Stakeholder Advisory Group on ELF EMFs (SAGE)

Second Interim Assessment 2009 – 2010

Electricity Distribution
(including low-voltage and intermediate-voltage circuits and substations)
and
Report on Discussions on Science

Date of issue: 08 / 06 / 2010

Executive Summary

Extremely Low Frequency (ELF) Electric and Magnetic Fields (EMFs) are produced wherever electricity is generated, distributed or used. As evidence has emerged over the last few decades, the question of whether or not ELF EMFs may cause adverse health effects, particularly childhood leukaemia, at levels experienced commonly by the general public[1], has become a source of considerable scientific debate.

Well-understood effects, found at significantly higher exposure levels, are covered adequately by existing guidelines, which in the UK are set by Government on the recommendations of the Health Protection Agency. The Stakeholder Advisory Group on ELF EMFs – SAGE – was formed in 2004 to investigate practical precautionary measures to address the possibility of health effects at lower levels, and to give advice to Government.

SAGE is made up from stakeholders representing a broad spectrum of views, including campaign groups, relevant industries, and the Government. It brings together many areas of expertise, including those with significant expertise in scientific and policy-making disciplines, as well as voices representing sections of the public. SAGE is funded equally by Government, the electricity industry, and the charity CHILDREN with LEUKAEMIA.

We structured our work in SAGE by looking in turn at the EMFs produced by different sources. In the first phase of our work, we considered high-voltage power lines, house wiring, and domestic appliances, and reported on possible precautionary measures for these in our First Interim Assessment in 2007. Government responded to these recommendations in 2009. In the second phase of our work, we have considered distribution networks, and this makes up the main content of this Second Interim Assessment. We have also addressed certain aspects of the scientific evidence and how it is used, and report on this briefly too.

"Distribution" covers a number of aspects: the power lines at intermediate voltages which distribute electricity from where it leaves the high-voltage system; substations and transformers, which reduce the voltage and allow switching of circuits; and the final distribution circuits at 230 V which supply the power to homes. Of these, it is the final distribution circuits that affect the greatest number of people.

We have identified a number of practices that could reduce exposures in different ways. Many of these are already existing best practice for other reasons, and we recommend that the bodies responsible for them be informed that EMFs constitute an additional reason for retaining these practices. Ceasing some practices, such as the method of earthing used in the UK called "protective multiple earthing", would have strong-enough negative impacts elsewhere (in this case, the risk of electric shock and equipment damage would increase) that we feel they cannot be recommended on EMF grounds.

Some of the causes of elevated exposures were identified as involving a fault somewhere in the distribution networks. As a result, we consider the whole area of distribution is one where valuable progress can be made by promoting a greater awareness of EMF issues in electricity companies. Not only will this allow earlier diagnosis of the problems themselves, but the recommendations have the advantage of benefiting both the electricity company and the end consumer.

In this Second Interim Assessment we have focussed on measures that are practical and easy for Government to take forward, rather than radical new measures or any major changes to regulation or current practice. Furthermore, the recommendations that we put forward are all low-cost options. We consider it important therefore that Government take forward the actions we recommend; we do not want these recommendations to languish by default. Where possible we have been specific about what action needs to be taken and who within Government needs to take it.

Where we have identified existing practices that are beneficial in EMF terms, we recommend that Government communicate clearly and specifically to the relevant authorities that EMFs are an additional reason for continuing this practice. This includes, for the electricity industry, practices to do with balancing loads on circuits, identifying and repairing broken neutral conductors, disconnecting redundant cables, siting new substations away from homes, and use of compact designs for new substations; for the gas and water industries, practices to do with use of plastic pipes; and for the electrical installation industry, practices to do with installations in multi-occupancy buildings. We give full details of all of these in our Assessment.

We identify several measures which could not be justified for general introduction, but which offer useful options that may be available for use in specific situations where a consumer desires to reduce exposures at their own cost. These include a range of options, from inserting plastic sections in gas and water pipes, up to having equipment moved, replaced, or redesigned.

We identify a few modest new measures which should be introduced, such as the electricity industry extending a measure called “optimum phasing”, already introduced by the Government for high-voltage power lines following the SAGE First Interim Assessment, to certain other overhead power lines. We also suggest that when a substation or transformer is identified as the source of elevated exposure, the electricity industry should always be willing to investigate and to offer options for reducing the exposure where practicable, though implementing the options would generally be at the consumer’s choice and cost. The electricity industry have been fully involved in developing these conclusions, and we understand that the they will be willing to introduce them if requested to do so by Government, perhaps through a Code of Practice. Government should ensure this happens, but does not need to introduce or change regulations to achieve it.

There are some measures that may be feasible in principle but which require further investigation (mainly to ensure safety is not compromised) before they can be recommended for implementation in the UK. These include fitting electrical devices called inductors, either where distribution circuits meet in the street or where the cables enter a home; these devices alter the paths which currents take. Other measures, such as routine measurements on distribution circuits to identify situations that may produce elevated exposures, or quantitative restrictions on proximity of substations or power lines to homes, require further investigation as to their feasibility or proportionality. In all these cases we specify what the further investigations are that need to be done.

Finally, in order to create the greater awareness of and sensitivity to EMF issues that we feel will be the most productive way forward on EMFs from electricity distribution, we recommend more information for the public, and a package of training for electricity industry staff. Again, we understand that the industry will be willing to embrace this; Government must retain the final responsibility, but it should be easy to achieve.

It would be helpful, and, we believe, realistic for Government to respond to our recommendations within six months, ie by the end of November 2010, and we urge them to do so as this would reflect the importance of the issues covered and the work that has gone into producing these recommendations.

Arising from our discussions of the science underlying this area, we have identified the following areas that we believe should be explored further as they will better inform the creation of policy:

- how appropriate risk-management policies are chosen, including health-economics considerations such as cost-benefit analyses;
- how, and more importantly why, different countries have responded to the same scientific evidence with different policies; and
- the communication of these issues.

We intend to continue providing input to the Government as a stakeholder group, and will be reassessing where best to focus our efforts in the future to maximise the value of the process. We welcome Government input to this, and this is an additional reason to ask for a response from the Government within six months as it will enable further work to be carried out by the group without a break in continuity.

In summary, we make the following recommendations for precautionary measures concerning distribution systems:

- 12 measures that are already existing best practice for other reasons;
- 7 new measures;
- 11 measures that are available to consumers in specific circumstances; and
- 5 measures where further investigation is required.

List of Recommendations

We list here those options where the recommendation is either to endorse existing best practice or to introduce new measures. These options, along with those recommended for further investigation or as available in special circumstances, are summarised in Section 7 on page 38 and are described and discussed in detail in Section 9 on page 43.

Net currents in distribution circuits:

- **DNOs make reasonably practicable effort to balance loads on three-phase final distribution circuits**
- **DNOs assist customers who take a three-phase supply to balance loads to the extent reasonably practicable**
- **DNOs investigate and repair broken neutrals**
- **Disconnect redundant cables, when they are assessed as genuinely redundant, and when work is being done on the circuit anyway**
- **Use plastic gas and water pipes for new build**
- **Insert plastic sections in metal gas and water pipes when work is being done anyway**

Wiring in multi-occupancy buildings:

- **Site plant rooms away from occupied rooms**
- **Use separate-neutral-and-earth cables for risers**
- **Use compact risers**

Intermediate-voltage circuits:

- **DNOs make reasonably practicable effort for heavily loaded double-circuit intermediate-voltage lines to have optimal phasing and loads balanced between the two circuits**

Final distribution substations:

- **Reasonably practicable efforts be made to site substations distant from homes etc**
- **New substations to have compact design where reasonably practicable**
- **Use compact designs when refurbishing substations where reasonably practicable**
- **Arrange components in the substation in the lowest-exposure layout reasonably practicable**
- **DNOs to consider instances of substations producing elevated exposures when requested and, where practically feasible, to offer options for reducing the exposures at the consumer's choice and cost.**
- **DNOs to record instances of substations producing particularly high exposures so that EMF issues can be factored in to future investment and maintenance decisions for that substation.**

Training and response:

- **Information for the public**
- **DNOs to investigate instances of high EMF exposures when notified of them**
- **Develop awareness within DNOs, by training of relevant staff, of how elevated exposures can be an indication of system problems (but recognising that development of a workable training package is needed first)**

As well as these recommendations relating to distribution networks, we also make the following recommendations to Government concerning the future of SAGE:

SAGE asks Government to:

- **reconfirm that Government does indeed want SAGE to continue;**
- **say whether there are particular policy issues that Government wants SAGE to consider (to complement SAGE's own thinking about what it should look at next); and**
- **confirm that Government will consider seriously whatever advice may emerge from SAGE in future.**

Contents

Section A: Introduction

1 Introduction to SAGE

Over the course of the last 30 years there has been a growing understanding of the effects of electric fields (EF) and magnetic fields (MF) on people. Together EFs and MFs are known as electric and magnetic fields, EMFs. SAGE is concerned only with "extremely low frequency" EMFs, such as produced by electrical power, and future uses of "EMFs" in this Assessment refer to just these frequencies.

In 2004 the UK changed from its previous UK-specific exposure guidelines to international guidelines (specifically, the 1998 International Commission on Non-Ionizing Radiation Protection, ICNIRP, Guidelines[1] in the terms of the 1999 EU Recommendation[2]), which set electric and magnetic field levels (eg a magnetic-field reference level for power frequencies of 100 μT) above which members of the public should not usually be exposed. This represented a modest tightening of the guidelines for members of the public. However this left open the question of how to respond to the body of science concerning effects on people at lower levels such as 0.4 μT. This question is controversial for several reasons, and it involves levels which can be found in some homes, from their wiring circuits and from the cables supplying them, from appliances and equipment, and in homes that are near to power lines.

The Stakeholder Advisory Group on ELF EMFs was set up in November 2004 to involve all key stakeholders to address this question. This group process deliberately set out to change the dynamic and type of relationships that had existed between stakeholders over the preceding 20 or so years, which had been characterised by incessant conflict and "standing on opposing sides at inquiries". The state of relations between stakeholders at the start of this process was therefore not good. Although it would be wrong to claim that all relationships are now ideal or that SAGE delivers all participants' desired outcomes, significant progress has been made towards better communication over the process as a whole since then and continues to be made.

The aim of the process was agreed by stakeholders in November 2004 as:

> **"To bring together the range of stakeholders to identify and explore the implications for a precautionary approach to ELF EMF (electric and magnetic fields) and make practical recommendations for precautionary measures".**

[1] ICNIRP (1998). Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Phys, 74(4), 494-522.

[2] COUNCIL RECOMMENDATION of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC)

The SAGE process published its "First Interim Assessment" in April 2007[1]. The present document is the Second Interim Assessment and covers the work conducted by SAGE since then. For convenience, the work up to April 2007 is described as "SAGE Phase 1" and the work since then as "SAGE Phase 2".

The body of science that forms the context for SAGE's discussions was discussed in detail in the First Interim Assessment (p13):

> "Historically, early suggestions concerned childhood cancer, and childhood leukaemia in particular. Other health outcomes for which, with varying degrees of certainty, there have been suggested links to ELF EMFs include (in alphabetical order): adult leukaemia, adult brain cancer, Alzheimer's disease, amyotrophic lateral sclerosis (ALS, the most common form of motor neurone disease), breast cancer, other childhood cancers, depression, electrical sensitivity symptoms, certain types of heart disease, miscarriage, and suicide."

This stakeholder group is not a formally constituted body nor are the participants formally appointed by Government. Rather the dialogue process has been constructed to involve all the key stakeholders as defined by their knowledge, experience, professional responsibility, and the impact on them of any future Government decisions. This has included a mix of industry, national Government departments, the Devolved Administrations, regulators and advisory bodies, academics, individuals, local and national campaign groups, and professional bodies. The group feels that its makeup is broad enough to give the work produced credibility and validity in the context in which it is presented.

One of the ways of working that was agreed from the start was not to have a high profile Chair and follow a conventional path for advisory committees and similar bodies. Instead, stakeholders agreed to keep the structure more informal and work with a professional facilitator. R K Partnership Ltd were engaged in this role and acted as process consultants and managers for the SAGE Phase 1. Golder Associates and Nigel Westaway Associates have performed that role in SAGE Phase 2.

There are about 40 Stakeholders directly involved in the process (see the list of participants on page 74 at the end of this Assessment). Together, they are referred to as the Main Group. This "Main Group" is the overall decision making body within the process. However this group is too large to undertake detailed work so subgroups have been formed. In SAGE Phase 2, these have been

- a Distribution Working Group (DWG), to examine the technical issues around exposures from distribution systems and how they could be mitigated;
- a Science Forum (SF), open to all SAGE participants, to explore areas of disagreement over the science and the reasons for them; and
- a Process Group (PG), to advise and assist the facilitators in running the process.

The membership of these groups is listed in Section 12 on page 74.

It has been one of the core principles of the process that decisions be taken by consensus. However, it was recognised that this was not always going to be possible so it was also agreed that, as well as identifying where consensus exists, the areas where consensus does not exist should also be

[1] Stakeholder Advisory Group on ELF EMFs (SAGE) Precautionary approaches to ELF EMFs First Interim Assessment: Power Lines and Property, Wiring in Homes, and Electrical Equipment in Homes Date of issue: 27/04/2007, available at www.dh.gov.uk/en/Publichealth/Healthprotection/DH_4089500

identified and the reasons set out. This principle is carried through the work into this SAGE Assessment.

2 What has happened since the First Interim Assessment

SAGE's First Interim Assessment was published in April 2007. Although it was published publicly, it was principally directed at Government and was sent to the Department of Health with copies to the Department of Communities and Local Government and the then Department of Trade and Industry.

The Department of Health (DH) asked the Health Protection Agency for their comments on the First Interim Assessment. These comments by HPA and the response to them by DH, all within 2007, are publicly available[1].

There was then a delay, which became a serious cause for concern to SAGE; SAGE wrote to relevant Ministers twice expressing this concern. Finally, however, on 16 October 2009 Government gave its response to the First Interim Assessment in a Written Ministerial Statement[2]. Government accepted some of SAGE's recommendations and rejected others, and also set out some aspects of EMF policy that had not been explicitly addressed by SAGE.

