would need to consider such expenditure in the light of the principal and other objectives before allowing any such costs to be passed to consumers. Similarly, companies would wish to consider the interests of their shareholders before themselves absorbing such costs. Voluntary adoption of precautionary measures would therefore also be heavily dependent on a favourable cost/benefit assessment.

If electricity companies incur costs and Ofgem allow this cost to be passed through, the cost comes to rest on electricity consumers, which includes most households but also industry.

If electricity companies incur costs and Ofgem does not allow this cost to be passed through, the cost is borne by shareholders in these companies. Many of these are insurance companies, pension funds etc, so much of the cost is effectively spread across society, but in different proportions.

If Government intervene to pay compensation themselves, the cost is borne by taxpayers, again spread across all of society.

Where electricity companies are not liable to pay compensation and do not elect voluntarily to do so, the cost rests where it first falls, with those individual landowners happening to own land near power lines.

3 Compulsory powers

Compulsory powers are provided to acquiring authorities to compulsorily purchase land or rights in land to carry out a function which parliament has decided is in the public interest. Electricity Transmission and Distribution companies as licence holders under the Electricity Act 1989 have compulsory-acquisition powers under Schedule 3 and Schedule 4 of the Act.

The Electricity Act 1989 provides two methods whereby rights may be obtained from landowner to place electricity apparatus, these are:-

- “necessary wayleaves” detailed in Schedule 4 of the Act
- a compulsory-purchase order to acquire a right in land eg an easement detailed in Schedule 3.

For overhead power lines, if a voluntary agreement cannot be made with the landowner then it is normal for the electricity company to seek a “necessary wayleave”. When installing underground cables, it is normally the case that a CPO for an easement will be sought. Where an existing overhead line is held on a voluntary wayleave and a landowner terminates that agreement and serves a notice to remove, then an application for a necessary wayleave may be made to retain the line in situ.

Compensation following the grant of a right under either Schedule 4 or 3 is payable and if it cannot be agreed between parties then may be determined by reference to the Lands Tribunal. An extract from the Electricity Act 1989 is given in Section 5 of this paper.

The compulsory powers can be granted
“*for any purpose connected with the carrying on of the activities which he is authorised by his licence to carry on*.”

At present, the purposes for which the powers are granted are for wayleaves and easements relating to the presence of pylons, poles or conductors on or over the land in question. Because there is no need for electricity companies to obtain rights over land further to the sides of a power line, which is not crossed by the line, the compulsory powers are not used for that purpose.

If, as a precautionary measure, it became necessary to acquire rights over lands not crossed by the power line, eg to prevent future development there, the powers under schedule 3 are adequate to cover this. No new legislation would be necessary. However, this would be such a departure from current practice that it would probably need a very clear steer from Government that this is what they intended, and would probably need to be written explicitly into whatever guidance was used to establish this new regime.

4 Applicability of existing legislation to EMFs

We consider here the extent to which EMFs may be covered by other existing legislation. Many legal provisions do not specifically refer to EMFs, and opinions as to their relevance are somewhat speculative, not having been tested in the courts. The following paragraphs are not intended to provide a definitive legal opinion but merely provide an indication of the range of legislative measures which may, or may not, be relevant. Small differences in legal provisions may be found in Scotland, Northern Ireland and Wales compared with those appertaining in England.

Relevant statutes are:

Health and Safety at Work Act 1974 **-** Management of Health and Safety at Work Regulations 1999

EU Recommendation on limitation of exposure of general public to electromagnetic fields 1999

EU Directive on the minimum health and safety requirements regarding the exposure of workers to the risk arising from physical agents (Electromagnetic fields) 2004 which is due to be introduced in UK law by 2008.

These are mostly concerned with field strengths that produce known effects. Electricity and EMFs are not covered under Planning (Hazardous Substances) Act 1990 legislation relating to hazardous substances.

4.1 The precautionary principle

The UK Government ratified the Rio Declaration on Environment and Development following the UN Conference on Environment and Development in1992.
Principle 15 of the Rio Declaration states: "*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*."
Principle 1 states **"***Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature*".

The EU provides for a precautionary approach to environmental harm under Art 174* EU treaty (*previously Article 130r before the Treaty renumbered).
Article 174(2) states *"Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Community. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay".*

However the Court of Appeal has held that that the Sec. of State is not obliged to adopt a precautionary principle for national policies under Article 130r (now Article 174) unless required by an EU directive.

4.2 Planning considerations

Under s57 Town and Country Planning Act 1990 (TCPA 1990), any proposed development or change of use of land normally requires a grant of planning permission from the local planning authority (LPA). When considering a planning application, the LPA may grant permission with or without conditions attached or refuse planning permission.

Under s90(2) TCPA 1990, power lines which have been granted consent by the Secretary of State under s37 of the Electricity Act 1989, may be deemed to have been granted planning permission.

Part 17 (G) of Town and Country Planning (General Permitted Development) Order 1995, allows permitted development rights for other categories of electricity lines.
Part 17 (G)(a) allows permitted development rights for the installation or replacement in, on, over or under land of an electric line provided it is not on a highway and does not require consent under s37 Electricity Act 1989.

Under s70 TCPA 1990, when making a decision about whether to grant planning permission, the LPA has to have regard for the Local Development Framework (or Local Development Plan, now being phased out) as far as material to the application and any other material considerations.
Section 38(6) of the Planning and Compulsory Purchase Act 2004 requires the LPA to determine the planning application in accordance with the local development framework unless material considerations indicate otherwise.

Material considerations can include perceived or potential adverse health effects.

4.3 Environmental Impact Assessments

Under the Environmental Impact Assessment) (England and Wales) Regulations 2000*****, certain higher voltage power lines applications to the Secretary of State for Trade and Industry for consent for certain higher voltage power lines require an EIA. These are (Schedule1):

(2) “ an electric line installed above ground with
(a) a voltage of 220 kilovolts or more and
(b) a length of more than 15 kilometres, the installation of which (or the keeping installed of which) will require a section 37 consent.”

In addition Schedule 2 provides for an EIA where a power line will have a significant effect on the Environment, including:

(3) an electric line installed above ground with a voltage of 132 kilovolts or more, requiring a s37 consent but which is not Schedule 1 development.

(4) an electric line installed above ground in a sensitive area, requiring, a s37 consent but which is not Schedule 1 development and does not fall within para(3).

(4)(a)-(i) Lists Sensitive areas and includes Areas of Special Scientific Interest, land within 2 kilometres of SSSI, Nature Conservation areas, National Parks, The Broads, World Heritage sites, Monuments under Ancient Monuments and Archaeological Areas Act 1979, Areas of Outstanding Natural Beauty and European Sites under Conservation (Natural Habitats) Regulations 1994.

The 2001 EU Directive on Strategic Environment Assessment (SEA) was transposed into *The Environmental Assessment of Plans and Programmes Regulations 2004*.* It extends environmental impact assessment from projects to plans and programme.

An EIA has to be undertaken by statutory bodies when preparing certain plans, which also include future development projects which are listed in Annex I and II of the 1997 EU Environmental Impact Assessment Directive.

Legislation derived from the EU Habitats Directive and EU Birds Directive prevents large infrastructure projects going ahead unless no reasonable doubt remains as to possibility of significant adverse effects on the habitats or species.

Plans or programmes falling within the criteria might involve overhead power lines.

4.4 Statutory Nuisances under the Environmental Protection Act 1990 (EPA)

The EPA 1990 lists a number of matters that constitute statutory nuisances. Local authorities can serve abatement notices and pursue either criminal or civil proceedings. These nuisances are described in the overview given in Section 6 of this paper taken from the EPA 1990.

EMFs do not seem to fall within any of these categories.

It could possibly be argued that the premises in Item 1 are contaminated by EMF. "*Contaminated land*" is defined in section 78A(2) EPA. It is any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of *substances* in, on or under the land, that-

(a) significant harm is being caused or there is a significant possibility of such harm being caused; or

(b) pollution of controlled waters is being, or is likely to be, caused;

[(b) significant pollution of controlled waters is being caused or there is a significant possibility of such pollution being caused;]

"Substance" is defined as follows:

"*substance" means any natural or artificial substance, whether in solid or liquid form or in the form of a gas or vapour*;"

EMFs would seem not to fall within the definition of substance, since they are forces rather than matter in a physical form (solid, gas or liquid). Therefore it seems unlikely that EMFs could give rise to "contaminated land". Even if they did, this would not create a statutory nuisance:
"*No matter constitutes a statutory nuisance to the extent that it consists of, or is caused by, any land being in a contaminated state.*"

In conclusion therefore, even if EMFs could be shown to cause demonstrable harm, it would seem unlikely that the EPA would encompass it as a statutory nuisance. There have been suggestions that EMFs may be covered by Contaminated land legislation, though again this seems unlikely.

Similarly, other provisions of the Environmental Protection Act, such as those relating to pollution control, waste and clean air, do not appear to be directly relevant.

4.5 Civil Action

There are other private law areas where problems with electricity transmission or EMF have given rise potentially to remedies through the Civil Courts.

There have been various nuisance cases involving this subject matter and it has also been established that License holders owe a common-law duty to take reasonable care to avoid acts or omissions which can be reasonably foreseen and are likely to injure persons closely and directly affected by those acts (ie the effects of electricity and EMFs).

Case law seems to suggest that at present a claim in negligence against a License holder in respect of safety issues arising from EMFs would not presently succeed.

4.6 Future changes

The legal provisions outlined above have been in place for many years. Generally, when tested in the courts, they have not proved to be relevant to EMFs, especially where there are low field strengths with uncertain effects.