In the meantime, SAGE continued its work. New facilitators were engaged as described above. Some stakeholders left the process and others joined.

SAGE had, at an early stage, split up the subject of exposures to EMFs and possible precautionary measures by the sources of exposure, envisaging four areas of exposure, each of which would raise different technical issues, have different amounts of information available and therefore might need different expertise and a different approach:

- high-voltage power lines;
- intermediate and low-voltage distribution systems;
- wiring and appliances/equipment in homes; and
- transport and other sources.

Phase 1 had considered high-voltage power lines, and wiring and appliances/equipment in homes. Phase 2 now moved on to consider distribution systems.

In addition to considering this next technical area, Phase 2 also decided to address more explicitly some of the issues around the science of ELF EMFs. SAGE is not constituted as a scientific body; it has no remit to pronounce on the science. Its membership is not chosen with science specifically in mind. In Phase 1, recognising this, there had been an attempt to exclude specific discussion of the science; to recognise different views of the scientific evidence as assessed by other bodies, but to concentrate on the primary task of exploring what precautionary measures might stem from these views rather than forming its own view. However this became recognised as a block to progress; science is so central to why SAGE exists that to exclude discussion of it is artificial and unhelpful.

[1] www.dh.gov.uk/en/Publichealth/Healthprotection/DH_4089500

[2] "Government response to the Stakeholder Advisory Group on extremely low frequency electric and magnetic fields (ELF EMFs) (SAGE) recommendations.", Written Ministerial Statement 16 October 2009, available from www.dh.gov.uk/en/Publichealth/Healthprotection/DH_4089500

Accordingly, SAGE decided to create a Science Forum in Phase 2 to complement the technical work on Distribution. The remit was deliberately left fairly open, as the intention was primarily to create a forum for the discussions that many participants wanted to have, rather than deliver a predetermined output. However, it was clear that the Science Forum would not pronounce between alternative views of the science; the primary focus should be on understanding why these different views exist.

SAGE Phase 1 had devoted some effort to making assumptions about the nature and extent of any risk in order to allow quantitative risk estimates to be made, and then to use those risk estimates in a cost-benefit analysis. That cost-benefit analysis, although drawing on existing practice, was also a source of considerable effort and debate within SAGE. SAGE Phase 2 has, on the whole, avoided this level of detailed or quantified analysis of risks, costs and benefit, utilising instead a simpler model of the issues. This should not be taken as either endorsing or rejecting any decisions made in SAGE Phase 1.

SAGE Phase 2 started work in earnest in the second half of 2008. It was originally envisaged as a slightly over two-year programme of work running to the end of 2010. However, after roughly one year, it was decided to accelerate and partially truncate this phase of the work so as to finish in April 2010. This decision was taken for various reasons. This was primarily frustration with the slow pace and sometimes unproductive nature of work in SAGE Phase 2 (though work has since progressed to give a more fruitful outcome). But also, the Government Response to SAGE Phase 1 indicated that Government was likely to be guided by SAGE's Assessments but would not regard them as definitive and would be unlikely to introduce any policies that required significant changes to current practice, and this added to a sense within SAGE that it would not be productive to devote great effort to dotting every last "i" and crossing every last "t".

Nonetheless, the participants in SAGE have an enthusiasm for continuing with some form of dialogue, albeit with conditions or reservations, and this is explored further in section 11, "Intended further activities", on page 72.

Section B: Discussions and Recommendations on Distribution

3 Purpose of the Distribution Working Group

The Stakeholder Advisory Group on Extremely Low Frequency Electric and Magnetic Fields (SAGE) considered high-voltage overhead transmission lines (132 kV and above) in Phase 1 of its work. These account for barely half of instances of background fields in homes above 0.4 μT and perhaps a quarter of instances above 0.2 μT. Of the rest, it is believed the bulk come from low-voltage sources. These include wiring and appliances/equipment in the home, also already addressed in SAGE Phase 1, but low-voltage distribution wiring is the cause of the magnetic fields in the majority of typical homes, and any consideration of how to reduce magnetic fields needs to address fields from this source.

The SAGE Distribution Working Group (DWG) was convened by the SAGE Main Group in October 2008 and first met in January 2009, to complete SAGE's work on electric and magnetic fields produced by the UK domestic electricity supply system. Its focus was the fields from substations and distribution wiring at voltages of 400/230 V – 66,000 V.

In general terms it was expected that the DWG would consider the following questions.

- How are the fields produced, how strong are they, and what is the extent of public exposure to such fields in the UK? (Human exposure has largely concerned childhood exposure to fields within the home but exposure of adults, in-utero exposure, and exposure in public buildings such as schools and libraries has also been considered.)
- What are the options for mitigating these exposures?
- What are the practical and economic implications of mitigation?
- What would be the benefits of mitigation?

A package of possible mitigation options (or a range of such packages) which might constitute a basis for UK policy and practice, was to be assembled and presented to SAGE Main Group.

3.1 DWG Membership

It was agreed that the DWG membership must represent a balanced cross section of SAGE membership as well as containing sufficient expertise, although the DWG recognised that, depending on the topic being discussed and the stage in the work, it might be appropriate to convene special meetings on occasion and to widen the invitation list accordingly.

DWG membership is currently as follows:

- Paul Bicheno (Institution of Engineering and Technology)

- Roger Coghill (Coghill Research Laboratories)
- Stuart Conney (Department of Health)
- Caroline Hampden-White (CHILDREN with LEUKAEMIA)
- Andy Hood (Energy Networks Association & Western Power Distribution)
- Pat Keep (Department of Health)
- Jill Meara (Health Protection Agency)
- Alasdair Philips (Powerwatch)
- Graham Philips (EM Radiation Research Trust)
- Peter Roberts (Energy Networks Association)
- John Swanson (National Grid & Energy Networks Association)
- Adrian Todd (Kilmorack Community Council)

When options for reducing exposures would involve a Distribution Network Operator (DNO) spending money, SAGE recognises that DNOs are constrained to some extent by their economic regulator, Ofgem. It would therefore be desirable for Ofgem to be involved in the discussions around these issues (Ofgem are not currently involved in the SAGE process).

SAGE asks Government to open a dialogue with Ofgem on the matters covered by SAGE.

4 Distribution Networks

4.1 Introduction to Distribution Networks

The UK Electricity System is essentially made up of three key stages, broadly analogous to the UK road network, as shown in Figure 1:

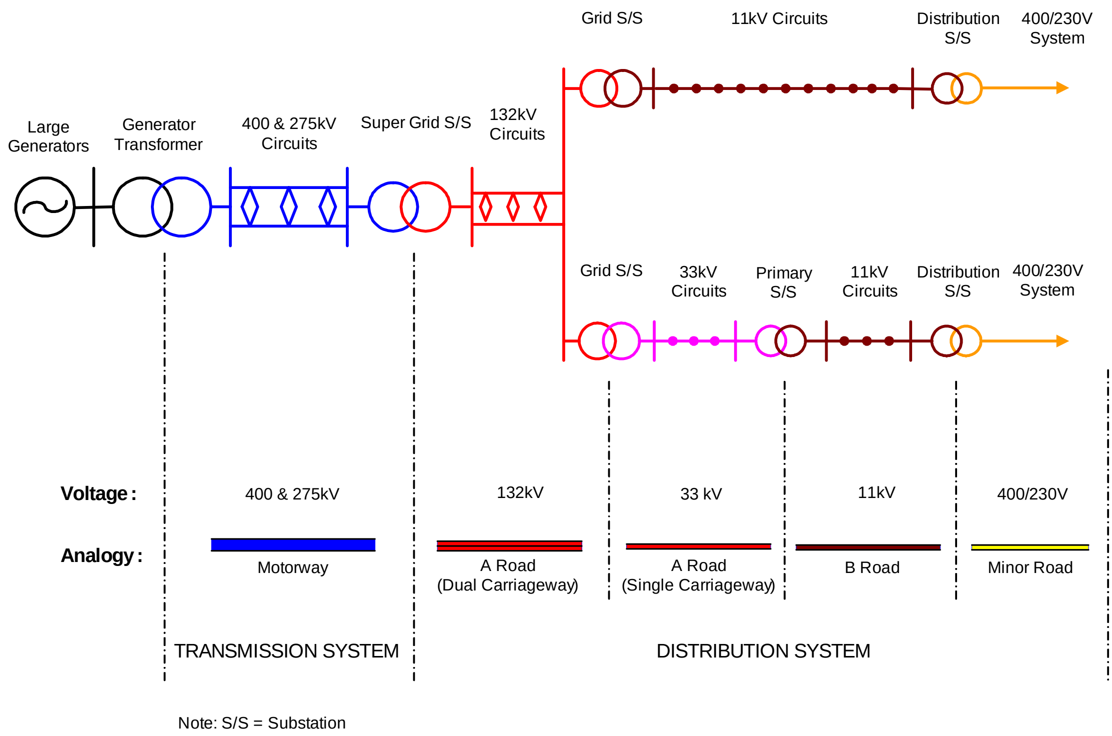

Figure 1
Overview of the UK power system

- Electricity generation. Traditional electricity generating stations, such as coal-fired stations, and renewable generators such as hydroelectric and wind power schemes are usually located away from heavily populated areas. The electricity generated is stepped up to a higher voltage at which it connects to the transmission network.
- Electric power transmission. The transmission network is the system for bulk transfer of electrical energy over long distances, as far as substations connected to the local distribution network, where the voltage is stepped down. (Power is usually transmitted at high voltages (132 kV and above) to reduce the energy lost in transmission.)
- Electric power distribution. This is the final stage in the delivery of electricity to end users. Distribution voltages vary, depending on customer needs, equipment and availability.

The DWG has been concerned solely with the third stage above (ie distribution systems that begin as the primary circuit leaves the substation and ends as the secondary service enters the customer's meter). Within these networks there may be a mix of overhead line systems including steel pylons, traditional wood poles and wires, and various types of underground cable.

Figure 2
Typical 33 kV overhead line
double-circuit line (can also be single-circuit)

Figure 3
Typical 11 kV overhead line
single-circuit line (can also be double-circuit)

Figure 4
Typical 400 V overhead line
open wire (can also be insulated and bundled)

Figure 5
Typical 11 kV underground cable

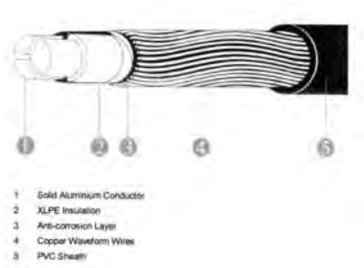

Figure 6
Typical 400 V 3-phase underground cable
(as used for distribution main)

Figure 7
Typical 400 V single-phase underground cable
(as used for service cable)

In the UK, the electricity that goes into a normal home is at a voltage of 230 V. But for technical reasons, the vast majority of high voltage and most low voltage systems are three phase (ie. they utilise three phase conductors). 230 V is the single-phase voltage; the equivalent three-phase voltage is 400 V. Most final distribution circuits supply electricity to several houses at once from three phases, and are usually referred to as "400 V circuits". Balanced three phase systems:

- are more efficient;
- allow larger loads to be supplied;
- allow longer circuits to be installed (voltage drop is lower); and
- are cheaper (overall).

This means that a typical final distribution circuit can be represented as shown in Figure 8, with successive homes connected to different phases:

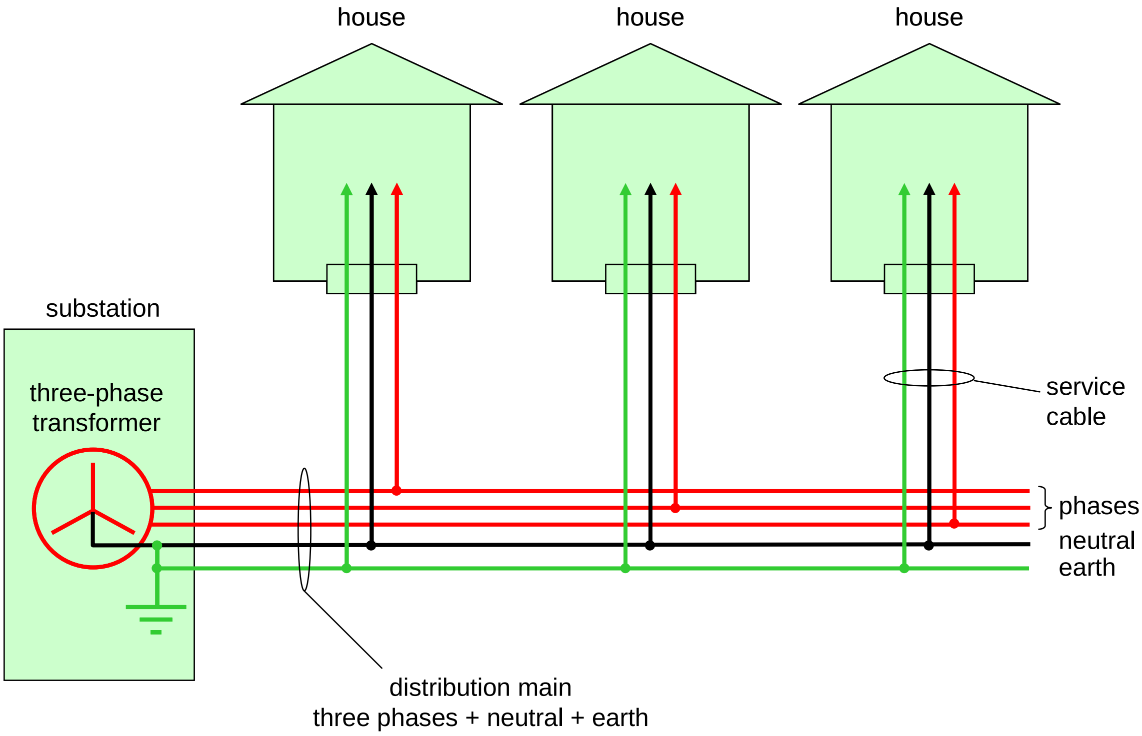

Figure 8
Typical UK distribution circuit showing houses connected to different phases

Figure 8 shows the three phase cables in red, the neutral in black and the earth in green (current conventions for wiring colours are different to this, with the phases brown, black and grey, the neutral blue, and the earth green and yellow striped). Each of the 3 houses is supplied from one of the phase cables. "Distribution main" refers to the main cable running from the substation, "service cable" refers to the connection from this to each individual home.