We cannot preclude the possibility that Government might wish to amend an existing piece of legislation, for example the EPA, so as to make in encompass EMFs. We do not believe this would automatically follow as a consequence of a decision to take precautionary action, but as this is a political matter not a legal or scientific one we cannot be dogmatic.

5 Extracts from schedules 3 and 4 to the Electricity Act 1989

Schedule 3 Electricity Act Powers of Acquisition

1.—(1) Subject to paragraph 2 below, the Secretary of State may authorise a licence holder to purchase compulsorily any land required for any purpose connected with the carrying on of the activities which he is authorised by his licence to carry on.

(2) In this paragraph and paragraph 2 below "land" includes any right over land (other than, in Scotland, a right to abstract, divert and use water); and the power of the Secretary of State under this paragraph includes power to authorise the acquisition of rights over land by creating new rights as well as acquiring existing ones.

Where CPO powers are used under Schedule 3 compensation may be payable and the reference is made to section 7 of the Compulsory Purchase Act 1965

In assessing the compensation to be paid by the acquiring authority under this Act regard shall be had not only to the extent (if any) to which the value of the land over which the right is to be acquired is depreciated by the acquisition of the right but also to the damage (if any) to be sustained by the owner of the land by reason of its severance from other land of his or injuriously affecting that other land by the exercise of the powers

Schedule 4 Electricity Act

"the necessary wayleave" means consent for the licence holder to keep the electric line installed on, under or over the land and to have access to the land for the purpose of inspecting, maintaining, adjusting, repairing, altering, replacing or removing the electric line.

7.—(1) Where a wayleave is granted to a licence holder under paragraph 6 above—
    (a) the occupier of the land; and
    (b) where the occupier is not also the owner of the land, the owner,
may recover from the licence holder compensation in respect of the grant.

(2) Where in the exercise of any right conferred by such a wayleave any damage is caused to land or to moveables, any person interested in the land or moveables may recover from the licence holder compensation in respect of that damage; and where in consequence of the exercise of such a right a person is disturbed in his enjoyment of any land or moveables he may recover from the licence holder compensation in respect of that disturbance.

(3) Compensation under this paragraph may be recovered as a lump sum or by periodical payments or partly in one way and partly in the other.

(4) Any question of disputed compensation under this paragraph shall be determined by the Tribunal; and sections 2 and 4 of the [1961 c. 33.] Land Compensation Act 1961 or sections 9 and 11 of the [1963 c. 51.] Land Compensation (Scotland) Act 1963 shall apply to any such determination.

6 Statutory Nuisances under the Environmental Protection Act

Under s 79(1) EPA 1990, the local authority (LA) has a duty to inspect its area and to investigate complaints of nuisance. If a LA is satisfied a statutory nuisance exists or is likely to occur, then it must take steps to make the person responsible to abate the nuisance.

S79 (1) lists a number of matters that constitute statutory nuisances.

(a) any premises in such a state as to be prejudicial to health or a nuisance;

(b) smoke emitted from premises so as to be prejudicial to health or a nuisance;

(c) fumes or gases emitted from premises so as to be prejudicial to health or a nuisance;

(d) any dust, steam, smell or other effluvia arising on industrial, trade or business premises and being prejudicial to health or a nuisance;

(e) any accumulation or deposit which is prejudicial to health or a nuisance;

(f) any animal kept in such a place or manner as to be prejudicial to health or a nuisance;

(fa) any insects emanating from relevant industrial, trade or business premises and being prejudicial to health or a nuisance*****;

(fb) artificial light emitted from premises so as to be prejudicial to health or a nuisance*****;

(g) noise emitted from premises so as to be prejudicial to health or a nuisance;

(ga) noise that is prejudicial to health or a nuisance and is emitted from or caused by a vehicle, machinery or equipment in a street or in Scotland, road; and (h) any other matter declared by any enactment to be a statutory nuisance;

[*****s79(1)(f)(a) and (b) added as new statutory nuisances by Clean Neighbourhoods and Environment Act 2005].

Supporting Paper S17

S17 Power lines: effects on land and property values

If a piece of land was previously eligible to receive planning permission for development, but then, because it is near a power line, that development is no longer permitted, the land loses value. This would be one of the consequences of introducing a ban on development near power lines.

However, there may be other reasons why land or property near power lines might lose value. Fear of the possible health effects of EMFs might make people reluctant to buy homes near land. A similar effect might be produced by people’s concern, not about possible health effects themselves, but about the future home value or the ability to sell it being affected by other people’s concerns. Both of these could be strengthened by a Government policy preventing new homes near lines. In this Supporting Paper, we discuss these effects.

This paper is based upon experiences of the property market and research. It utilises an understanding of the property market in an attempt to develop possible modes of response to the recommendations which SAGE makes.

1 Which parts of the property market would be affected?

One reason for devaluation of existing homes near power lines would be if people’s concern about exposing themselves or their family to possible health effects made them less willing to buy such homes.

Consider first the situation if the concerns are limited to childhood leukaemia. The logic behind this scenario is that the accepted wisdom is that the risks, if any, of childhood leukaemia are low and, by definition, that it only affects children. Consequently those families without children (or who do not anticipate having children) should, logically, perceive few problems when considering purchasing or selling property within any zone determined by SAGE. What effect there would be, would be a function of supply and demand, demand being influenced by the number of prospective purchasers with/without children. It is also possible that, due to the existence of this knowledge already within the market place, that purchasers, sellers and occupiers have already factored it into their buying process. Hence possible effects may have partly been absorbed by the market. Any publicity associated with a SAGE report might be expected to raise the profile and concern, having a negative affect on the market which then might be expected to ameliorate with time. It could also be argued that, with the passage of time, any certainty which a SAGE report might bring would help to reduce stigma and uncertainty in the long run.

Consider now the situation where the concerns extend to other adverse health effects as well. The logic here is that, unlike with childhood leukaemia, the possible risks are not so clearly known or defined and hence a greater uncertainty exists. Furthermore, those possible risks relate to adults and hence all potential purchasers and sellers are affected. It might be argued that the potential for adverse purchasing decisions decreases with the age of those involved in the process and their familiarity with living near high voltage apparatus. The initial effects may be less predictable and probably greater than if just childhood leukaemia were considered. However, should any resulting precautionary approach adopted by Government meet with general acceptance, this would probably bring some certainty to the market. In the longer run this should reduce uncertainty and hence partially mitigate effects which stigma might have on property.

Regardless of what a house buyer may feel about possible health effects themselves, they may be less willing to buy a home near a power line if they fear that in the future the home could lose value because of a change in the science or because of a shift in other people’s perception of the possible health risk.

2 General factors affecting property values

The following sections develop the possible manner in which the recommendations which SAGE makes, and in due course any decisions by Government, are likely to impinge upon the open-market dynamic for residential property. The impact that might be expected would be a function of the market dynamic. This can be sub-divided into a number of categories:

2.1 The state of the market itself

When a property market is buoyant, properties sell well and there is a relative increase in demand for property. In such markets, purchasers become less fussy and hence properties might be expected to sell quite quickly. This would similarly be expected for properties with defects which at less favourable times might be difficult to sell. As a result, any potential for SAGE recommendations to produce a reduction in open market value would be less than at other times. This is what would be expected to happen to properties with defects or in less attractive situations. The reduction experienced would depend upon other factors (see below) and in the cases of a known defect might be greater, equal, or less than the costs of rectification.

Value of property in good condition	A
Cost of remediation	B
Value of property with defect	A – (B+C)

Where C = the reward required by purchasers for taking on the problem. C can be expected to decrease with the demand for the property, the desirability of the property, the certainty of the remediation and, depending upon the facts, as prospective purchaser’s socioeconomic ranking lowers.

When a market is poor and there is an apparent shortage of ready and willing purchasers in relation to the amount of properties offered for sale, properties with defects would normally be expected to experience a reduction in open market value. In order to induce a purchaser to buy a property it may be necessary for the vendor to lower the price such that the purchaser attains a potential profit, should they the sell on the remediated property.

Value of property in good condition	A
Cost of remediation	B
Value of property with defect	A – (B+C)

Where C = the reward required by purchasers for taking on the problem. C can be expected to increase with any reduction in demand for the property, the desirability of the property, the uncertainty of the remediation and, depending upon the facts, as prospective purchaser’s socioeconomic ranking increases.

2.2 Socio-economic grouping.

As the socio-economic grouping lowers, the market might expect purchasers to be less sensitive to problems with properties. In general, first-time purchasers, for instance, have less choice than subsequent purchasers and so are less able to purchase alternative property instead. Similarly, anecdotal evidence would suggest that there is a link between affluence and the ability to act in an informed manner. It is certainly true that the ability to afford expert advice increases with income. The result is that properties at the lower end of the housing market might be expected to experience a relatively lesser decrease in market value than those at the upper end. This again would depend upon other factors such as the state of the market and the particular characteristics of a property.

2.3 Familiarity with a problem

Anecdotal evidence would suggest that familiarity with a problem might be expected to reduce the potential for a reduction in open-market value. For example, properties in mining areas and which have experienced subsidence problems such as residual tilt, floors and walls out of alignment, and some cracking can find purchasers, probably due to the fact that such defects are more common and prospective purchasers may well be familiar with them. This would be less likely with similar defects in areas where such problems are not common. The relationship of familiarity with a risk and the lowering of an individual's perception of that risk is frequently reported in risk research. This would suggest that properties which have been within the distances from power lines that SAGE has been considering are less likely to be affected, where mature properties and the surrounding communities have a longer standing history with the relevant power lines when compared with relatively new developments and communities.

There are probable exceptions to the above. Where communities are familiar with a risk, but are more aware of the downside of that risk than those less familiar, a greater reduction might be experienced. Examples of this have been found for areas affected by coastal erosion and flooding. There may also be communities who campaign against something like a power line or a mobile-phone mast. In such cases their campaigning may increase the prominence of real and alleged adverse affects resulting in a larger adverse affect than might otherwise be expected. High profile cases with press coverage may also increase the prominence of the issue under debate and hence increase awareness, resulting in a wider public response, although this might still be constrained within a locality.

3 Duration of any devaluation

Research into issues which affect property such as flooding, forest fires and mining suggests that while the open-market value of properties may be adversely affected by negative environmental issues such as flooding and forest fires, the negative effect decreases with time and the resulting lack of publicity. Properties which may prove unsaleable immediately after a flood become more saleable as the memory of the flood recedes to a point where full open-market value, as if there had been no flood, can often be achieved. It is possible that a similar situation might arise as a consequence of recommendations by SAGE or Government decisions, ie, there may be an immediate effect which ameliorates with time.

4 How likely is devaluation near power lines?

It is accepted that there is already some devaluation of homes near power lines. The exact extent of this might be disputed, but for properties on estates, where the visual setting of the home is not a major part of its attractiveness, devaluations in single-figure of percent may be typical. Higher devaluations occur where the visual setting of the property is more important. Although it is difficult to separate the effects, it seems likely that most of the devaluation that occurs at present is attributable to the visual and general amenity impact of the power line, rather than EMF concerns.

We identify two possible triggers for a change to the present situation. One is the publication of this Report by SAGE. We expect this will lead to some publicity, raising the profile of the issue, and that this might lead to some further devaluation of properties. This would be related to public awareness and perception, and therefore, as we have already discussed, might be a transient effect, possibly reducing over time.

The other trigger would be if Government decided to introduce restrictions on new homes near power lines. The situation where Government had decided it is undesirable to live near power lines on health grounds could lead to a further devaluation of existing such properties, which might take longer to reduce, or might not reduce to the same extent.

It could be argued that such devaluation is unlikely. The cumulative effect of publicity on the EMF issue so far has led to a small effect, if any, on property values. There have been some reasonably high-profile TV programmes, for example, and arguably, given the history of EMF media coverage, it is hard to see what it would take to produce the greater level of public concern that would lead to substantial devaluation. In a nutshell, if devaluation has not already happened it is unlikely to in the future. Further, it is possible that bringing clarity to the situation of EMFs, with clear recommendations and clear Government advice, could remove some present uncertainty and thereby have a positive effect on property values.

Alternatively, it could be argued that the history of some other issues (eg the timber-framed-buildings saga stemming from the World in Action programme of 1983, where a single TV programme alleging quality and safety issues with timber-framed buildings made such buildings almost unsaleable at any price for a while) proves that public concern, whether or not justified by facts, can have a major effect on property issues. Timber-framed buildings are now, a decade or two later, commonplace and suffer no specific devaluation. However, property devaluation and a major change in house-building practice were brought about by the concerns created by one single TV programme. How much greater could be the effect, it could be argued, of Government endorsing health concerns through formal policy. Some anecdotal support for this view came when a version of some draft SAGE recommendations was leaked in the media in 2006. Calls to the electricity industry helpline increased dramatically, mainly from people concerned about their house value, and this included some agreed property sales which apparently fell through purely because of the media stories. It is impossible to deduce from these anecdotal instances how widespread such effects might be, but they are evidence that at least some effect should be expected.

5 Possible extent of devaluation

It is clear from the discussion in this paper that we cannot be certain how much devaluation would occur in different scenarios. We therefore consider four different scenarios, which are intended to cover the entire conceivable range; by covering the whole range, it is hoped not to prejudice the discussion of where within that range reality would lie.

The scenarios are:

1 No devaluation: costs limited to loss of development potential

2 Modest devaluation: loss of development potential, plus
  - 5% devaluation of homes within the distance of the no-building policy

3 Medium devaluation: loss of development potential, plus
  - 15% devaluation of homes within the distance of the no-building policy for the larger lines, ie National Grid lines
  - 10% devaluation of homes within the distance of the no-building policy for the smaller lines, ie 132 kV lines
  - Further devaluation of some homes outside the distance of the no-building policy: 5% for homes at up to 50% beyond the specified distance for the larger, National Grid, lines only

4 High devaluation: loss of development potential, plus
  - 25% devaluation of homes within the distance of the no-building policy for the larger lines, ie National Grid lines
  - 15% devaluation of homes within the distance of the no-building policy for the smaller lines, ie 132 kV lines
  - Further devaluation of some homes outside the distance of the no-building policy: 10% for homes at up to twice the specified distance for the larger (National Grid) lines only.

The total loss of value for these four scenarios is shown in Figure 1.

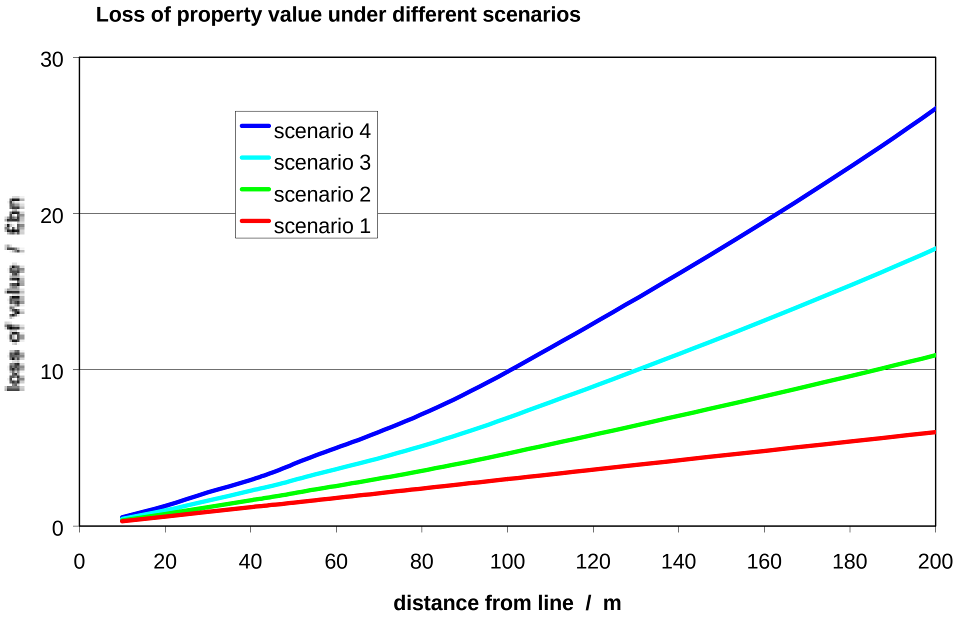


Figure 1: Best estimates of total loss in value of residential property and loss of development value of land for a restriction instituted at various distances from the power line under four different scenarios

At closer distances to the lines, ie well within 50 m, much of the property affected would belong to grantors, entitled to receive compensation from National Grid or other electricity company. At larger distances, ie much beyond 50 m, most would not be grantors and would not be entitled to compensation under existing rules.

These figures are for high-voltage overhead power lines at 132 kV and above. Smaller power lines at lower voltages are not included. Nor are any knock-on effects for other components of the electricity system such as substations or underground cables.

Supporting paper S18

S18 Power lines: possible options considered

Section 5 describes the process of identifying, analysing, and narrowing down options for dealing with homes in proximity to power lines. This paper gives more information on some of the options considered. A subsequent paper, Supporting Paper S19, gives a more formal cost-benefit analysis of some of these options. This paper sets out to be less formal but instead to capture the flavour of the discussions that we had in SAGE about these options.

1 Possible action: purchase existing homes

1.1 Possible ways of implementing this policy

This would be a policy designed to remove people from the fields around existing power lines by buying their homes.

This could be envisaged in various forms:

Which homes are involved:
- All homes within a certain distance of power lines are compulsorily purchased
- On a certain date, there is a one-off offer to buy all homes within a certain distance of power lines
- There is a rolling offer to buy all homes within a certain distance of power lines

What happens once the homes are purchased:
- Once purchased, homes are demolished
- Once purchased, homes are offered for resale
- Once purchased, homes are offered for resale, but only, eg, to households with no children, or for non-residential use

The financial arrangements:
- Purchase is at market value
- Purchase is at market value as it would be in the absence of the power line
- Purchase is at a premium to market value

The consequences of the policy depend on which of these options is chosen. Some of these alternatives involve moral issues which are outside the scope of this paper.

1.2 Effectiveness at reducing exposures

If people are removed from a certain distance of power lines, they are removed from that exposure. This can be quantified from the data presented in Supporting Paper S14.

1.3 Possible consequences and costs

The cost of buying homes within a certain distance of power lines can be assessed from the data in Supporting Paper S15. Suitable adjustments can be made, for example if compulsory purchase requires payment of a premium, or if the policy creates consequential devaluation at larger distances.

This policy would remove a certain number of homes from the national housing stock.

1.4 Further points emerging in SAGE discussion

Costing is complex, depending on what future use is made of the buildings. Also it depends on the perspective: the original owner is presumably compensated, so the impact is on second and subsequent transactions. If the property were used for residential use but not including children, this is effective under the assumption of possible health risks from childhood leukaemia only.

2 Possible action: controls on land use around power lines

2.1 Relation of this policy to previous one

The previous section considered purchase of existing homes near power lines. This section considers the more modest policy of applying this prospectively only, not retrospectively, ie stopping any new homes from being built near power lines but not doing anything directly with existing homes. However, one possible consequence of this prospective-only policy is that it nonetheless causes devaluation of existing properties, and this is included in the consideration of this possible action below.

2.2 Effectiveness at reducing exposures

The effect of controls on developments near to power lines can be assessed from the graphs of field-versus-distance in Supporting Paper S14.