Note that there are different ways of earthing such circuits, which affect the way magnetic fields are produced and are therefore discussed in more detail later; this diagram shows just one possibility.

4.2 Substations

Substations have several basic functions:

- to change the system voltage level along the distribution system, using transformers; (Electricity may flow through several substations between generation plant and final consumer and the voltage may be changed in several steps.)
- to switch off the electricity if a fault occurs, using equipment such as circuit breakers and protection/control equipment); and
- to provide switching facilities so that particular sections of the distribution network can be switched in and out, to allow equipment to be disconnected for maintenance and so that electricity supplies can be maintained or restored if part of the system develops a fault.

The DWG has been concerned mainly with final substations that step down voltages from 11 kV to 400 V for domestic purposes. There are over 400,000 of these (see Table 1). Such substations may be ground-mounted or pole-mounted, outdoors in fenced enclosures or indoors in special purpose structures, or even within residential buildings (eg. maintenance rooms in blocks of flats).

Figure 9
Pole mounted substation

Figure 10
Older design of indoor substation

Figure 11
Newer design of compact ground-mounted substation

As well as these final distribution substations, there are a much smaller number (see Table 1) of substations at higher voltages, as illustrated in Figure 12 and Figure 13. The DWG has not specifically considered these, but recommends that they should be considered in the next phase of SAGE's work.

Figure 12
400 kV substation

Figure 13
33 kV substation

Table 1: Numbers of Substations in England and Wales (1989)

Transmission System	
National Grid (400 and 275 kV)	238
Distribution System	
>650V (i.e. 132 kV, 33 kV etc.)	4,849
Final Distribution	
Pole Mounted	260,435
Ground Mounted	166,015
Total (All Voltages)	431,537

4.3 Earthing

Earthing is the practice whereby connections are established to ensure that any conducting part of equipment which can be touched and which is not normally live, but which can become live if the insulation fails ("exposed conductive parts") are at the same electrical potential as the general mass of the earth, which reduces the risk of electrocution. Earthing conductors, also known as protective conductors, also provide a path for fault current to flow, should an item of equipment fail, enabling fuses to operate or other protective devices to trip, to disconnect the faulty equipment. A typical earthing system will comprise a buried electrode (buried copper conductor and copper tape) connected to a collection of wires and cables which are themselves connected to the electricity system and electrical equipment.

This differs from protective bonding, which is the practice of intentionally connecting together all metallic non-electrical items ("extraneous conductive parts") in a building as a protection measure, so that even if the connection to a distant earth ground is lost or if a fault on the electricity system occurs, the occupant will be protected from dangerous potential differences. Examples of items that may be bonded include metallic water piping, gas piping, structural metalwork etc.

It is a legal requirement to earth electricity networks in the UK, providing a path for current to flow through should a fault occur within the electricity system or equipment, so that protection systems (eg. fuses and circuit breakers) can operate quickly and disconnect the supply.

Three typical systems are in use for earthing in final distribution circuits:

- Separate Neutral and Earth (the cables are described as SNE and the earthing system is described as TN-S), as shown in Figure 14. The protective earth and neutral are separate conductors that are connected together only near the power source. This system is safe and reliable as long as the protective conductor remains intact, but more expensive than other systems, as a separate protective conductor in addition to the neutral is required. The protective conductor is not monitored in any way and therefore failure of an earth connection, which can occasionally occur, is likely to go unnoticed until a fault occurs.

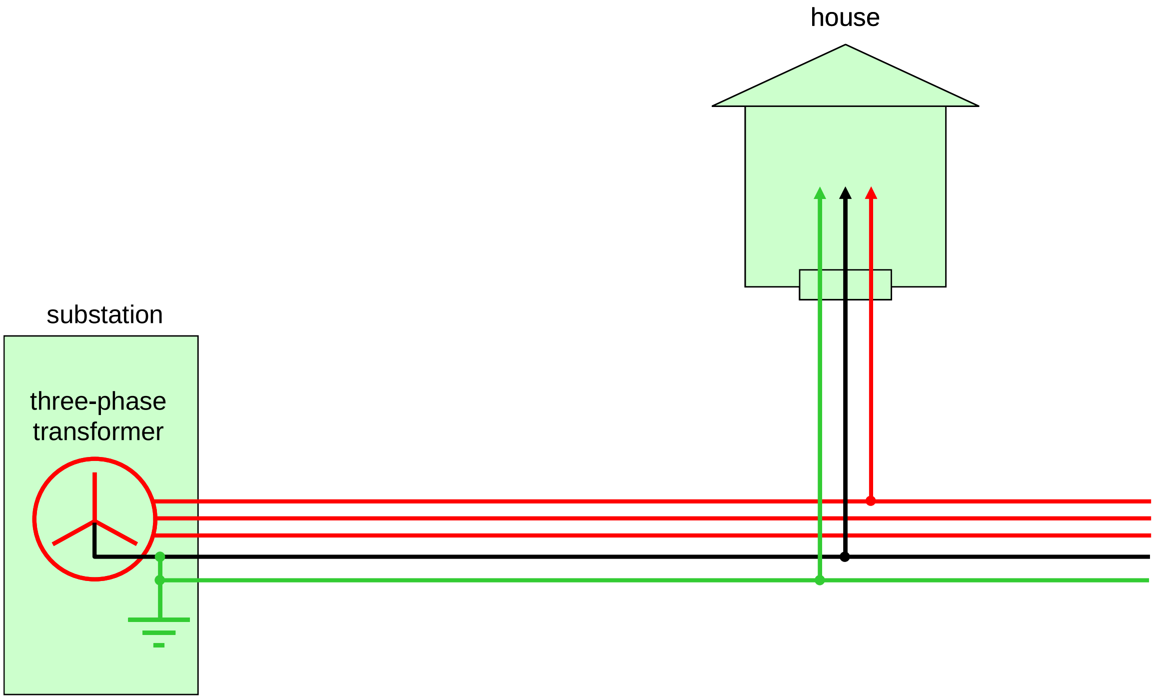

Figure 14
TN-S earthing system

- Direct Earthing (TT), as shown in Figure 15. The protective earth connection of the consumer is provided by a local connection to earth, independent of any earth connection supplied by the electricity company through their cables. Because the earth connection is often not as good – expressed in technical terms, the "earth fault loop impedance" is normally much higher - a residual current device (RCD) is also needed. This is a less safe and less reliable system, as it does rely on the customer installing and maintaining adequate earthing and an RCD and so may be expensive for the customer. The earthing system is not monitored in any way, and failure or progressive deterioration of an earth connection or failure of the RCD would go unnoticed until a fault occurs. It is cost-effective for the Distribution Network Operator as the distribution system does not need a separate earth conductor. But DNOs are legally required (under the Electricity Safety Quality and Continuity Regulations 2002[1]) to provide an earth terminal for new connections (as long as it is safe to do so) and therefore cannot force a consumer to use this method.

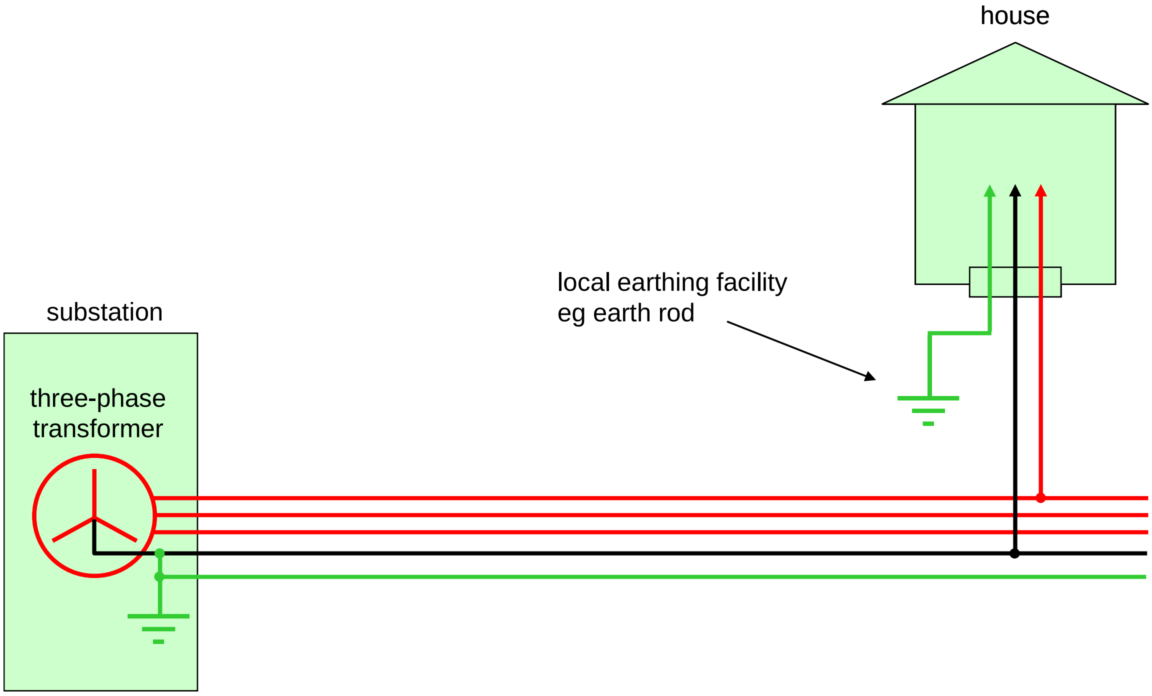

Figure 15
TT earthing system

[1] The Electricity Safety, Quality and Continuity Regulations 2002 (S.I. 2002/2665)

- Protective Multiple Earthing (PME, resulting in a system known as TN-C-S), as shown in Figure 16. The Distribution Network Operator (DNO) system uses a combined protective neutral-and-earth conductor, which is at some point (in a system built from new with pme, at the entry into the home) split up into separate protective earth and neutral lines. This is a safe and reliable system. The earthing system can be monitored, since the earthing conductor is used as the system neutral and any fault on it manifests itself as voltage fluctuations which cause lights to flicker. It is cost effective, as the neutral and earth conductor are combined. PME is unsuitable for some types of connection (eg. boats and caravans).

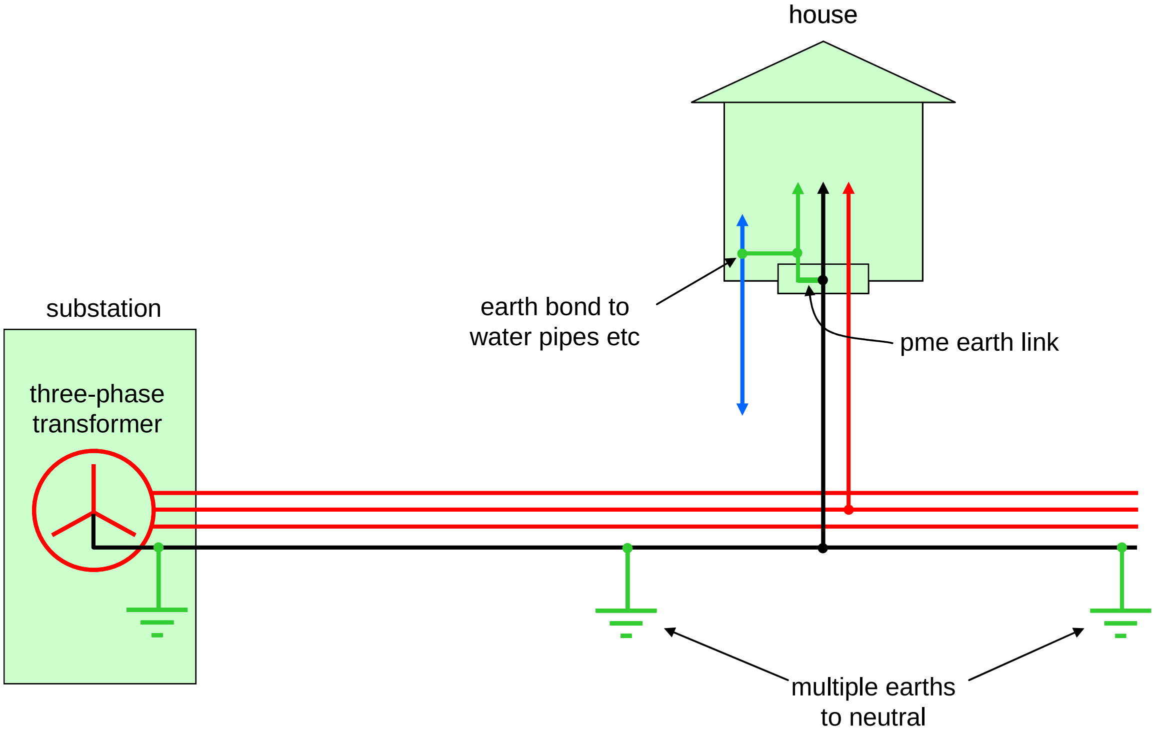

Figure 16
TN-C earthing system

Many circuits were installed before PME was introduced, but later converted to PME. They still have Separate-Neutral-and-Earth cables (SNE), but the neutral has been earthed at multiple places as required for PME (it is possible to repair these circuits using Combined-Neutral-and-Earth cables (CNE), where the separate neutral and earth from the old cable are both joined to the combined neural-earth conductor in the new cable, so sometimes the separate earth conductor may not exist all the way).

5 Human exposure to EMFs from Distribution Networks

5.1 Distribution Networks and Electric Fields

The most comprehensive set of measurements available[1] found that the average electric field in UK homes is about 10 V/m with lights turned off and 12 V/m with lights turned on. 90% of fields were in the range 5-25 V/m. These values are away from electrical appliances and equipment; higher values can often be found close to energised mains equipment. There is no hard-and-fast definition of what constitutes an "elevated" electric field, but based on these figures, fields would be normally be considered "elevated" if they were several tens of V/m.

The DWG considered whether people are exposed to electric fields from distribution systems. It concluded that this is generally unlikely to a significant extent, for the following reasons:

- The electric field strengths from distribution systems are much weaker than those generated by high voltage transmission lines.
- Within the home, people are largely screened from these fields by the fabric of the building.