2.3 Possible consequences and costs

Suppose there were a policy of not building homes within a certain specified distance of overhead power lines (132 kV and above).

The immediate effect is that:
- National Grid and the rest of the electricity industry face valid compensation claims for loss of development potential of land, spread over 10-15 years. As explained in Supporting Paper S16, who ultimately met the cost of these claims could depend on whether it was a mandatory or voluntary policy.
- Some landowners, who owned land within the specified distance but who were not grantors, would experience a financial loss with no compensation payable.
- Sites available for new home construction are removed or reduced in size. The overall effect on the number of homes able to be built is probably small but there are some sites, for example in Thames Gateway, where the effect could be considerable.

There would be further effects if this policy led to devaluation of existing homes near power lines. The extent to which this would happen is uncertain.

We have discussed all these possible effects on land and property values in Supporting Paper S17. We conclude that we cannot be at all certain as to what the devaluation effect on existing property would be or how long it would last, but it seems likely there would be some effect. For restriction on development applied at a distance of 60 m, for example, we estimate the total loss of value could range from perhaps one or two to perhaps five billion pounds. This has to understood in the context of the general discussion in Supporting Paper S17.

2.4 Further points emerging in Working Group discussion

Visual impact: not straightforward to assess as it leaves the existing situation unchanged.

Costs: from a societal point of view, we would need to include the cost of not building in one area in terms of the consequences for building in other areas. Also, the effect may be greater for small developments: larger developments have more scope for building around any restrictions.

Impact on property price: good design of a development can alter the impacts. There may be an increase in property value for people living immediately adjacent to the affected zone. But if leaving a green corridor through a development increased the overall value of a development, developers would be doing it already. Some of the impact on property price stems from visual effects, in which case screening can help.

Effectiveness at reducing fields: depends on the distance concerned. The distance would have to be greater than 50 m to make a significant difference. The distance for electric fields may be lower as electric fields inside the home are screened by the building already. For corona ions, distance has to be very much greater, perhaps up to 1 km. Corona ions would be more of a problem in more populated areas because of the greater pollution.

Reliability of supply: makes no difference to existing situation.

Ease of implementation: relatively easy to see what policy changes etc would be needed.

Environmental impact: green-field sites are left undisturbed so better than building on them; with brown-field sites it is less clear whether this is an advantage or not.

Future proofing: greater distances give more flexibility as you can always change your mind and build there later. But if you have built elsewhere instead (possibly on green-field sites) this cannot be undone.

Safety: houses should not be built where they are unsafe anyway. But overhead lines cannot be entirely safe, and changing the type of activity that goes on underneath them, especially with wood-pole lines, may have a safety implication.

3 Possible action: Improved routing of new lines

3.1 General discussion

Clearly, if a line can be routed further away from homes, the exposures produced are reduced.

Re-routing an existing line away from homes amounts to building a new stretch of line.

For new lines, electricity companies already make some effort to route them away from existing homes. Sometimes, the routing involves “splitting the gap” between two existing homes, and therefore it is hard to see, in these instances, how the distances could be increased. In other cases, greater separation could be achieved at the cost of greater overall length of line. In some instances, therefore, a policy of keeping new lines further away from homes than they are now would equate either to not building the lines or to undergrounding, whereas in other cases it would be possible but would result in increased costs. The extent of these costs is likely (judging from previous experience) to be a matter of disagreement between electricity companies and other affected parties.

Because of the difficulty in gaining consent for new overhead lines, there are very real business drivers discouraging electricity companies from seeking to relocate existing lines which have valid consents, but where subsequent housing or other development has been built close by. One of the difficulties is that (under the present regime) there would be no guarantee that new development would not, at a later date, be built close to any relocated line.

4 Possible action: rerouting of existing line

4.1 Points emerging in Working Group discussion

Visual impact: Rerouting an existing line improves matters for an individual householder, as the line is removed from their vicinity. But from the perspective of society as a whole, the line is still there somewhere, and therefore still has a visual impact somewhere.

Cost: needs to take account of probable extra length

Effectiveness at reducing fields: the line needs to be rerouted by at least 50 m, and there has to be an assumption the rerouting does not bring it closer to another property. To reduce corona ions would have to move greater distance, perhaps 1 km.

Reliability of supply; the rerouted line will be longer so in principle less reliable.

Environmental impact: have to drive machinery over land and may end up with more pylons.

Future proofing: more flexible than some options for the future, but could end up just creating another problem.

Safety: a risk for construction workers.

5 Possible action: undergrounding

5.1 Effectiveness at reducing the field

The data on field values in Supporting Paper S14 showed that a direct-buried underground cable produces higher magnetic field immediately above the route centre but lower fields to the side.

This suggests that placing a 400 kV line underground typically confines exposures of 1 µT to within about 10 m (down from 30-40 m), and exposures of 0.4 µT to within about 15 m (down from 50-60 m). However, it is likely that fields at these distances are influenced proportionately more by imbalances in the loads which are not allowed for in the calculation, so some caution should be exercised.

Cables in tunnels are deeper and therefore produce lower fields at ground level.

5.2 Cost of undergrounding

The cost of undergrounding depends on many factors, such as the method adopted, the terrain, the capacity of cable required, and the length. The following table gives some approximate ranges for National Grid cables.

Method of undergrounding	Cost per km / £M	
	low end of range	high end of range
Direct buried (trench)	**6**	**12**
of which:		
the physical cable itself (conductor and insulation)	2.0	5.0
civil engineering works (digging the hole etc)	2.3	3.1
other costs (engineering, planning, project management, public relations)	2.0	4.0
Tunnel (3 m diameter deep-buried tunnel)	**9**	**17**
of which:		
the physical cable itself (conductor and insulation)	2.2	5.5
civil engineering works (digging the tunnel etc)	3.3	6.8
other costs (engineering, planning, project management, public relations)	3.0	5.0

Table 1 Approximate costs of undergrounding for 400 kV cables

For 132 kV underground cables, for a typical line the cost would be in the region of £1.3 to 2.5 million per kilometre. This could rise to over £3m per kilometre in urban areas and in exceptional conditions the cost could rise to upwards of £10m per kilometre. When undergrounding an existing line, the underground route usually has to be longer than the overhead route was. For rough planning purposes, 50% increase in length is reported as typical.

We believe the figures we have used for the costs of undergrounding are representative figures from UK practice. We are aware of various figures from elsewhere, primarily in Europe. Many of these are consistent with our UK figures; some suggest lower costs elsewhere. We are investigating reports of lower costs from Ireland but have not completed this. Where there are reports of lower costs, we have been unable to pin down whether they are like-for-like, and if they are, what the reason is for any differences, so we have continued to use our UK costs.

5.3 Further points emerging in Working Group discussion

Visual impact: even better than rerouting as it removes the impact altogether (though terminations need considering).

Impact on property value: creates a green corridor, and developers have to provide green space anyway (applies to trenches only, not tunnelling).

Effectiveness at reducing fields: eliminates electric field and corona ions altogether, so is the best option for this. Reduction of magnetic fields depends on depth of burial and width of corridor.

How easy is it: not liked by landowners (but they can still make some use of land) and not liked by industry (because of cost and difficulty of building and connecting).

Environmental impact: same problems as rerouting but worse.

Future proofing: sunk cost is not recoverable. May limit future use of land as you would not want to dig up the cable.

Safety: an issue for construction workers and an ongoing public safety issue.

6 Possible action: Engineering changes to lines

6.1 Raising clearances of lines

Higher lines are further from where people are and therefore produce lower fields. The extent of this can be seen from Supporting Paper S14.

Increasing the clearance over the whole range illustrated, from 8 m to 24 m, decreases the typical range of 1 µT from roughly 30-40 m to 20 m, and decreases the typical distance for 0.4 µT from roughly 50-60 m to 40 m.

For new lines, the incremental cost of making them slightly higher is probably relatively low. For existing lines, the cost of increasing the clearance by up to say 4 m is of the order of £100k per span for National Grid lines. Greater increases than this would probably involve rebuilding the whole line. There is also the obvious visual detriment to consider.

6.2 Compact lines

In principle, making a line more compact – the conductors closer together – reduces the field. Research has been conducted on this in America.

Making a line more compact increases the risk of spark-over between conductors and hence reduces the reliability of the line. UK electricity companies believe that UK lines are already about as compact as is possible without starting to lose significant reliability. It would, of course, be possible to assign a lower priority to reliability compared to other issues than at present, and hence affect this judgement.

One consequence of making lines more compact is that spans may have to be shorter and hence more pylons are required (though in turn the pylons could then also be lower). This has an effect both on the cost and on the visual impact.

6.3 Optimising phasing

With a double-circuit line (two separate electrical circuits on the two sides of the same row of pylons or poles), the fields to the sides of the line can be reduced by wiring the two circuits in something known as “transposed phasing”. The effect of this is shown in Supporting Paper S14. The effect of this is clearly quite large. The distance for the typical field to fall to 1 µT changes from roughly 50 m to 30 m, and the distance for 0.4 µT changes from roughly 90 m to 45 m. For 132 kV lines, the distance for 0.4 µT changes from roughly 30 m to 15 m

National Grid policy is to use transposed phasing where possible (and has been since the 1950s when construction of the National Grid started). Roughly 90% of the system has transposed phasing. The rest is mainly either single-circuit or where three lines join at a “T” point, where completely transposed phasing is impossible without introducing a separate phase-transposition tower. For 132 kV lines, between 70% and 90% (depending on the distribution company) of lines are double-circuit as opposed to single circuit, and of these, between 70 and 90% are transposed. If it is assumed, based on the National Grid experience, that at most 90-95% of lines could be transposed, this suggests 12% of 132 kV lines are not currently transposed but potentially could be.

The cost of making a National Grid line transposed is estimated as £60k where this can be done simply by changing the terminations at the ends of the circuits, and £400k where a phase-transposition tower is required. For 132 kV lines, a phase-transposition tower is estimated as £300k and changing terminations at the ends of circuits is estimated as between £10k and £50k (we use an estimate of £20k). A phase-transposition tower has a complicated arrangement of crossarms and is bulkier, more visually intrusive, and more expensive than an ordinary pylon.

6.4 Balancing loads in two-circuit lines

Where a line has transposed phasing (see previous section), the most effective reduction in the field is obtained when the loads in the two circuits are equal. The cancellation between the two circuits reduces as the balance between the loads reduces.

Loads may be unbalanced for several reasons:
- One circuit is switched out for maintenance.
- One circuit may supply electricity to different places to the other, so inevitably resulting in different loads. One instance is where a substation or a power station is “teed” into one circuit only.
- The rating of switchgear in a substation may not be high enough to cope with the fault currents that could flow if the system were operated completely interconnected. Accordingly, some connections are deliberately not made (one common instance is referred to as substations being operated “split”) and this prevents the loads distributing themselves evenly between the two circuits.

In normal operation of an electricity system, loads are allowed to distribute naturally in the most efficient way, which will tend to result in balanced loads, except where one of the above conditions occurs. Put differently, electricity operators do not deliberately create unbalance, but some degree of unbalance often occurs during normal system operation.

To reduce this minimum unavoidable level of unbalance would normally require construction of new lines or installation of new equipment in substations.

Unbalance affects the fields only for transposed phasing, not for untransposed phasing.

Any unbalance within a single circuit, usually expressed as a “zero-sequence current”, can make a significant difference to small fields at large distances from power lines, but makes only a few percent difference to fields of 0.4 µT.

The calculations of fields used in this Report generally make suitable allowance for unbalance between circuits. Specifically, the 60 m average distance for 0.4 µT is calculated from actual load records and therefore reflects the actual amount of unbalance. The distance would be lower if circuits were better balanced.

Points emerging in Working Group discussion

To improve balance requires expenditure, either for new lines or new switchgear in substations, which would need assessing, but would almost certainly outweigh the benefits.

If new lines were built to improve balance, this could well add to the overall amount of exposure to EMFs.

It would be possible to issue an encouragement to system operators to balance loads, but this would make little difference as existing unbalance is largely inherent rather than a matter of choice.

6.5 Screening of fields from overhead lines at source

Electric fields from overhead lines can be reduced by building extra earthed screening conductors underneath the live conductors. Magnetic fields can be reduced by building extra conductors which carry a current designed to create a magnetic field which partially cancels the field from the original line.

Points emerging in Working Group discussion

Visual impact: Involves more metal in the sky so not so good. Taller pylons may actually be better than compact lines or screening – the marginal increase in height is less of an objective impact than the extra conductors of eg screening.

Effectiveness at reducing fields: can be effective but depends on how much money you are willing to spend. It probably makes corona ions worse as it increases the electric field on the surface of conductors.

Reliability of supply: more “stuff” in the sky so more risk of sparkover or something going wrong. Considered by National Grid engineers as very unreliable. But in principle, could be designed to be reliable.

How easy: a new technology so a lot of work to develop it before it can be done the first time, but easier subsequent times

Environmental impact: construction damage only

Future proofing: more reversible than say undergrounding

Safety: issue for construction workers and ongoing public hazard

7 Possible action: screening of buildings

7.1 General discussion

Electric fields are readily perturbed by most objects which are even just slightly conducting.

The field is basically increased above the object and decreased to the sides. Therefore a short object, such as a low fence, can increase the field, and a tall object, such as a tree, can decrease it in the areas where people actually are. A tree or trees could be planted close to the property to provide maximum screening to that property, or close to the line, where it is probably less efficient at reducing the field unless it is as tall as the line, but where it may provide simultaneous screening to multiple properties.

This applies to the field outdoors; indoors, electric fields are heavily attenuated by the building materials anyway. Further screening could be achieved if desired by thin layers of earthed metal foil on all walls, but there is probably little point.

Magnetic fields are not significantly perturbed by ordinary building materials. In principle, a room or even a whole building can be screened by enclosing it in either aluminium or copper (eddy current screening) or steel or a high permeability material such as mu-metal (ferromagnetic screening). The thickness of material required can be considerable, eg a centimetre of aluminium. Often, a significant fraction of the room needs to be covered; gaps for windows may be acceptable but floors, ceilings and all four walls may need covering.

7.2 Further points emerging in Working Group discussion

(The Working Group considered planting trees and screening buildings as separate options.)

Planting trees:

Effectiveness at reducing fields: could make corona ions worse as corona ions are attracted to tall, pointy objects. There is an issue of whether trees are more effective close to property or close to line.

Reliability of supply: no effect.

Environmental impact: good – we all like trees.

Future proofing: can chop them down.

Safety: trees can be a hazard in their own right.

Are the trees planted more mature or allowed to grow?

Screen the building itself:

Cost: this option is applied “per building” rather than “per line” so cost depends on how many buildings there are.

Could reduce the attractiveness of the building.

Future proofing: sunk cost cannot be recovered.

8 Possible longer-term actions

This section notes possibilities that would reduce exposures from overhead lines, but which relate to broader issues of energy policy or technological developments and probably should not be seen as immediate options.

8.1 Microgeneration

Increasing use of microgeneration reduces the amount of electricity that needs to be transported larger distances.

8.2 Direct Current transmission

DC transmission produces lower AC (ie power frequency or ELF) fields, though it does produce large DC fields.

Points emerging in Working Group discussion

Visual impact: DC lines tend to be lower than AC lines because they are single-phase rather than three-phase. Any impact on property value may therefore be less.

Effectiveness at reducing fields: makes corona ions worse in every situation where it has been tried.

Reliability of supply: more complex than AC so poorer reliability.

Environmental impact: extra converter stations needed.

Future proofing: would make sense over a long length of line but short sections very problematical.

Safety: risk for construction workers.

8.3 Superconducting cables

Superconducting cables produce low external fields.

8.4 Reduced security of supply

The need for new power lines is often driven by the requirement to have enough redundancy and spare capacity to provide a sufficiently reliable electricity system. If the required level of reliability (usually called the "security of supply") were reduced, the need for new power lines could be reduced, though not eliminated altogether.

9 Possible action: provide information

9.1 Points emerging in Working Group discussion

In itself, providing information has little effect; it would probably be used in conjunction with other options.

Visual impact: could make existing situation worse by drawing attention to it.

Cost: not zero but low.

Impact on property price: information helps when people are already worried, but if they are not worried it can have a negative effect. Effect of information depends on many things and is difficult to predict.

Effectiveness at reducing fields: there is no direct effect but secondary effects might occur.

How easy is it: do not need permission to do it, but would need work in developing the message.

Future proofing: could be hard to change a message once people have got it into their minds.

10 Possible action: do nothing

10.1 Points emerging in Working Group discussion

Future proofing: buildings would still be built under power lines

Supporting Paper S19

S19 Power lines: applying cost-benefit methodology

Supporting Paper S18 summarises, in a fairly informal manner, our general discussion of the options for reducing exposures from power lines. As described in Section 5.2, we used a process called dominance analysis to narrow down these options. For the options that appeared to be remaining in consideration, we performed a more formal cost-benefit analysis, using the cost-benefit methodology we developed and describe in Supporting Paper S6. That application of the cost-benefit methodology to a subset of the options we considered for power lines is described in this paper. The order in which we consider the options is the same as in Supporting Paper S18, but because we only consider a subset here, the section numbering is different.

In the following sections we calculate, for each option, the “cost per home removed from a field of 0.4 µT”. This is the “cost” side of the cost-benefit calculation. The “benefit” side is the same for all the options, that is, the cost for each option has to be compared to the following benefit as explained in Supporting Paper S6:

- Benefit per home removed from a field of 0.4 µT under the “WHO/HPA” view and with the assumption that magnetic fields do actually cause childhood leukaemia: £1k
- Benefit per home removed from a field of 0.4 µT under the “California” view: perhaps a hundred or so times larger.

In Supporting Paper S6, we discussed “first-round” and “second-round” costs. “First-round costs” are the immediate costs of the option, and these are what we aim to quantify and to include in our cost-benefit analysis. “Second-round costs” are knock-on effects elsewhere; we aim to note these if they significant, but not to quantify them.

In our work, we considered separate scenarios for childhood leukaemia based on either “Ahlbom” or “Draper”, as we describe in Section 2.1 and Supporting Paper S4. We performed cost-benefit calculations for “Draper”, but for simplicity do not present them here, as it was only the calculations based on “Ahlbom” which we used in forming our recommendations.

1 Do not build new homes within a certain distance of lines

1.1 General considerations

Consider applying this option to the whole country.

Suppose the distance is 60 m and it is done just for the National Grid lines. So all new homes that would experience a field greater than 0.4 µT from National Grid lines are "removed" (in fact, stopped from ever being built). At present, roughly 0.1% of the housing stock, approximately 25,000 homes, is within these distances (see Supporting Paper S15). We assume that the entire future building programme might, at most, double this - it might add as many new homes near lines as there are existing homes. An alternative approach is to consider just the land currently allocated for development in Local Plans. Making assumptions including the possible housing density of any new development, we calculate that if all this land were developed it might at most add up to half as many homes near new lines as there are near existing lines. We take these two estimates as indicating a range. Therefore the maximum benefit of preventing the new build is the benefit of removing from 12,500 to 25,000 homes from a field of 0.4 µT. When we include 132 kV power lines in the option as well, the number of homes involved doubles, to approximately 25,000 to 50,000, under the same assumptions.