Any electric fields found in the home are more likely to emanate from household wiring and appliances, which were addressed in SAGE Phase 1 as recorded in Section 3 of the First Interim Assessment.

The topic of electric fields has not therefore been pursued any further by the DWG and the remainder of this report is concerned only with the exposure to magnetic fields from the distribution system.

5.2 Distribution Networks and Magnetic Fields

The average background magnetic field in UK homes is 0.05 μT[2]. Fields between, say, 0.01 and 0.1 μT would often be regarded as within the normal range. Exactly what is regarded as an "elevated" field is not a precise definition, and may vary eg between rural and urban areas depending on what typical fields are in each area. Epidemiological studies of childhood leukaemia have often used cut-points of 0.2 and 0.4 μT to classify exposures, and this has led to focus on exposures above these values. The United Kingdom Childhood Cancer Study (UKCCS)[3] found that 2% of homes had fields above 0.2 μT and 0.4% above 0.4 μT (these refer to the 24 hour average field present in the general volume of the home; higher fields are readily found in almost all homes for short periods and close

[1] "Electric Field Surveys in Homes", A K Blackwell, National Grid Technical Report TR(E)334, 1999, summarised in "Residential power-frequency electric and magnetic fields: sources and exposures", J Swanson, Radiation Protection Dosimetry 1999 83:9-14

[2] Comparison of residential power-frequency magnetic fields away from appliances in different countries. Swanson J, Kaune WT. Bioelectromagnetics 1999;20(4):244-54; Exposure to power-frequency magnetic fields and the risk of childhood cancer. UK Childhood Cancer Study Investigators Lancet 1999 354:1925-31

[3] Exposure to power-frequency magnetic fields and the risk of childhood cancer. UK Childhood Cancer Study Investigators Lancet 1999 354:1925-31

to electrical equipment and appliances). When we use the term "elevated" it is these levels we have in mind, particularly fields or long-term exposures greater than 0.4 µT.

The main source of systematic information used by DWG to assess which sources of field produce elevated exposures, and how often, was a study performed by the Health Protection Agency (the "Residential Sources Study")[1]. They took all the homes which had been classed as "high" exposure by the UKCCS, and revisited them to find out the source of that elevated field. They presented results for two different levels of "high" field, above 0.2 µT and above 0.4 µT. The results are summarised in Figure 17 and Figure 18.

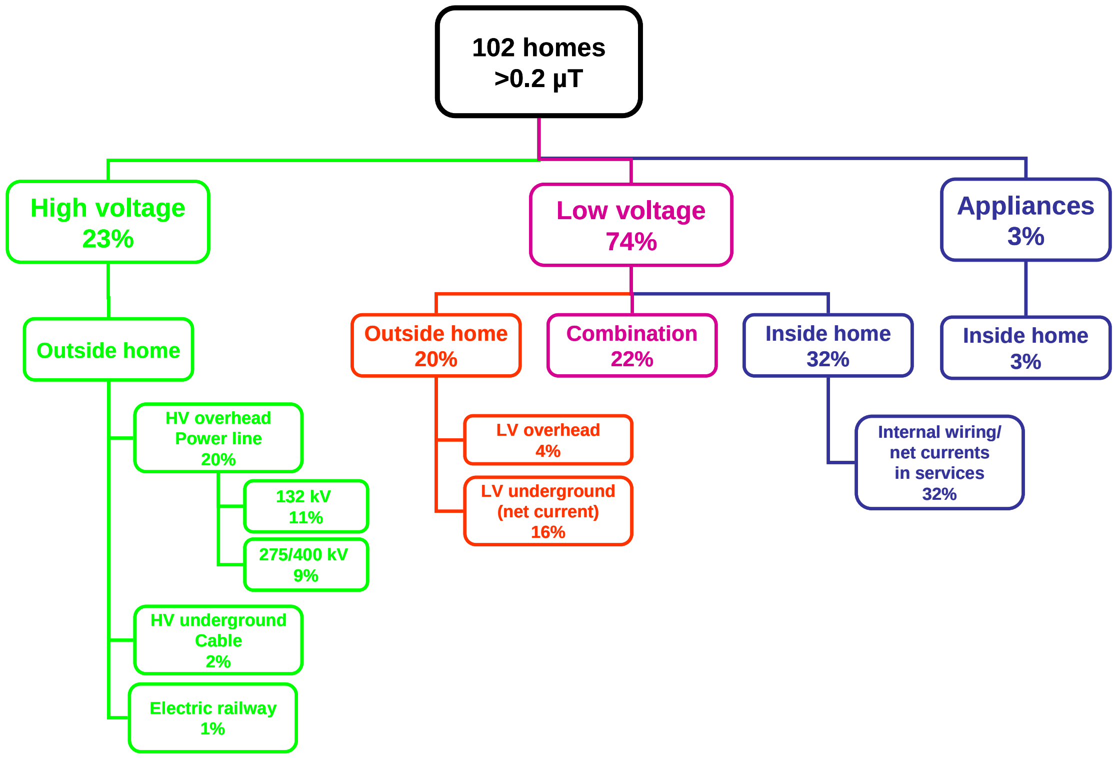

Figure 17
Results of Residential Sources Study for fields >0.2 µT
(the terminology "appliances" comes from the original study but should be taken as including all electrical equipment)

[1] Investigation of the sources of residential power frequency magnetic field exposure in the UK Childhood Cancer Study. Maslanyj MP, Mee TJ, Renew DC, Simpson J, Ansell P, Allen SG, Roman E. J Radiol Prot. 2007 27:41-58.

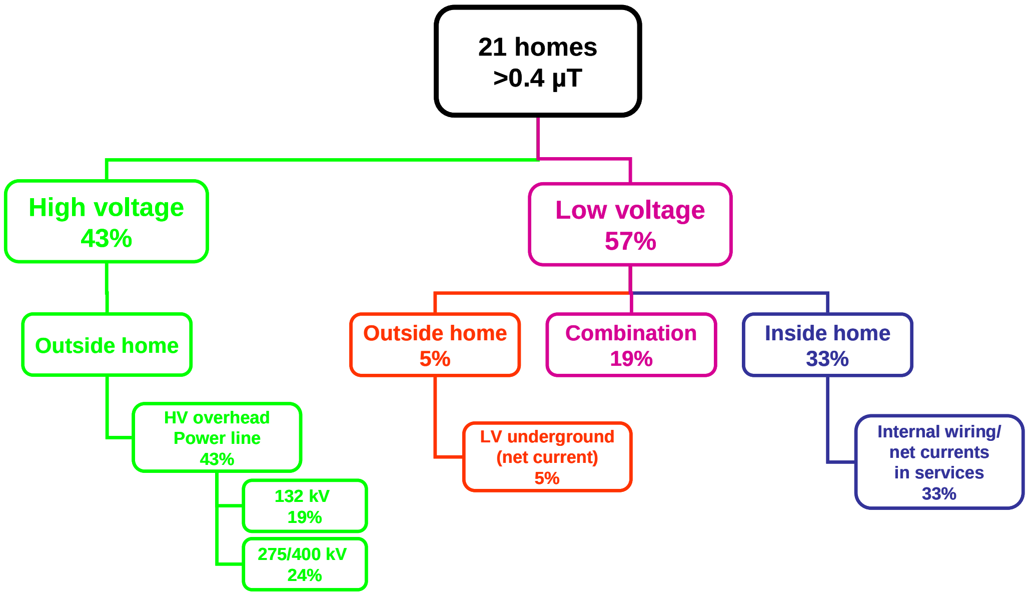

Figure 18
Results of Residential Sources Study for fields >0.4 µT

This shows that:

- although these elevated fields are rare, low-voltage underground distribution cables and service cables are a relatively common source of them when they do occur. The Residential Sources Study did not allow unambiguous separation between homes where the source was net currents in services entering the house and homes where it was house wiring. However, roughly half of instances of homes with fields greater than 0.4 µT appear due to net currents and hence to low-voltage distribution, equating to 0.2% of homes nationally.
- neither substations nor overhead lines or cables at voltages between 132 kV and 400 V were responsible for any instances of these elevated exposures in this sample of homes. This does not mean, of course, that there are no instances of elevated exposures produced by substations or intermediate-voltage lines. Members of the DWG reported specific examples where this does happen. It merely means such instances are sufficiently rare not to have featured in this sample. One single instance in the residential sources study would correspond to a prevalence in the population of 0.02%, or 4000 homes nationally. So this can be taken as an estimate of the upper limit of the true prevalence in the population.

5.3 Magnetic fields from circuits without net currents

Distribution wiring is the commonest source of magnetic fields in homes in most countries including the UK. However, the way in which distribution wiring produces magnetic fields is quite complicated, depending largely on "net currents". For simplicity, the magnetic fields produced by circuits without net currents are described first, then net currents are described.

Any circuit will produce a magnetic field, the strength of which is dependent on the distance from the conductors, the size of the current, and the separation distance between the currents making up the circuit.

The magnetic field produced by a current in a conductor falls with distance from the conductor. Where there is more than one current forming part of one or more electrical circuits, there is also partial cancellation between the magnetic fields produced by individual currents, and that cancellation generally becomes better at greater distances. Overall, the magnetic field is highest at the point of closest approach to the conductors and falls quite rapidly with distance. Therefore overhead lines produce a magnetic field which peaks underneath the conductors and falls rapidly with distance either side.

For intermediate-voltage lines (11 kV, 33 kV, 66 kV etc), typical fields are suggested to be of the order of 1 to 1.5 μT, and fall off to background levels at 10-20 m from the line, as shown in Figure 19.

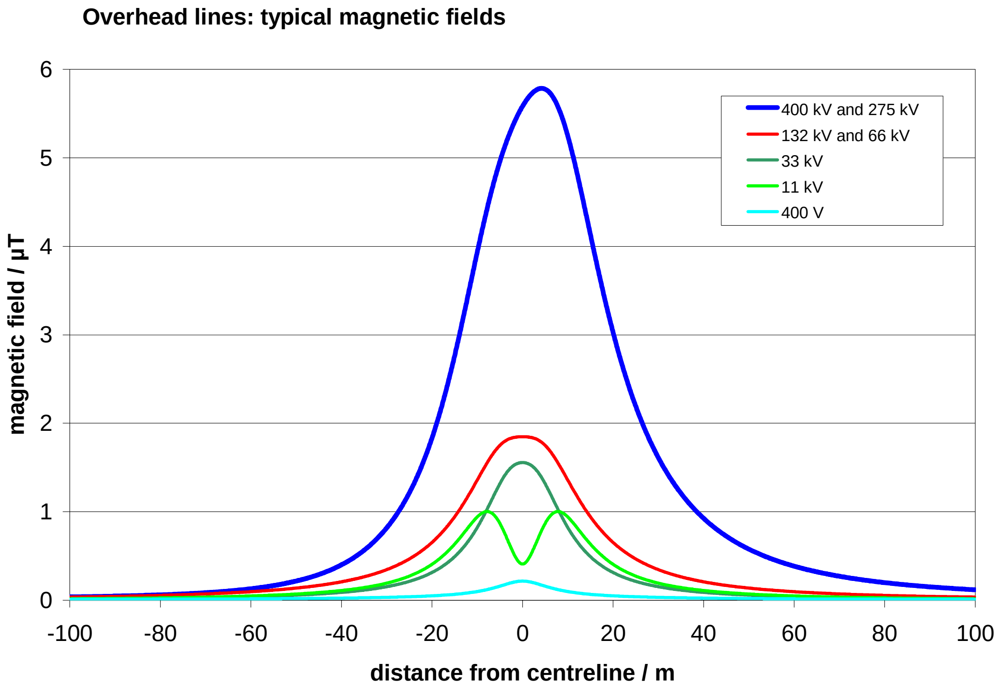

Figure 19
Typical magnetic fields produced by various voltages of overhead lines

Not many homes fall within this distance from an overhead line, and indeed the UKCCS Residential Sources Study did not record any overhead lines between 400V and 132 kV as the source of fields above 0.2 or 0.4μT. Hence, the DWG agreed that these intermediate voltage overhead lines were not a major contributor of human exposure to magnetic fields, although acknowledging that there are exceptions (principally where lines are unusually heavily loaded, for example as a result of independent generation schemes embedded within the system).

At final distribution voltages (400/230 V), some homes have distribution with separated-phase overhead wiring, in which the individual conductors are separated, usually by 0.3 m or so. With separated phases, magnetic fields can arise from the load currents on the conductors, just as with intermediate-voltage lines. However, the separation is smaller, the currents generally smaller, and these fields from the load currents in final distribution circuits are generally not that significant. Instead, fields from final-distribution circuits generally come from something called a net current.

5.4 Magnetic fields from net currents

Most UK homes have underground distribution, where the individual conductors are very much closer together within a single sheath. In a simple circuit of this type, where the load current drawn by a house passes out along a phase conductor and back along the neutral conductor, the currents are exactly balanced, as shown in Figure 20. Each conductor produces a magnetic field, but because the conductors are extremely close together the magnetic fields cancel, and there is a negligible external field.