The two major immediate or “first-round” costs that would go with a ban on new development near lines are the loss of value of land that would have been developed and now cannot be, and the consequential devaluation of existing homes. We have made estimates, albeit with uncertainties, of how much these costs are: see Supporting Paper S17. Suppose the distance were 60 m; the loss of land value, considering only land currently allocated for residential development in Local Plans, would be approx £1-2bn and the devaluation from £0-2bn depending on the assumptions we make. For 100 m, the figures are approximately £4bn and £0-6bn respectively. Note that, of the loss of value due to loss of development potential, some is compensatable by the electricity companies and some not, but this is not relevant for our purposes, we just need to know the total amount. Note also, flexible design of a site can minimise the loss of value. This probably would indeed offset some of the loss for smaller distances, but proportionately less for larger distances.

Following on from these “first-round” costs, there would be other costs as the housing market adjusted, as development plans changed to allocate different land for development, and as planning permission was granted in different places. We note these as “second-round costs”. The overall result of these could be an increase of value for some land or home owners that partially offsets the first-round costs. However, we are not confident that we have fully understood or identified all these costs and distributional effects.

An alternative way to understand the costs and where they fall is to consider different sections of society.

- If we consider just the electricity industry, the cost is only that part of the loss of value of land and of any consequential devaluation of existing homes for which compensation is payable, which is less than the total loss of value.
- If we assume that the electricity industry passes these costs through to consumers, we can consider “consumers” as a section of society, and the cost is the similarly less than the total loss of value.
- If we consider the electricity industry and/or consumers plus those people close to power lines directly affected by the restrictions, the costs rises to include the total loss of value.
- If we consider all landowners in the whole country as well, the second-round costs mean the overall cost may be reduced, but we do not have clarity on this.

On our assumption of removing 25,000 - 50,000 homes that would otherwise be built but would not be under this option, therefore, the £1-2bn total cost equates to £20-80k per home, and we can say:

- Cost per home removed from 0.4 µT, considering just loss of development potential of undeveloped land: £20-80k
- Cost per home removed from 0.4 µT, including estimate of devaluation of existing homes: £20-160k

1.2 Time-limited introduction of “do not build within a certain distance”

It would be possible to introduce any restriction on new development near lines as a temporary restriction for say 5 years and subject to review after that. The thinking is this reduces the cost because:

- not everyone who is entitled to compensation would get around to applying within the 5 years (though given a few land agents touting for business, most probably would)
- some of the compensation is delayed, which, if we accept the principles of discounting (and this is pure discounting of money, not of health benefits) reduces its cost
- there is a theoretical possibility that the restriction might be removed after the 5 years. So the compensation for loss of value, eg as awarded by the Lands Tribunal, ought to allow for this and be less than for an indefinite ban. However, we suspect in practice most people would feel the chances of the restriction being removed were slim, and therefore the reduction in compensation would be small.

In any event, the cost as we have calculated it in terms of loss of value remains the same. These arguments (certainly the first two) affect only the payment of compensation, which is a different issue. We therefore conclude this option is unlikely to help much.

1.3 Do not add new land to the pool of land already allocated for development

There are compensation costs associated with ceasing to allow development near lines partly because, where land is allocated for development in Local Plans and there is a clear expectation of getting planning permission, there is a liability for compensation if the development is not allowed.

Suppose instead that land that is already allocated for residential development close to power lines is still allowed to be developed, but, through DCLG (formerly ODPM) policy, no further land close to power lines is allocated as Local Plans are revised.

In Section 2.6 and Supporting Paper S8, we noted that Switzerland has introduced precautionary policies affecting, among other things, homes near power lines. Their restriction is expressed in terms of the field (1 µT) rather than the distance from the power line. However, it applies only to homes built in the future on land not yet “zoned for building” (a similar concept to the UK “allocated for residential development”); land already zoned is excluded. In that respect, what the Swiss have introduced corresponds to this option.

The costs and benefits of this option are both reduced.

The costs are reduced, partly because the loss in value of the land in question is less; it was not valued at the full development potential, only at some lesser value reflecting the reduced certainty of ever being allowed to develop it. Where the land is owned by a grantor, they are entitled to compensation for the loss in value. It might be harder to agree the amount of compensation, because there could be argument about how much of the value of the land was dependent on the possibility of future development, but compensation would still be payable.

The other component of the cost of introducing corridors is the possible consequential devaluation of existing homes. We cannot be certain how great this would be. It seems likely that it would be less for this option than for the full “no new homes near power lines” option, but that it would still occur to some extent.

The benefits are also less, because the amount of development prevented from happening is likewise less. If we consider a period just a few years into the future, most development would take place on land already allocated for development, which is excluded from this option, and so the benefit would be minimal. As we consider longer periods, however, more and more of the future home building program might take place on land not yet allocated for development, and so the benefit of this option becomes greater, though always less than the straightforward “no new homes near power lines” option.

It follows from these considerations that the benefits of this option are deferred even further into the future than for the straightforward “no new homes near power lines” option, whereas the costs, in principle, still occur more or less straight away.

We have not done a detailed comparison of costs and benefits, but as both scale down, arguably in roughly the same proportion, it seems unlikely the ratio would be radically different from the main “no new homes near power lines” option.

2 Do not build new lines near existing homes

Suppose that whatever we say about building new lines would apply literally just to building the new line. That is, once it was built, it becomes an existing line, and the question of whether homes can be built near it in the future gets dealt with under whatever policies are chosen to deal with new homebuilding. If that were the case, the costs of "don't build a new line within 60 m of an existing home" would range through:

- zero, if the route that would otherwise be chosen already meets this requirement
- x% extra on the cost if the route has to be made x% longer to meet this requirement (assuming costs are proportional to length, which is not true but is good enough for the time being)
- N x say £200k if the only way of achieving the requirement is to buy N existing homes within 60 m (probably using CPO powers). We use £200k as a guess of the average amount required proactively to purchase homes that might be near new power lines.
- L x say £10M if the only way of achieving the requirement is to underground L kilometres

These figures are for National Grid lines and would be lower at lower voltages.

However, it is arguable that the two situations are not separate, and that when we say "don't build a new line within 60 m of existing homes" we also mean "... and ensure it stays this way in the future". In that case, the cost of the option includes the extra element of acquiring sufficient rights over land within 60 m of the new line to ensure that no-one can build residentially there in future, probably using Compulsory Purchase powers (discussed in Supporting Paper S16), and this would be a significant extra cost. We would have to decide whether the rights have to be acquired over all land within 60 m, or only that land which is currently allocated for development in Local Plans.

Note also that this proposal would mean the situation around new lines was different from the situation around existing lines - non-grantor landowners would receive compensation for new lines but not for existing lines.

Such calculations would have to be done on a case-by-case basis.

3 Rerouting lines as an option for existing or new buildings near existing lines

The biggest problem for rerouting at high voltages is finding the routes, but we need to consider costs as well.

For a National Grid line, we assume the base cost for building shortish sections of new lines in urban-ish areas (if someone wants to build lots of homes, presumably it cannot be completely rural) is £1M per km. We assume the optimum route was (usually at any rate) the route taken by the existing line. Therefore the rerouting, which cannot take the optimum route, has to be longer; we assume it is 50% longer, giving £1.5M per km diverted.

Consider the extreme case of the highest possible likely housing density. We know that the single span on the National Grid system with the highest housing density has 200 homes within 60 m (see Supporting Paper S14). It is 340 m long, giving 600 homes per km within 60 m and therefore within 0.4 µT. If we assume that once the line has been rerouted, no-one ever wants to build near it in the future, probably an unrealistic assumption, these are the homes that are removed from the field, at a cost of (£1.5M per km) / (600 homes per km) = £2.5k per home. This is the extreme value because it is calculated from the span with the highest housing density. Most spans have lower housing density and therefore higher cost per home removed.

If, however, we assume that once we've rerouted the line, on average the same number of homes get built near the new line, over a period of say ten years, then we have gained only ten years of the benefit. As the whole benefit accrues over 70-odd years, then simplistically (ie ignoring discounting) the first ten years is 1/7 the benefit, or alternatively, the cost per home removed from the field is 7 times higher, or about £20k per home. It is possible to perform this calculation using different lifetimes or discount rates but the answers are likely to be close enough given the approximations already involved. This consideration does not apply if rerouting is combined with prevention of new home building.

We therefore have:

- Cost per home removed from 0.4 µT assuming no house-building near new line: £2.5k for highest likely housing density, higher for more realistic housing densities.
- Cost per home removed from 0.4 µT assuming there is house-building near new line: £20k for highest likely housing density, higher for more realistic housing densities.

Note that this is a clear case for recognising that there are other issues, eg visual amenity, in play; we are doing a calculation for the health aspect only.

4 Undergrounding

Suppose undergrounding a National Grid line costs £10M per km and undergrounding a 132 kV line costs £3M per km of overhead line removed. (See Supporting Paper S14 for a discussion of the costs; £10M is a mid-range value.) These are the first-round costs, and in this instance we have not identified any significant second-round costs, so these are the main costs we need consider.

We assume that, for National Grid lines, the average distance to get 0.4 is 60 m, so the number of homes within 60 m is the number of homes removed from a field of 0.4 µT by undergrounding. For 132 kV lines, we assume the equivalent distance is 30 m. In both cases we assume that undergrounding removes all homes within 60 m or 30 m from the field, that is, we have assumed the underground cable itself does not expose any homes to 0.4 µT. If it does, the benefit of undergrounding would be less than we calculate here.

Clearly, if it emerged that the cost of undergrounding was significantly less than we have estimated, the conclusions we draw here could change.

We consider the extreme case: the situation where undergrounding has the greatest benefit, which is clearly where there are the most homes close to a line. We know that currently the single span on the National Grid system with the highest housing density has 200 homes within 60 m (see Supporting Paper S14). It is 340 m long, a density of 600 homes per km or 5000 homes per square km. Basing our calculations on this example is an extreme in two ways. One is that this is the highest housing density; most spans have a lower density and therefore a lower benefit. The other is that this is a single span, and in practice, undergrounding is feasible only for several consecutive spans. The number of homes, averaged over the length that would have to be undergrounded in practice, would be less than the value for the single most extreme span.

4.1 Undergrounding applied to existing lines and homes

Consider the "per home" calculation. For the extreme case – the existing span with the highest housing density – there are 600 homes per km within the 60 m distance, and the cost of undergrounding is £10M per km. We therefore calculate:

- Cost per home removed from 0.4 µT: £17k

This is the extreme case; most spans do not have this many homes, and this calculation does not allow for the several consecutive spans that need to be undergrounded in practice, so in practice, the cost per home removed from 0.4 µT would be higher.

For 132 kV lines, the cost of undergrounding is lower, but so is the benefit, as the fields are lower to start with. We estimate a typical cost of undergrounding is perhaps three times lower (£3M per km of overhead line replaced), and 0.4 µT occurs up to perhaps half the distance (30 m). This suggests the cost per home removed from a field of 0.4 µT would be slightly less than for National Grid lines, but not enough to change the conclusions. We cannot be more precise as we do not have detailed information on numbers of homes within 30 m of 132 kV lines.

An alternative approach is to consider the total cost of undergrounding all relevant spans. Table 2 in Supporting Paper S15 suggests there are approximately 1500 spans of transmission with at least one home within 60 m. Placing even a fraction of these underground would take decades and would require extensive other work to retain a functioning electricity system. Because of the difficulty of locating the sealing-end compound where the transition is made from overhead to underground, considerably greater length than just these spans themselves would need to be buried for 275 and 400 kV lines (this is less of an issue for 132 kV lines where the transition can sometimes be made on the end pylon without a separate compound). However, with all these provisos, the cost of placing all relevant existing overhead lines underground would clearly be tens of billions of pounds.

4.2 Undergrounding applied to existing lines and new homes

If we assume that in future, it is unlikely that new building will create any spans with a higher housing density than the maximum that already exists, we conclude that the cost per home removed from a field of 0.4 µT is likely to be similar for new home-building as for existing homes. We recognise, however, that health is not the only issue relevant to the economics of undergrounding, and we deal with this explicitly in Section 5.

4.3 Undergrounding applied to new lines

It is almost inconceivable that an electricity company would seek to build a new overhead power line in areas with this high a housing density. In practice, considerations of physical access, aesthetics, and acquisition of property rights would have forced the undergrounding option long before the economics of health became significant.

5 Rephasing of overhead lines

Supporting Paper S14 describes how rephasing a double-circuit overhead line – converting it to “transposed phasing” – reduces the magnetic field, and Supporting Paper S18 discusses the cost of doing this. The National Grid system was designed from the outset to have transposed phasing where possible (for other engineering reasons, not for EMF reasons). Over 90% is transposed, and there is little realistic scope for increasing this. The 132 kV system was not systematically designed with transposed phasing; much is now transposed, but we estimate there is 12% - about 2000 km – that is not transposed but could be considered for conversion. Sometimes, this conversion could only be achieved by building a new pylon, a “phase-transposition tower”, which has a complicated arrangement of crossarms and is bulkier, more visually intrusive, and more expensive than an ordinary pylon. We have assumed that this would not be a realistic option. Sometimes, however, a line could be converted to transposed phasing simply by rearranging the order of the connections between the end pylons of the route and the substations. The estimated cost of this is rather speculative, but we use an estimate for 132 kV lines of £20k where it is possible at all.

For a typical 132 kV line we assume the rephasing reduces the range of 0.4 µT from 30 m to 15 m, so it is homes within this distance band which are removed from the field of 0.4 µT. We have no good information on how many such homes there are for real 132 kV power lines, and therefore we proceed by making some alternative assumptions. If a line can be converted to transposed phasing for £20k, the cost per home removed from a field of 0.4 µT is:

- £20k if there is one home in the relevant distance band
- £1k if there are 20 homes in the relevant distance band
- £200 if there are 100 homes in the relevant distance band
- £40 if there are 500 homes in the relevant distance band

It seems likely that at least some lines will have 20 or more homes at the relevant distances, and therefore that this option is justified in cost-benefit terms, considering just childhood leukaemia (the “WHO/HPA” view), in at least some situations. However, the cost varies from line to line, the number of homes varies from line to line, and our cost-benefit calculation makes no allowance for the uncertainty in whether magnetic fields actually do cause childhood leukaemia. So there is considerable uncertainty in identifying which lines there is a justification for rephasing.

An alternative approach to considering this, sticking with the “WHO/HPA” view, is to estimate that, if magnetic fields do cause childhood leukaemia and with all our other assumptions, 0.5 cases per year of childhood leukaemia are attributable to 132 kV lines. So 12% of this, 0.06 cases per year, are attributable to those lines we could contemplate rephasing, and if rephasing halves the fields, half this, or 0.03 cases per year, one case every thirty years, is the maximum that could be removed. We would assign a value to society of £50M per case per year, so the maximum value to society from rephasing, if every line were converted, would be £50M x 0.03, or £1.5M across the whole country. This sets a scale on what is being envisaged here.

Supporting Paper S20

S20 Power lines: distance and field as alternative ways of expressing recommendations

1 Introduction

This paper considers whether, if some form of restriction on homes near power lines or on power lines near homes is desired, it is best expressed directly in terms of the field produced by the power line, or whether the field is best converted to a distance for practical application of any such restriction.

The discussion is based primarily on childhood leukaemia and hence the figure of 0.4 µT. If action were being contemplated on the basis of other possible adverse health effects, and if further information had become available on the relevant exposures for those effects, the calculations could be adjusted accordingly.

2 Factual information

The conversion from field to distance varies from line to line according to the load on the line. For National Grid Lines:

Type of field	Distance for field to fall to 0.4 µT
Average field over whole year: average over all lines (based on sample of 43 lines)	60 m
Average field over whole year: line producing highest field (based on sample of 42 lines so might be higher values on other lines)	150 m
Highest field likely to be encountered in practice at any one time (guesstimate)	200 m
Theoretical highest field ever produced (but never encountered in practice)	280 m

At a distance of 60 m from National Grid lines, for 70% of lines the field has already fallen below 0.4 µT, and for 30% the field is still greater than 0.4 µT. In terms of land area, at a distance of 60 m, about 85% of the land area affected by 0.4 µT is included, with only about 15% of that land area falling outside 60 m. If we assume uniform development, so that land area is proportional to number of people living there or likely to live there in the future, this means a restriction expressed as 60 m would cover about 85% of the people exposed to 0.4 µT, and leaving only about 15% of those people still exposed.

For other lines:

Voltage of line	Distance in m for "typical" field to fall to 0.4 µT
275/400 kV (National Grid)	50-60
132 kV	10-30
11/33 kV: lines on pylons or larger wood poles	0-20
11/33 kV: smaller lines on wood poles	0
400 V	0

For 132 kV lines, calculations suggest there would be likely to be homes exposed above 0.4 µT, and this is confirmed by the HPA investigation into sources of high fields in homes[1]. We therefore have reasonable confidence in including these lines in our "best available option", although the exact distance for 132 kV lines does not have as solid an evidence base as for 275 kV and 400 kV lines.

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[1] Maslanyi M P, Mee T J, Allen S G, Investigation and Identification of Sources of Residential Magnetic Field Exposures in the United Kingdom Childhood Cancer Study (UKCCS), HPA-RPD-005, August 2005. http://www.hpa.org.uk/radiation/publications/hpa_rpd_reports/2005/hpa_rpd_005.htm

For lines at 11 kV and 33 kV, we note that calculations suggest it is possible for fields to exceed 0.4 µT, certainly for the larger lines. However, we also note that the HPA investigation into sources of high fields in homes found no instances at all of fields greater than 0.4 µT from these voltage lines. We conclude that for these lines the calculations are probably unrepresentative, and that on present understanding, no restriction for these voltages should be included in our "best available option". However, direct measurement of fields from a representative sample of these lines would be desirable. We have transferred responsibility for considering this further to the Distribution working group which we expect to start next.

3 Alternative distances

In the previous section, we explained our choice and justification of the distance of 60 m as an appropriate distance for any restriction on homes near power lines. Here, we perform the calculations to allow alternative distances to be assessed if desired.

The following table shows how the number of lines and homes affected changes as the distance changes. We stress these calculations are based on a sample of 42 lines.

Distance	% of lines for which this distance includes the 0.4 µT distance	% of homes with fields of 0.4 µT or greater covered by this distance
40	25%	70%
60	70%	85%
80	80%	95%
100	98%	98%

The costs will also change. As the distance decreases, the amount of land affected and hence the loss of value of land reduces. However, any offsetting effect of sensitive planning of the development becomes proportionately more important. As the distance increases, the amount of land and hence the loss of value increases, to a first approximation in proportion to the distance. However, any costs arising from devaluation of existing properties increases more rapidly than this, because existing housing density also increases with distance. We have not attempted to quantify either of these effect and therefore cannot say exactly how much the costs go up or down as the distance varies.

We have not attempted similar calculations for lower-voltage lines.

4 Options for how to assess fields

The field from a power line can be assessed either by measurement or by calculation.

Measurements have the advantage of being direct and relatively transparent (little specialist knowledge is needed to observe whether a reading on a scale is above or below 0.4, though specialist knowledge is needed to operate the meter).