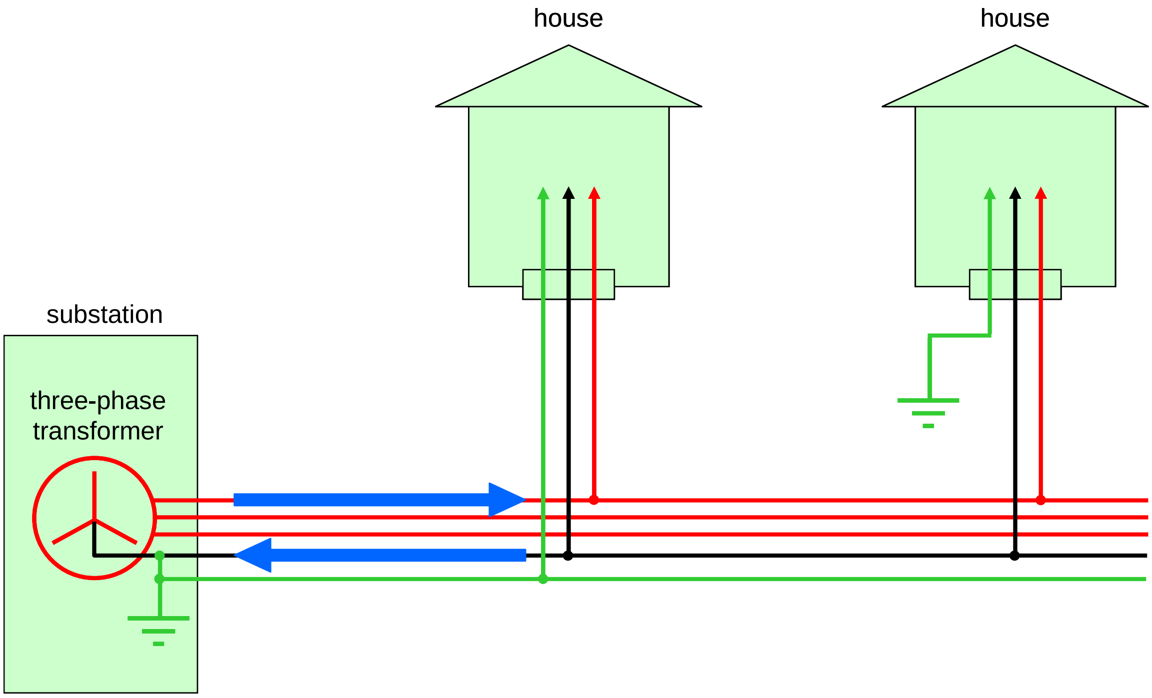

Figure 20
System with no multiple earthing: balanced currents

In practice, the situation is more complicated, because of "net currents". Net currents are produced when the neutral conductor is earthed or grounded in more than one place. With multiple earthing, some fraction of the neutral current in a circuit can divert out of the neutral conductor and return to the substation through water pipes, gas pipes, sewers, or the ground itself, as shown in Figure 21. The currents remaining in the cables are no longer balanced and the circuit then has a "net current". It often produces net current not only in the distribution circuits but also in any conducting utilities, all of which contribute to the background magnetic field in homes.

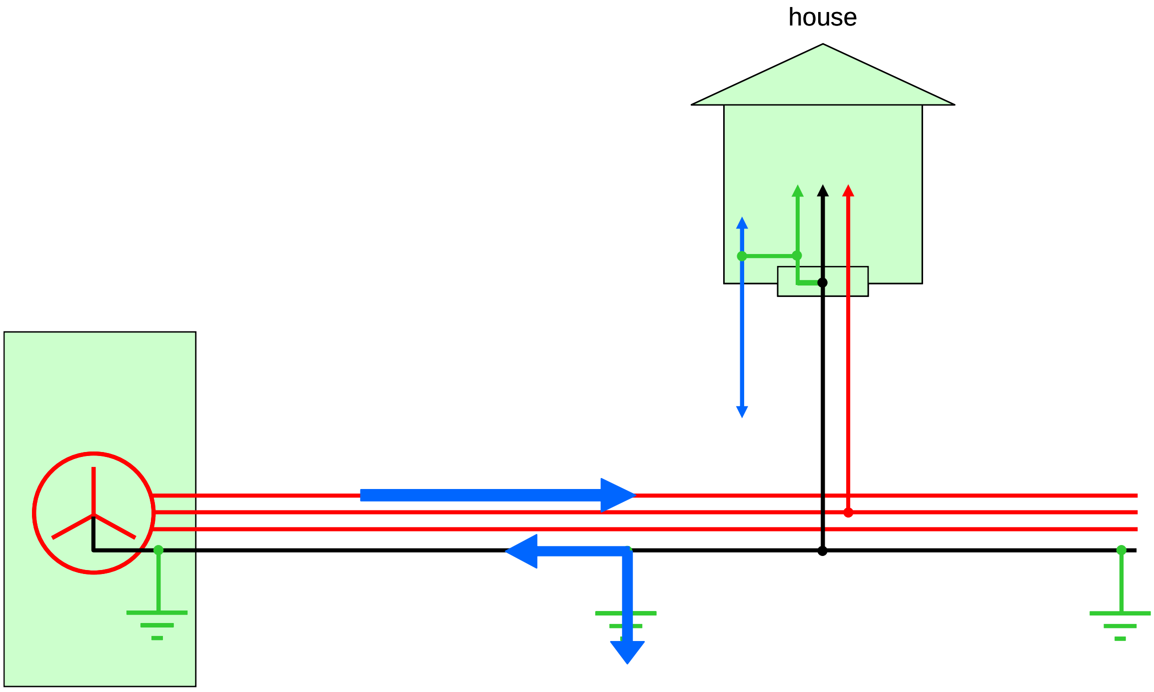

Figure 21
System with multiple earthing: diverted neutral current produces net currents

Before the Protective Multiple Earthing (PME) system was introduced in the 1930s, the neutral for each distribution circuit was earthed at the substation but nowhere else, so no net current could arise. Each house had its own earth (connected either to the earth in the distribution circuit or to a local ground rod) which was entirely separate from the neutral. However, PME has become increasingly common on 400 V distribution circuits and is now used on about 85% of overhead circuits, 65% of underground circuits and 30% of supplies to individual consumers in England and Wales[1]. Virtually every distribution circuit in the country has a net current, but its magnitude depends on the impedances of individual PME links and interconnections between circuits, making it difficult to predict.

Sometimes the net current arises from accidental connections through incorrect wiring, or in appliances involving heat and water (washing machines, water heaters), where general corrosion can degrade the neutral insulation and the bare conductor can come into contact with the chassis. Measurements on samples of homes in the UK suggest that many homes have such accidental connections. In measurement made in a sample of homes "as found" the proportion showing evidence of neutral-earth connections was up to 20%. But when scientists actively looked for such connections they were found in 70%[2]. In some, but not all, this results in house wiring becoming a significant source of magnetic field. This was addressed in SAGE's First Interim Assessment.

[1] Net currents in underground distribution circuits in the UK: implications for assessing magnetic-field exposures. J Swanson. J. Radiol. Prot. 1996 16 275-286

[2] Net currents in underground distribution circuits in the UK: implications for assessing magnetic-field exposures. J Swanson. J. Radiol. Prot. 1996 16 275-286

In some situations, the net current in PME circuits can also be much bigger. For example, if the neutral conductor is interrupted or broken, so that none of the neutral current can return through that cable, it can all divert into the earth or into an adjacent circuit via a link box, as shown in Figure 22. The net current is then 100% of the neutral current.

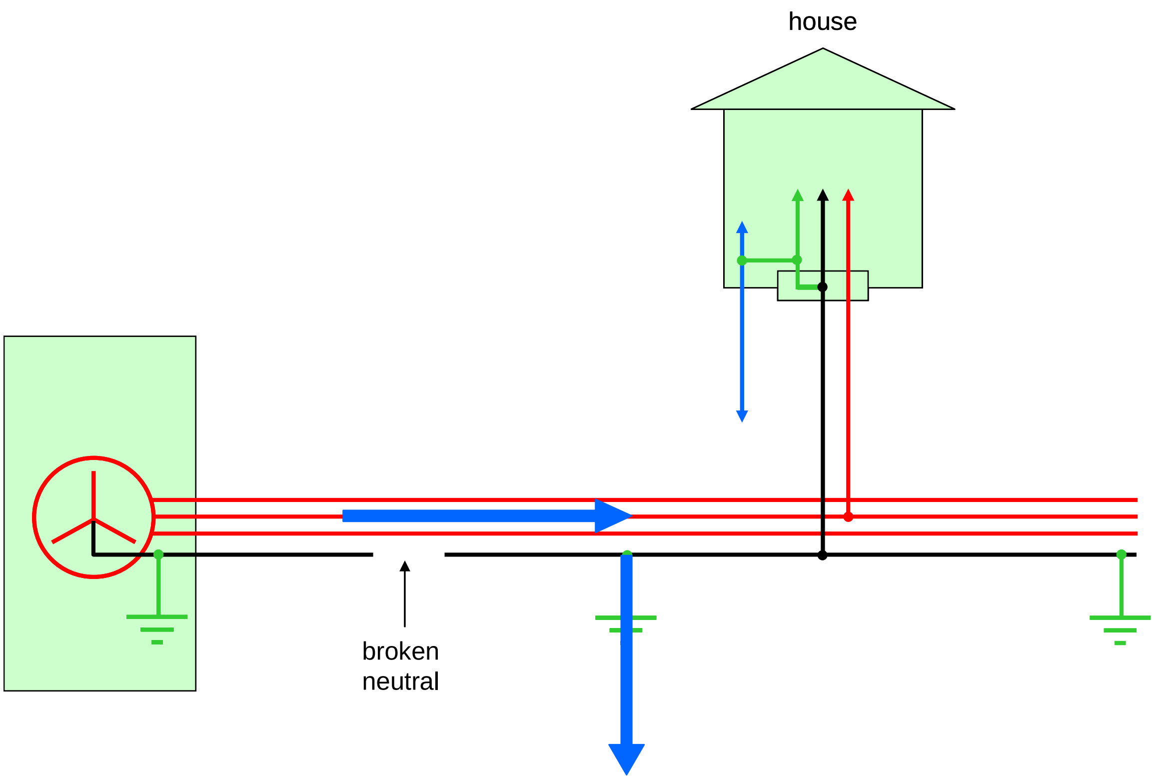

Figure 22
Broken neutral produces larger net current

Another wiring practice that can produce net currents is the use of link boxes. In urban areas, circuits from adjacent substations often meet each other at a link box, helping to maintain low voltages should a break occur in the neutral elsewhere (interconnected neutrals). Normally, the neutral link is left in, but the phase links are left out, and inserted only if it is necessary to backfeed one circuit from the other substation. The neutral current in one circuit can divert into the other circuit, creating a net current in both circuits, as shown in Figure 23. This applies whether the circuits have PME or not.

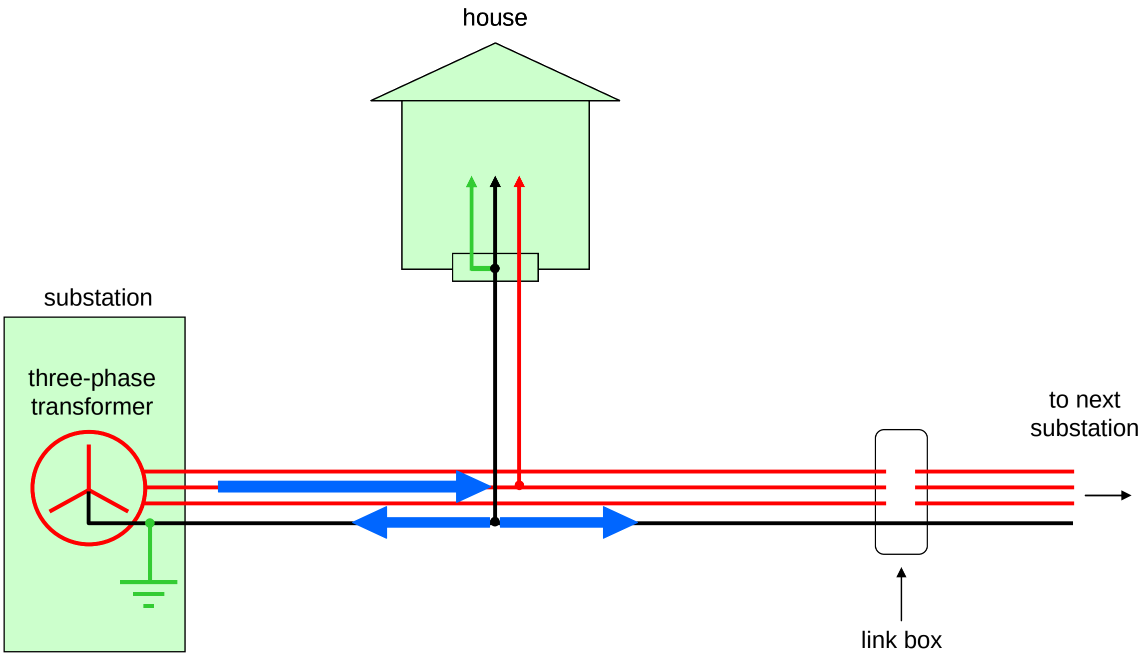

Figure 23
Interconnected neutrals at link produce produces larger net current

In a few areas of the country (one example being central London), phase links as well as neutral links may be left in place routinely. This would usually be for positive reasons such as reducing voltage fluctuations. SAGE has not explored what the implications of this are for net currents.

Studies indicate an average net current in a sample of underground 400 V distribution circuits in urban areas to be 3.6 A (at the point where they left the substation), which on average was 15% of the neutral current[1]. Background fields typically vary between homes from below 0.01 µT to above 0.1 µT even in the absence of high-voltage lines. The geometric-mean background field in a sample of homes throughout the country caused predominantly by net currents was 0.036 µT with 90% of them in the range 0.01 to 0.14 µT. In any given home, they will also vary with time, broadly following the daily and annual variations of load on the relevant circuit. Fields are therefore generally highest at the time of highest demand, usually the early evening. Fields can also be higher, sometimes significantly so, at times of low demand, eg the early hours of the morning, if off-peak electricity use in some but not all homes produces unbalanced loads and hence high neutral and net currents.

[1] Net currents in underground distribution circuits in the UK: implications for assessing magnetic-field exposures. J Swanson. J. Radiol. Prot. 1996 16 275-286

The various contributory factors to net currents are summarised in Figure 24.