However, measurements have a number of disadvantages. There is still some debate about correct technique. They require the correct instruments and calibrations. They can be time consuming, and always require a site visit. They can only be specific to the load conditions at time of measurement, and as loads vary continuously, measurements at one point in time can never give a long-term average. There is considerable difficulty in measuring the field just from the power line and not from other sources, particularly inside homes, which easily leads to people assuming the line is exceeding a given value when in fact the field comes from other sources. Finally, for a line that has not been built yet, it is clearly not possible to perform measurements at all.

The alternative is to calculate fields from power lines. This can be done with varying degrees of sophistication depending on the accuracy required.

The advantages of calculations are that they can be performed for any desired load condition and for proposed new lines; multiple calculations for different conditions can be performed for relatively little effort. The calculation process and any assumptions can be made available to other scientists, and everyone ought to be able to agree the answer.

The disadvantages are that calculations may not be trusted so much, particularly by non-scientists. They require appropriate software. Performing completely accurate calculations, taking account of zero-sequence currents, is hard (though this level of sophistication rarely makes significant difference to fields of order 0.4 µT, it is an issue really only for lower fields). Finally, a calculation is only as good as the load data entered into it. With measurements, the measurement is specific to the load at one particular time. With calculations, calculations for different times and for averages over time can easily be done, but only if the relevant loads are available and agreed.

Our requirements are for a method that can be used for proposed new lines as well as existing lines; that can deal with average fields over time not just fields at specific times; and that will lead to the maximum of agreement and minimum of dispute. It is clear that calculations meet this specification and measurements do not.

5 Options for how to express any restriction

Any restriction originates as a field, 0.4 µT or some other value. Any restriction finally gets realised as a position on the ground; either a home (or line) is allowed to be built at a particular location or it is not. So at some point, the field has to be converted to a distance from the line. This could be done at various points in the process:

- The field could be converted to a distance before the restriction is created, so that the restriction is expressed in terms of a distance (or a number of distances for different situations)

- The restriction could be expressed as a field, and this could then be converted on some specified basis to a distance, say once for each different power line

- The restriction could be expressed as a field, and the conversion of this to a distance could be left for resolution on a case-by-case basis.

The objectives in choosing between these alternatives include:
- Fairness. Any policy expressed as a distance would result in some people still being exposed above 0.4 µT and others unnecessarily restricted below it.
- Ease of use. Planning officers and developers need to know whether they can build at a certain position or not and will therefore wish to covert any field into a corresponding distance as quickly and easily as possible.
- Simplicity. Although calculations are easier than measurements, they still require resources, data, and specialist software, and, eg, performing separate calculations for every power line in the country would be a large undertaking.
- Accessibility. The process of converting fields to distances will usually require specialist expertise and is therefore not readily accessible to private individuals, most local authorities, or small developers.
- Non-ambiguity. Converting a policy expressed as a field into a distance requires choice of a load (or more than one load) in the line to perform the calculation. The obvious choice of load is the annual average. However, this is not routinely collected or published. Further, it would have to be produced by the electricity companies, and experience shows that when contentious matters involving people’s property and rights are at issue, data provided by power companies will often, understandably, not be trusted. Some alternatives to average load are listed below, but none appears preferable.
- Defensibility. There may be interests who wish to challenge any restriction. During the process of consultation leading to the creating of any policy, it would be easier to defend a policy expressed as a field, as this has the clearer link to the health issue. Once a policy is created, however, it would be much easier to defend the application of a policy expressed as a distance. Whether a home is within, say, 60 m is relatively easy to establish, whereas whether 0.4 µT was or was not exceeded at a particular location could be the subject of lengthy argument at an Inquiry or Hearing, which is not the best place to adjudicate these technical issues.
- Flexibility. The planning system seeks to avoid rigid rules and to allow some flexibility on a case-by-case basis. However, expressing any restriction as a field or as a distance would both result in a rigid “line on the ground” in any specific case, so neither allows this flexibility.

- Future-proofing. Fields from lines vary over the years as loads vary. If the restriction were expressed as a distance, this would not matter. If the restriction were expressed as a field, potentially any decision made about development or compensation would have to be revisited at intervals.
- Due recognition of the uncertainties in our knowledge about the health effects of living near power lines. These uncertainties need not be repeated here. A restriction based on a measured or calculated field may be perceived as affording 0.4 µT as a threshold more precision that justified by current scientific knowledge.

Some of us feel distance is preferable and some field. Overall, in view of these factors, particularly the need for simplicity and clarity, the desire to create a policy that reduces rather than creates disputes at a local level, and the obvious desire not to have to revisit individual decisions frequently, the group as a whole concluded any policy should be expressed in terms of the distance, probably one distance for each voltage of line or group of voltages.

The main disadvantage of this is the unfairness: some people would still be exposed over 0.4 µT whereas others would be unnecessarily restricted below it. However, this unfairness is partly illusory. We have clearly recognised that 0.4 µT is not a threshold for health effects and therefore the idea that we are protecting some people absolutely and equally certainly exposing others to risk is wrong. All we can do is to introduce measures that seem likely to reduce any risk generally for as many people as possible, and in that context, the precise value of 0.4 µT should not feature too highly.

We believe that a policy expressed as a distance would be challenged during its introduction, albeit mistakenly as we have just described. However, once a policy that eg “no new line would receive Consent if it came within x metres of a home” was in place, we believe it would be easy to apply to specific situations, would not consume disproportionate time or effort in argument, and decisions made under this policy would be readily defensible against Judicial Review.

6 Options for what load to use when converting field to distance

Whether the field is converted to distance once nationally, or separately for each line, a choice still has to be made about the load. We believe the best quantity is the annual average. There are, however, alternatives:

- Annual average load on the line
    - This is not routinely collected
    - Is available for existing NG lines but probably not for some lower-voltage lines
    - Difficult to predict accurately for new lines

- Typical load on line, or normal operating conditions
    - Easy to come up with a number but the number is subjective and hard to defend; notoriously difficult to define “normal” or “typical”

- Load on line at time of winter peak
    - Already publicly available for all NG lines (but not for all lower-voltage lines)
    - Available as prediction for future lines too
    - Gives an indication of the maximum field, but not always the actual maximum on that line

- Rated load of line
    - Gives an undoubted maximum field, but never achieved in practice
    - Still some ambiguity as there are continuous and various short-term ratings.

Note that ideally the quantity should be the annual-average field rather than the annual-average loads. Calculating the field from the annual-average loads in a two-circuit line can give misleading answers for a line with transposed phasing, if the difference between the two circuits was larger during the year than it is expressed as the annual average. Calculating the field at each instant of time, then averaging these fields to get the annual average, is preferable for transposed lines but more time consuming.

Abbreviations and Acronyms

AC	Alternating Current
ALL	Acute Lymphocytic Leukaemia
ALS	Amyotrophic Lateral Sclerosis, the most common form of Motor Neurone Disease
AM	Arithmetic Mean
AMDEA	Association of Manufacturers of Domestic Electrical Appliances
BS	British Standard
BSI	British Standards Institution
CLA	Country Land and Business Association
CML	Council of Mortgage Lenders
CPC	Circuit Protective Conductor
CPO	Compulsory Purchase Order
DC	Direct Current
DCLG	Department for Communities and Local Government (formerly part of ODPM)
Defra	Department of Food and Rural Affairs
DfES	Department for Education and Skills
DH	Department of Health
DNO	Distribution Network Operator
DTI	Department of Trade and Industry
EDM	Early Day Motion
ELF	Extremely Low Frequency
EF	Electric field
EIE	Electrical Installations and Equipment (SAGE Working Group)
EMFs	Electric and Magnetic Fields
ENA	Energy Networks Association
EPA	Environmental Protection Act 1990
EPA	Environment Protection Agency (US body)
ESQCR	Electricity Safety, Quality, and Continuity Regulations 2002
FUW	Farmers' Union of Wales
GM	Geometric Mean
HPA	Health Protection Agency (part of which was formerly NRPB)
HPA-RPD	HPA Radiation Protection Division
HSE	Health and Safety Executive
Hz	Hertz (unit of frequency)
IARC	International Agency for Research on Cancer
ICNIRP	International Commission for Non-Ionizing Radiation Protection
IEE	Institution of Electrical Engineers, now part of IET
IET	Institution of Engineering and Technology, successor body to IEE
kV	Kilovolt
MF	Magnetic Field
MND	Motor Neurone Disease
MOA	Mobile Operators' Association
NCRP	National Council on Radiation Protection and Measurements (US body)
NFU	National Farmers' Union
NGT	National Grid Transco (former name of National Grid)
NI	Northern Ireland
NICE	National Institute for Health and Clinical Excellence
NIEHS	National Institute of Environmental and Health Sciences (USA body)
NRPB	National Radiological Protection Board (now part of HPA)
ODPM	Office of the Deputy Prime Minister, now DCLG
Ofgem	Office for Gas and Electricity Markets
PLP	Power Lines and Property (SAGE Working Group)
PME	Protective Multiple Earthing
QALY	Quality Adjusted Life Years
RCBO	Residual Current Circuit Breaker with Overload Protection
RCD	Residual Current Device
RCM	Rate of Change Metric
RCMS	Rate of Change Metric Standardised
RF	Radio Frequency

RIA RICS RPD	Regulatory Impact Assessment Royal Institute of Chartered Surveyors Radiation Protection Division (of HPA)
SAGE	Stakeholder Advisory Group on ELF EMFs
T THD TWA	Tesla (unit of magnetic field) Total Harmonic Distortion Time Weighted Average
UKCCS	United Kingdom Childhood Cancer Study
V/m or V m^{-1}	Volt per metre (unit of electric field)
WHO	World Health Organization
µT	Microtesla