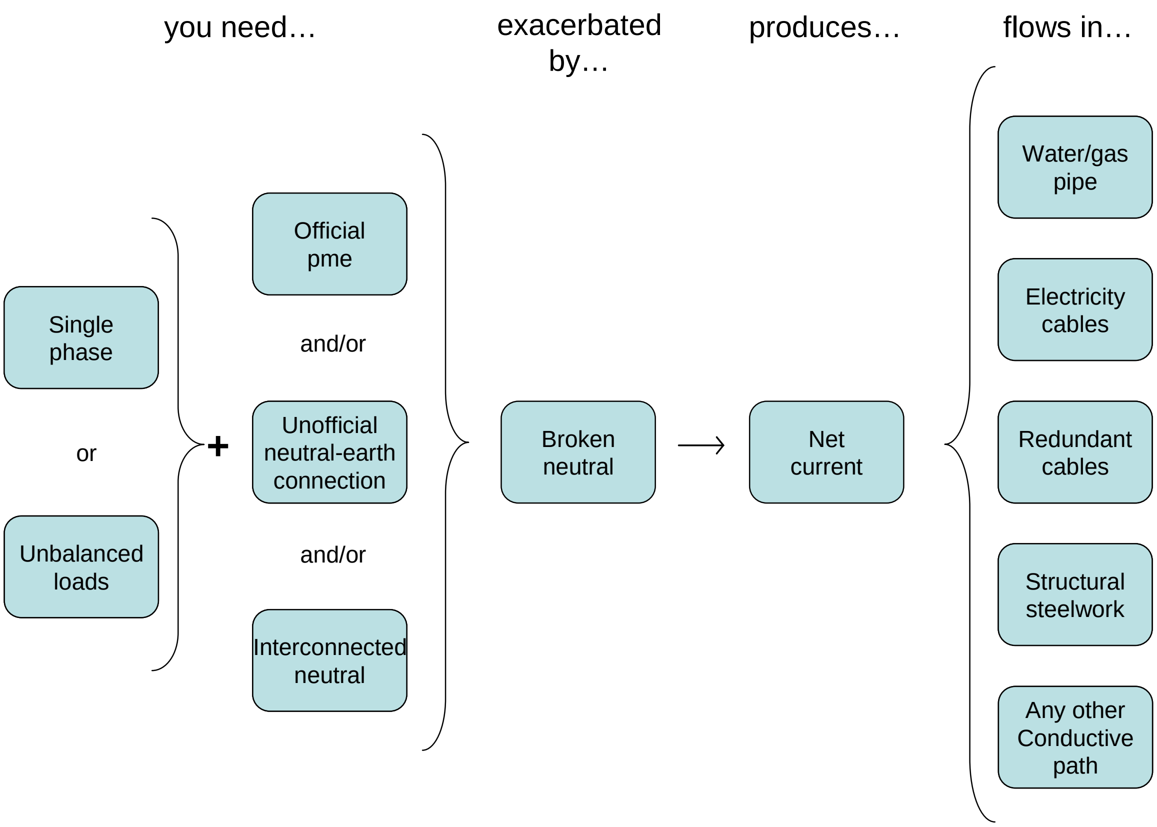

Figure 24
Summary of the factors producing net currents

5.5 Substations

This section concerns the final distribution substations that convert electricity to the 400 V or 230 V supplied to homes. SAGE has not yet considered higher-voltage substations in detail and recommends this should be covered in the next phase of its work.

EMF exposures arise mainly, though not exclusively, from ground-mounted substations. Pole-mounted transformers generally produce no electric fields themselves (because they are enclosed in a metal tank) though there will always be electric fields because of the overhead lines connecting them. They also generally produce only relatively low magnetic fields, with the field in the vicinity coming mainly from the associated lines or cables.

The equipment inside a ground-mounted substation (particularly the busbars and switchgear) produces magnetic fields but these fall off with distance and, usually, the field at the perimeter fence may be slightly elevated (typically 1-2 μT) but falls to background levels within a further 2-5 metres. This means that in most cases a substation is not a significant source of exposure in homes. But sometimes, if the substation is right next to a house, it can be a reason for the field in the home being elevated. For example, substations built into blocks of flats or other large buildings (schools, libraries etc.) can result in fields in adjacent public or residential parts of the building.

The design of substations varies. The individual items of equipment in outdoor substations tend to be relatively compact but some older designs of indoor substations can be laid out more spaciously – the frame with all the fuses can be spread over a wall, and the busbars may be fastened to a wall or ceiling and be fairly well-spaced, offering less opportunity for cancellation of fields. Older substations can therefore produce higher magnetic fields. Newer substations tend to be more compact, with switchgear bolted to the transformer, compact fuses and plastic screening to prevent contact with live equipment, in small, low voltage cabinets, and bundled cables from transformers to the fuseboards, all reducing the size of fields generated.

Even for older structures however, substations are not a major source of fields in the home, simply because of the physical separation between them and the great majority of residential buildings. The UKCCS Residential Sources ("High Homes") Study did not record any substations as a source of fields above 0.2 μT. However, although the incidence of high fields in the home attributable to substations is low, in a small number of particular cases substations may be responsible for significantly elevated fields.

Finally, it should be noted that a substation is a hub for wires and cables feeding into and out of it, and although high fields may be experienced around a substation, these are generally attributable to the configuration of wires and cables rather than the equipment inside the substation.

6 Methods adopted by the Working Group

6.1 Classification of mitigation options

As the work of the Group developed, it became apparent that it was helpful to structure the options it considered that could be used for reducing fields around four different parts of the distribution system, each representing a different source of fields. These are relatively self-contained and distinct and the options that need considering are largely different for these different parts. A fifth heading, "training and response", cuts across all the other parts, and is different in character as it addresses "human factors" rather than straightforward engineering decisions.

The five headings under which the work is structured are therefore:

- **Net currents in distribution circuits**
- **Wiring in multi-occupancy buildings**
- **Intermediate voltage circuits**
- **Final distribution substations**
- **Training and Response**

6.2 Methods used to assess mitigation options

The DWG first assembled a long-list of mitigation options, deliberately including every possible option even if it had little realistic chance of being recommended.

Next, it screened these options against a series of assessment criteria shown in Table 3 below. This exercise led to some options being recognised as not viable without further work. For other options, it identified needs for further information, which was gathered by DWG members where possible. This was a progressive process that interacted iteratively with the screening exercise over a number of meetings.

Table 2: Assessment Criteria

Effectiveness	If this option were implemented, how well would it perform in reducing public exposure to power frequency EMFs?	What proportion of distribution EMF exposures, including specifically elevated exposures, are attributable to the source(s) it addresses?
		To what extent will it reduce the exposures attributable to this source / these sources?

Safety	What are the non-EMF safety implications of this option?	Will this work bring additional safety benefits?
		Will this work cause additional safety hazards?
Practicality	From a practical point of view, how realistic would it be to implement this option?	How easy / difficult is it to implement?
		To what extent can it be focused on the actual problem source(s)
		Is it applicable only to new systems or can it be retro-fitted?
		How long will it take?
		What expertise does it require?
		What are the implications for continuity of service, both during and after the work?
		Does it bring other (non-EMF and non-safety) benefits?
		Does it cause other (non-EMF and non-safety) problems, both during and after the work?
		How confident are we that it will work as expected – in the short term / in the long term?
Legal Compliance	How well does this option contribute to meeting regulatory requirements?	How will it contribute to compliance with current regulations?
		How will it contribute to compliance with expected changes in regulations?
		How easy is it to achieve changes in regulation e.g. international agreement?
Wider Implications	How well does the option perform in relation to the wider social and physical environment?	What is the overall environmental impact?
		How does it perform in terms of social equity?
Cost	What are the funding implications for this option?	What is the gross capital cost?
		What is the gross revenue cost?
		Can any cost element be netted off (e.g. because the work brings other benefits)?
		Are additional costs going to be generated to other parts of the system e.g. through additional maintenance requirements as a result.
		Is it likely to attract funding?

DWG generally took the view that if an option had adverse consequences for safety (in the conventional sense of risk from electric shocks or similar) this would be a reason to reject the option, as an increase in the risk of this sort of harm would almost certainly outweigh any EMF benefit as presently understood. By contrast, cost could rule out an option if it were obviously large and grossly disproportionate, but would not necessarily rule out the option if more modest; in those circumstances, a cost-benefit analysis would be needed.

Finally, with the benefit of the screening and of the information gathered, the DWG proceeded to rank the options. The categories into which the options were ranked evolved as the work progressed. The final set of categories is based on a traffic-light system:

"Should"	Options which DWG is confident in recommending "should" happen. Some of these (as it turned out, a majority) are already existing practice for other reasons. In this case the DWG recommendation is that they should continue but with a recognition that EMFs are also a reason for doing them, so that in future, if the other reasons change, EMFs do not get ignored. Others (as it turned out, rather few) are new measures that DWG recommends should be introduced. Where this happens, DWG is sufficiently confident it has assessed all the relevant factors to be able to make this recommendation. If, by contrast, DWG felt than an option looked promising, but that further work on the safety or cost-benefit issues was needed to determine whether it should in fact be introduced, it would be classed as "could" rather than "should".
"Could"	Options which do not fall into either the "should" or "don't" categories. In each case, this report explains the specific reasons. In many cases, however, the reasoning falls broadly into one of the following:
	Further investigation is needed before a recommendation can be made. This could be either technical investigations (eg as to whether the option would have unacceptable safety consequences) or a cost-benefit analysis to determine whether the cost of introducing the option is proportionate.
	The option cannot be generally recommended but may come into play in certain specified circumstances.
	"Consumer choice" where the option cannot be generally recommended, usually because the cost is disproportionate. However, if an interested party (for convenience described as a "consumer") does not mind bearing the cost and the option is practically feasible in the specific circumstances, then this becomes an available option. In these cases, generally speaking, the fact of DWG listing this does not change anything – the option would usually be available already – but DWG considers it helpful to list such options explicitly.
	DWG unable to agree. There were no options in this category.
"Don't"	Options which DWG is confident in recommending should not happen, either because they would not be effective, or, more usually, because the cost would be disproportionate or they would have adverse safety consequences which made them unjustifiable.

Where an option is happening already for non-EMF reasons, but DWG considered that EMFs should be recognised as an additional reason for the practice continuing, DWG was concerned that this conclusion should be recognised by the relevant bodies, so that, if in the future they were reviewing the practice, the EMF input should not be ignored. Ideally, those bodies would enshrine the option formally in best practice. Accordingly, DWG has attempted to identify actions, where appropriate, to inform the relevant body of these conclusions.

Some measures, both endorsement of existing practices or new practices, are low cost in some situations, but could become higher cost in other circumstances. For these, SAGE uses the terminology "to the extent reasonably practicable" or similar, implying that a judgement has to be made as to when the cost becomes unreasonable. This does not detract from the fact there are indeed many circumstances where these options are reasonable and SAGE considers they should happen.

7 Overview of conclusions on Distribution

This section gives an overview of the conclusions reached by DWG. The following section gives more detail, including descriptions and discussion of each of the forty-plus options considered.

As previously discussed, DWG split the subject of distribution into four technical parts, each representing a distinct source of magnetic fields, and one non-technical area:

- Net currents in distribution circuits
- Wiring in multi-occupancy buildings
- Intermediate voltage circuits
- Final distribution substations
- Training and Response

In none of these areas was DWG able to identify the "magic bullet": a single option that it could recommend that would dramatically reduce exposures.

The evidence from the HPA Residential Sources Study described earlier suggests it is the first of these technical areas, net currents in distribution circuits, that contributes the most to elevated exposures in homes. For this area, there is in fact an option that, in principle, would dramatically reduce magnetic fields: remove the system of protective multiple earthing that is now used extensively in the UK (and also, at the same time, remove neutral links in link boxes), as this is what primarily leads to the net currents and hence the elevated magnetic fields. However, the system of protective multiple earthing is used, at least partly, for safety reasons, to prevent electric shocks, and to remove it would compromise safety. DWG judged this was not justified and therefore could not propose this option. (Even if safety was not an issue, DWG would still have had to consider the cost of removing protective multiple earthing, which would be considerable, and the practicability on existing networks.)

Having ruled out this as a possible solution, DWG was left with identifying a number of practices that could, in one way or another, reduce the extent of net currents. DWG has not attempted to quantify the reduction in exposure that could be achieved (and in many cases the necessary data to do so are not available). Some measures are expected to achieve significant reduction, but it is recognised that for other measures the reduction would be smaller.

Many of these practices are already existing best practice for other reasons. DWG therefore reinforces the following options and recommends that the bodies responsible for them be informed that EMFs constitute an additional reason for retaining them:

- **DNOs make reasonably practicable effort to balance loads on three-phase final distribution circuits**
- **DNOs assist customers who take a three-phase supply to balance loads to the extent reasonably practicable**
- **DNOs investigate and repair broken neutrals**
- **Disconnect redundant cables, when they are assessed as genuinely redundant, and when work is being done on the circuit anyway**
- **Use plastic gas and water pipes for new build**
- **Insert plastic sections in metal gas and water pipes when work is being done anyway**

In addition, DWG recognised that in special cases when net currents have been identified as the source of elevated exposures, it is an option for the consumer to have the following done (at their expense):

- Choose to use a "TT" earthing system (local earth) (there are, however, some constraints on when this is possible)
- Retrofit plastic sections in existing gas and water pipes where work is not otherwise being done

Finally, it would be theoretically possible to reduce net currents by fitting inductors at particular places (either in place of neutral links in link boxes, or on service cables to homes). DWG identified that further investigation is needed of whether these could be successfully and safely implemented within UK regulations and standards. DWG also considered the option of DNOs performing routine measurements of net currents in substations to identify circuits with unusually high values (often a symptom of broken neutrals, something the DNO would wish to find out about for other reasons). Further investigation is needed of this before conclusions can be drawn.

The second technical area, building design, is a comparatively minor area, applying principally to multi-occupancy buildings. DWG reinforces current practice for new build:

- **Site plant rooms away from occupied rooms**
- **Use separate-neutral-and-earth cables for risers**
- **Use compact risers**

These same three options are available as retrofit options, at the consumers' choice and cost, where this source of field has been identified as causing elevated exposures. However, DWG recognised this was unlikely to happen much in practice.

DWG considered intermediate-voltage circuits, ie, principally, overhead lines at 11 kV and 33 kV. These are generally not a source of elevated exposure. They would become such a source only if unusually highly loaded, and DWG considered the principal reason for this would be if they were connecting power stations ("embedded generation"), which occurs relatively infrequently. Such a highly-loaded circuit could be regarded as a similar (although less strong) source of magnetic fields to the high-voltage power lines considered in SAGE Phase 1 and DWG accordingly adopted a similar approach:

- **DNOs make reasonably practicable effort for heavily loaded double-circuit intermediate-voltage lines to have optimal phasing and loads balanced between the two circuits**

DWG concluded that the issues around routing such heavily-loaded circuits away from homes needed further investigation, as the analysis and conclusions of SAGE Phase 1 for high-voltage lines might not be directly applicable.

Final distribution substations are another source, which, based on the HPA Exposure Sources Survey, only rarely produces elevated exposures in homes, but which is nonetheless known to do so at least sometimes. All such substations will in fact comply with the relevant exposure guidelines. Beyond this, DWG concludes that:

- **Reasonably practicable efforts be made to site substations distant from homes etc**

DWG considered further investigation was needed of whether this principle could be codified somehow as a limit or restriction on fields or distances.

New substations are normally of a compact design which produces lower fields and DWG considers this practice should continue with EMFs identified as an extra reason for so doing:

- **New substations to have compact design where reasonably practicable**

When substations are refurbished, they would normally be replaced with compact designs, and DWG considers this should continue.

- **Use compact designs when refurbishing substations where reasonably practicable**

Whether or not a compact design is able to be used, DWG considers that a new principle should be introduced where a substation is close to residential premises:

- **Arrange components in the substation in the lowest-exposure layout reasonably practicable**

Where an existing substation is identified as a source of elevated exposure, DWG identified a number of measures that could be taken, if desired, to reduce exposures, including changing various components for more compact designs, and screening the fields. DWG considered the DNO could not be required to implement these measures given that the substation complies with the relevant exposure guidelines, but considers the following new obligations on DNOs should apply:

- **DNOs to consider instances of substations producing elevated exposures when requested and, where practically feasible, to offer options for reducing the exposures at the consumer's choice and cost.**
- **DNOs to record instances of substations producing particularly high exposures so that EMF issues can be factored in to future investment and maintenance decisions for that substation.**

DWG has not yet considered high-voltage substations.

Finally, as already remarked, there are few new engineering measures or changes to engineering practice that DWG was able to identify that it considered should be introduced, and those measures where it reinforces current practice are not likely to produce dramatic reductions in exposures. DWG considers this whole area of distribution is one where more progress may well be made, not by trying to implement specific, defined, engineering measures, but by creating a greater awareness of EMF issues in electricity companies, so that they take them more seriously, are more likely to investigate, and more likely, having investigated, to be motivated to identify options. Thus DWG concludes the following should happen:

- **Information for the public**
- **DNOs to investigate instances of high EMF exposures when notified of them**
- **Develop awareness within DNOs, by training of relevant staff, of how elevated exposures can be an indication of system problems (but recognising that development of a workable training package is needed first)**

The electricity industry has been involved in developing all these conclusions. Where measures would fall to DNOs to take action or to implement, we fully anticipate that the DNOs would respond favourably to a request from Government to do so.

8 How SAGE would like Government to respond

SAGE has reflected on the lessons to be learnt from the response to the SAGE First Interim Assessment.

That response took two and a half years. SAGE considers that to be too long. We recognise that Government felt it appropriate to ask the view of its advisor on EMF matters, the HPA, and may well wish to do the same thing again. We recognise that seeking the formal view of the HPA as an organisation is different from the involvement HPA staff have had as a stakeholder within the process, though some stakeholders expressed reservations. We also recognise that any matter involving more than one Department and Minister is bound to be extended for that reason. But:

we nonetheless consider that Government should be aiming to produce a response to this Second Interim Assessment within about six months.

We understand that the Department of Health is the lead Department, but that specific actions would often fall to other Departments such as DECC and DCLG. To provide clarity and to streamline this process as much as possible, we have identified against each action we propose the Department that we think needs to take that action forward.

We recognise that measures that require new initiatives or changes to regulations are harder for Government to implement. Virtually all of our proposals are, we consider, either uncontentious and likely to be met positively by the relevant parties, or matters of communication and of endorsing existing practice. No new or changed regulations are needed. This should remove many of the obstacles that could otherwise be presented to implementing the proposals. Nonetheless, this does not relieve Government of the responsibility for making the proposals happen.

With the First Interim Assessment, we sensed that when Government came to put some of the proposals to relevant professional bodies, the proposals may have been presented without some of the context or reasoning and may therefore have appeared less convincing than they should have done. We accept this was partly SAGE's fault for not providing more of that context and reasoning in our Assessment. But:

we ask that, with this Second Assessment, when Government comes to put proposals to outside bodies, it ensures that those proposals are put convincingly and with the appropriate context, if necessary by involving SAGE members to make those presentations.

9 Mitigation Options: detailed conclusions

This section reports, in detail, the conclusions of the DWG for all options considered, grouped according to the five areas previously identified. For each option, a summary of the option and of the final ranking is given first, followed by more detail of the option, of the relevant information gathered about it, and of the reasons for the DWG's ranking.

9.1 Options relating to net currents in distribution circuits

As explained above, the DWG had developed the flow chart shown in Figure 25 to illustrate the factors which lead to a net current:

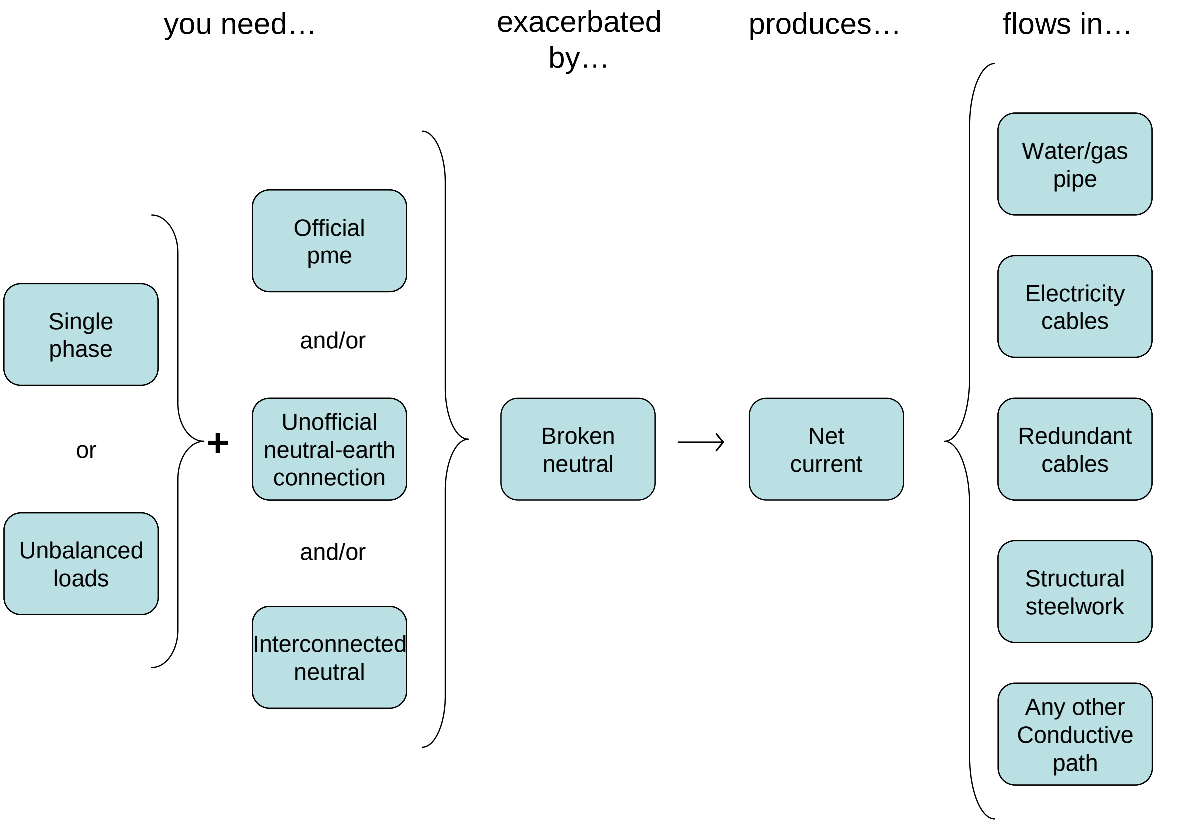

Figure 25
Summary of the factors producing net currents

This proved helpful for structuring the options that were considered, as different options relate to different stages of this flow chart.

9.1.1 Options that relate to the size of neutral current

Net currents arise from diversion of the neutral current, and therefore there are several options that relate to reducing the net current by means of reducing the size of the neutral current.

Option	DNOs make reasonably practicable effort to balance loads on three-phase final distribution circuits
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	With three-phase circuits, if the loads on the three phases are exactly equal, there is zero neutral current and hence no possibility of net current. Thus, the better the balance of the loads, the less the net current.
Relevant information	[insert information from peter Roberts on relevant standards]
Discussion	When installing a new circuit, DNOs will normally connect successive homes to successive phases, ensuring reasonable balance. This existing good practice isreinforced on EMF grounds. There may be scope for making slightly greater efforts, eg when connecting a new load to an existing circuit. But the DNO records will not necessarily always show which homes are connected to which phases.
Outstanding issue	How big does the imbalance of loads have to be before the DNO is expected to take further action?

Option	Improve balance of loads where this involves remaking joints
DWG conclusion	"Don't" Rejected (on grounds of cost)
Option detail	If loads have become unbalanced on a circuit, it is possible to improve the balance by excavating one or more joints and changing which phase certain loads are connected to.
Relevant information	
Discussion	Anything that involves excavating pavements and remaking joints is almost certain to be disproportionately expensive.

Option	DNOs assist customers with three-phase supplies to balance loads to the extent reasonably practicable
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	With customers who take three-phase loads, the customer can decrease neutral and

	hence net currents by balancing their own loads better.
Relevant information	
Discussion	The DNO normally have no control over how the customers connect their loads. But there may be scope for the DNO to assist eg by ensuring that all the different customers on a circuit don't all by default connect their first load to the red phase.

Option	**Legally require balanced loads**
DWG conclusion	"Don't" Rejected (on grounds of cost)
Option detail	In principle it would be possible to have a standard or regulation requiring a certain degree of balance
Relevant information	
Discussion	Anything that involves excavating pavements and remaking joints is almost certain to be disproportionately expensive.

9.1.2 Options that apply to the factors that allow a net current to be created

Net currents are created principally as a result of protective multiple earthing (pme) and the DWG considered a series of options to do with removing pme.

Option	**Abandon pme for new build**
DWG conclusion	"Don't" Rejected (on grounds of primarily safety and also cost)
Option detail	Conceptually the simplest way of preventing a net current from being produced is to remove all multiple earthing of the neutral, ie abandon pme and revert to previous systems of earthing. There are two main alternative systems of earthing that could be used: an earth provided by the electricity company from their network by an entirely separate cable (TN-S, using SNE cable) a local earth provided by the consumer (TT)
Relevant information	Cost: i) Extra cost for SNE service cables is £1 to £2 per metre (50% increase). ii) Extra cost for SNE mains cables is between £1.50 to £4 per metre (30% increase). Safety: PME is recognised as safer, because faulty earths under the old systems (TN-S and TT) are asymptomatic, whereas with PME, broken neutral/earths manifest themselves as consumer voltage problems. We have not found any quantitative analysis of the safety aspects. But we have found several documents written at the

	time PME was introduced, which talk of the then existing systems as obviously unsatisfactory and potentially unsafe, and there being a pressing need to introduce the new system (PME) to improve safety. For TT in particular, the comments above on safety apply, but even more so, as with TT (local earth) it is often harder to produce a good earth than TN-S (earth through distribution cable). Legal: DNOs have a legal obligation to offer an earth terminal for new connections, where it is safe to do so, under the Electricity Safety Quality and Continuity Regulations 2002. So the option of using TT systems instead of TN-C-C systems would require changes to regulations.
Discussion	Ruled out as pme is recognised as a safer system than the alternatives.

Option	**Abandon pme for existing networks, by retrofit or by progressive repair**
DWG conclusion	"Don't" Rejected (on grounds of safety and cost)
Option detail	Pme could removed from existing networks either by proactive replacement of whole circuits, or by a policy of only using SNE cables for repairs.
Relevant information	See previous option
Discussion	If the previous option (which applied to new build) cannot be justified, then retrofitting it, which has much higher cost and environmental implications, cannot be either.

Option	**Consumer chooses to use TT system (local earth)**
DWG conclusion	"Could" Available as an option at consumer choice and cost in special cases
Option detail	Although removing pme is not viable for systematic application to whole networks, there is an option that applies in situations where a consumer has identified that they have elevated fields due to high net currents specifically in the service cable and they wish to prevent those net currents flowing. They could disconnect the DNO earth and rely instead on a local earth.
Relevant information	
Discussion	DNOs have a legal obligation to offer an earth, but the consumer does not have to accept it, so this option is within existing regulations. Consumers should always obtain professional advice before adopting a different, potentially less safe, earthing system.

The DWG also considered whether pme could be, not abandoned, but modified so as to produce less net current.

Option	**Alter pme regulations to require fewer earths**
DWG conclusion	"Don't" Rejected (on grounds of feasibility/safety)
Option detail	Pme could be implemented with fewer earth connections required and hence less scope for net current
Relevant information	
Discussion	The existing regulations already require the minimum of earth connections consistent with adequate safety. In particular, earths are required at the end of each circuit branch for safety reasons, and these earths would still create net currents even if fewer earths were required elsewhere (fewer earths must always in principle reduce safety).

As well as protective multiple earthing, the other feature of distribution networks that allows net current is the neutral links that join the neutrals of adjacent circuits. Neutral links do undoubtedly contribute to higher net currents in some instances, but they are just one of the factors, so in assessing effectiveness of these options, it cannot be assumed they necessarily remove net currents by themselves. Removal of neutral links would need pme to be removed simultaneously to be fully effective.

Option	**Remove some or all neutral links**
DWG conclusion	"Don't" Rejected (on grounds of feasibility/safety)
Option detail	
Relevant information	
Discussion	It is doubtful if this would be effective, as if the neutral link is removed, PME regulations require earth bonds at both ends of the circuits, probably largely recreating the effect of the neutral link.

Option	**Replace some or all neutral links with inductive links**
DWG conclusion	"Could" Further investigation needed
Option detail	In principle, an inductive link could provide sufficient impedance to prevent or reduce net currents in normal operation, but not so high an impedance (probably by arranging for it to saturate which reduces the impedance during a fault) as to compromise its function during a fault.
Relevant information	
Legal	It was suggested that such an inductive link would constitute an impedance inserted into an earth, which is not permitted under existing regulations. If this interpretation turns out to be correct, regulations would have to be changed before this could be introduced.

Discussion	Further investigation needed. It would depend on being able to select a value of inductance high enough to reduce net currents and low enough still to comply with PME earthing requirements and to allow fuses to operate under fault conditions. In addition the inductors would need to be able to withstand fault currents and to fit physically into existing link boxes. DWG noted that a proper investigation would require considerable effort and asked whether there is sufficient prospect of a successful outcome to justify the investigation?

As discussed on page 31, DWG has not investigated options relating to leaving phase links in place in link boxes, but as this occurs only rarely, this is not a serious omission.

9.1.3 Options that apply to factors that exacerbate the size of any net current

One reason for a net current being unusually large is if there is a broken neutral, thereby forcing the whole of the current to return by a different path.

Option	**DNOs investigate and repair broken neutrals**
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to ask ENA to adopt this through a Code of Practice or similar * we believe this action would fall to DECC
Option detail	Broken neutrals are undesirable and should always be investigated and rectified by the DNO when they become aware of them.
Relevant information	One DNO reports 50 broken-neutral investigations per license area per year. Simple extrapolation therefore suggests 700 annually for the whole country. Commonest causes anecdotally reported to be deterioration and third party damage. DNOs already have a legal obligation under ESQCR, Regulation 7-1, to "take all reasonable precautions to ensure continuity of the supply neutral conductor".
Discussion	Identifying and repairing broken neutrals improves network reliability and safety and is therefore a desirable thing for DNOs to do, and indeed, DNOs do this anyway. It is not clear whether, realistically, DNOs can do more than they do at present, except that they might be more aware of elevated EMFs as a possible indicator of broken neutrals. This is considered further under "response and awareness"

Option	**Routine measurements to identify broken neutrals**
DWG conclusion	"Could" Further investigation needed
Option detail	Broken neutrals are currently identified principally through consumers reporting flickering lights. They could be identified more proactively through monitoring of net currents in circuits as they leave substations, or in neutral links at link boxes. This could be either a manual measurement, made with either a clip-on ammeter or a Rogowski coil, when routine inspection/maintenance visits are made to substations, or by installing remote-reading monitoring equipment.
Relevant information	Option of performing manual measurements during routine substation inspections: Approx. £10 extra per S/S inspection. This assumes that the work is carried out as part of the existing inspection (i.e. costs for travelling between sites have not been included). In addition to these costs, each substation inspector would have to be trained to carry out this work and would have to be equipped with suitable test equipment. These additional costs are estimated to be approximately £40,000 per DNO license area. Not all circuits will be physically capable of being measured. Note, within one representative DNO, ground-mounted distribution substations are normally inspected annually and pole-mounted substations are only formally inspected once every 10 years. Option of installing remote monitoring equipment: Approx. £1000 per substation, based on the cost for monitoring all ground-mounted and pole-mounted substations. Costs (per substation) will rise if only a proportion of substations are monitored. Assumed numbers of substations: 220,000 ground-mounted substations, 280,000 pole-mounted substations
Discussion	Both methods: investigation is needed of the appropriate threshold so that investigations are triggered only when there actually is a problem e.g. broken neutrals. If investigations are triggered by high net currents when there isn't actually a broken neutral, this would be an extra cost. More work is therefore needed on what level of net current, specifically measured at a substation, is an indicator of broken neutrals, as opposed to other causes. Measuring net currents in link boxes would probably be harder than measuring them at substations but DWG considers it should still be investigated.

9.1.4 Options that relate to the paths for a net current to flow in

Option	**Disconnect redundant cables**
DWG conclusion	"Should" Reinforce and endorse existing practice (with qualifications that the cables are assessed as genuinely redundant and work is being done anyway).
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	Disconnect redundant cables, when they are assessed as genuinely redundant, and when work is being done on the circuit anyway. Note that DNOs may decide there is reasonable likelihood of a particular cable being reused in the future and decide to retain it, even though it is currently not serving any purpose.
Relevant information	
Discussion	It is not worth proactively seeking out redundant cables in order to disconnect them, but a cable will normally become redundant as a result of some change to the system being made, and as part of that change, where the cable is genuinely redundant, it should be disconnected (and usually is). The decision whether to remove it having disconnected it would continue to be made, as at present, on non-EMF grounds.

Option	**Use plastic gas and water pipes for new build**
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to communicate reasons for this to relevant professional associations/trade bodies for gas and water industries. * we believe this action would fall to DECC, or would it be DCLG?
Option detail	Use of plastic pipes reduces alternative paths for net currents
Relevant information	
Discussion	This is believed to be routine practice already for new build.

Option	**Insert plastic sections in metal gas and water pipes when work is being done anyway**
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to communicate reasons for this to relevant professional associations/trade bodies for gas and water industries. Government* to identify where the debate about these issues is being

	conducted and ensure EMFs are part of that debate. * we believe this action would fall to DECC, or would it be DCLG?
Option detail	Use of plastic pipes reduces alternative paths for net currents. Where the main pipe is metal, inserting a short plastic section achieves this and is relatively easy to do when work is being performed anyway, eg a new meter is being fitted.
Relevant information	
Discussion	There are safety advantages in this (stemming from preventing fault currents from flowing through gas meters) and it is understood that it is largely existing practice. However, it is also understood that there may be some debate about whether it is in fact desirable, and EMFs should be fed into that debate as a reason for continuing or adopting the practice.

Option	**Retrofit plastic sections in existing gas and water pipes where work is not otherwise being done**
DWG conclusion	"Could" Available as option at consumer choice and cost in special cases.
Option detail	As above, but done proactively, where no other work is being done
Relevant information	
Discussion	For individual cases where it has been identified the source of elevated exposures is net currents in a gas or water pipe, this is a quick, effective way of reducing net currents. However, it will be up to the consumer to pay for this as it is unlikely the utility companies will want to replace pipe work at their cost, when it is operationally sound. There is no case imaginable where retrofit to the whole system would be recommended, rather than case-by-case.

Option	**Inductors on service cables**
DWG conclusion	"Could" Further investigation needed, with a view to availability as an option at consumer choice and cost in special cases.
Option detail	Fitting an inductor to the service cable increases the impedance of paths that do not pass back through the same inductor, thus "forcing" net current to return in the same cable it was supplied from rather than returning via an alternative path.
Relevant information	Investigated extensively in a Report[1] from the Electric Power Research Institute (EPRI, an industry research organisation in America) which has been examined by DWG. There are two variants: Option of slotting cylindrical inductors over the service cable: the EPRI investigation suggested there would often not be physically enough space to fit the

[1] Net Current Control Device. EPRI Report TR-111764 1998.

	required inductance (several meters of cable needed to be available). Option of inserting wound component in series with cutout: the EPRI investigation showed this is feasible and can reduce net currents. Cost not investigated but clearly likely to be £100+. Extensive further investigation would be needed of UK specific aspects (rating, voltage drop, safety under fault conditions, compliance with regulations). Update on US situation: the firm who were licensed to produce the device in 1998 report they made a few prototypes but nothing since because of lack of interest from utilities. They think the lack of interest is partly because of concerns about electrical safety/fire risk etc.
Discussion	Further investigation is needed as to whether this meets UK safety standards. Even then, because of the cost, it would probably be available as an option if the consumer is willing to pay rather than a candidate for general application.

Option	**Remove bonds from lightning conductors to electrical earths**
DWG conclusion	"Don't" Rejected (on safety grounds)
Option detail	Lightning conductors are bonded to electrical earths, and then constitute an extra (and good) earth to the electrical system.
Relevant information	Regulations call for protective bonding of lightning systems, so not to do so would be a contravention.
Discussion	Again there is a conflict here between EMF and safety. There is no case where retrofit would be recommended.

Option	**Change regulations to stop steelwork bonds**
DWG conclusion	"Don't" Rejected
Option detail	Removing bonds between the electricity system earth and structural steelwork in a building reduces the paths for net currents to flow in.
Relevant information	DWG did not pursue whether this would need to be done through the Building Regulations or the Wiring Regulations (BS7671) as the option was being rejected anyway.
Discussion	The bonding is present because it promotes safety, so removing it is unlikely to be justified.

Option	**Larger neutral conductors**
DWG conclusion	"Don't" Rejected (as ineffective)
Option detail	Increasing the size of the neutral conductor reduces its resistance and therefore makes it more attractive for net currents to return in it rather than diverting.
Relevant information	
Discussion	The relative impedances are dominated by the reactances rather than the resistances, so decreasing the resistance is relatively ineffective.

9.2 Options relating to wiring in multi-occupancy buildings

The wiring within homes was considered in SAGE Phase 1, and in general SAGE Phase 2 considers distribution to extend as far as the entry to a building. This leaves the wiring distributing power to the individual units of multi-occupancy buildings – typically the risers supplying individual flats in high-rise blocks of flats – as potentially not covered by either. It is therefore dealt with explicitly in this section. The main reasons for this being a source of exposure are if a plant room is immediately adjacent to a residential space, or if the risers are separated-phase.

Option	**Site plant rooms away from occupied areas (new build)**
DWG conclusion	"Should" Reinforce and endorse what would generally be good practice anyway
Action	Government* to communicate reasons for this to the relevant professional bodies, eg RIBA (representing architects), CIBSE (building service engineers), ACE (consulting engineers), and BRE (the Building Research Establishment). * we believe this action would fall to DCLG
Option detail	Plant rooms (containing meters, switchgear, distribution boards etc) can be a source of exposure because they are a concentration of currents and not necessarily well bundled.
Relevant information	Plant rooms would often be sited away from residential areas already to reduce noise and vibration.
Discussion	

Option	**Risers to use SNE cables (new build)**
DWG conclusion	"Should" Reinforce and endorse what is normal practice anyway
Action	Government* to communicate reasons for this to the relevant professional bodies, eg RIBA (representing architects), CIBSE (building service engineers), ACE (consulting engineers), and BRE (the Building Research Establishment). * we believe this action would fall to DCLG
Option detail	SNE cables avoid further earths to the neutral so reduce the scope for net currents and associated fields.
Relevant information	Energy Networks Association Engineering Recommendation G87 requires DNOs and Building Network Operators to use SNE conductors within risers.
Discussion	

Option	**Risers to use compact design**
DWG conclusion	"Should" Reinforce and endorse what is understood to be normal practice anyway
Action	Government* to communicate reasons for this to the relevant professional bodies, eg RIBA (representing architects), CIBSE (building service engineers), ACE (consulting engineers), and BRE (the Building Research Establishment). * we believe this action would fall to DCLG
Option detail	The closer together the conductors in a riser, the better the cancellation and therefore the lower the field produced.
Relevant information	
Discussion	

Option	**All of the above as retrofit**
DWG conclusion	"Could" Available at consumer choice and cost in special cases
Option detail	
Relevant information	
Discussion	In principle, if risers or plant rooms have been identified as the source of elevated exposures, there is an option for someone who is prepared to pay to have them moved, or retrofitted with compact designs, subject to practical feasibility. DWG recognises that the cost of this would normally be considerable. Further, although we use the terminology of "consumer", in practice the person affected will often be a tenant or leaseholder rather than the building owner, and therefore less able to make decisions about changes to the building. So this option is likely to be rather limited in practice, but is still listed because it remains an option in principle.

Option	**Screen the fields**
DWG conclusion	"Could" Available at consumer's choice and cost in special cases
Option detail	
Relevant information	Screening magnetic fields tends to involve considerable thicknesses of metal (usually layers of aluminium and a magnetic material such as mu-metal or similar). In practice, so far, it has not been used in residential settings but has sometimes been used in office environments or technical or scientific environments where low fields are essential.
Discussion	The difficulties of screening mean it will often not be a realistically feasible option.

9.3 Options relating to Intermediate voltage circuits

In this context, this refers to overhead lines at voltages above 400 V (which was considered under "net currents" in this report) and below 132 kV (which was considered under SAGE Phase 1). The principal voltages in question are 11 kV, 33 kV, and 66 kV.

Normally, these lines are not a significant source of exposure. They would become a possible significant source only if unusually heavily loaded. DWG identified that an increasingly common reason for a circuit being heavily loaded would be if it was connecting embedded generation.

Even a heavily loaded line at these voltages will produce lower EMFs than a typical high-voltage line. High-voltage lines were considered in detail in SAGE Phase 1 and similar conclusions are likely to apply. However, DWG recognised that in some respects (eg clearances from buildings and the ease of routing and rerouting) there could be differences. In any event DWG wished its conclusions to stand alone rather than to depend on previous work. Accordingly:

Option	**Heavily loaded double-circuit intermediate-voltage lines to have optimal phasing and loads balanced between the two**
DWG conclusion	"Should" DNOs to make reasonably practicable effort to achieve this
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	This applies only to double-circuit lines. The fields to the side of the line are reduced if the phasing (the relative order of the three phases) is optimal (usually transposed phasing) and if the loads on the two circuits are as nearly equal as possible. Under these circumstances, there is the greatest degree of cancellation between the magnetic fields produced by the two circuits and hence the lowest resulting field.
Relevant information	Estimates of numbers of generators currently installed at various power levels: Less than 271 generators in the range 1 to 5 MVA Less than 120 generators in the range 5 to 12 MVA Less than 61 generators in the range 12 to 50 MVA Less than 20 generators in the range 50 -100 MVA Less than 44 generators – 100 MVA or larger total >1 MVA: less than 518 (note: numbers are calculated from total power in each band, hence the "less than" qualification. Some of these, particularly the larger ones, will be connected at 132 kV or above rather than intermediate voltages.)
Unresolved issues	What is the criterion for "highly loaded" circuits?
Discussion	The requirement for balanced loads is not easily achievable if the two circuits run between different places. If that is the case, it could only be achieved by constructing extra substations or extra lines, which would be disproportionate. Optimum phasing is reasonably achievable only where it does not require replacing conductors that would not otherwise be replaced or building new structures.

Option	**Restrictions on routing new heavily loaded intermediate-voltage lines close to homes, schools and other public spaces**
DWG conclusion	"Could" Further investigation needed
Option detail	
Relevant information	
Unresolved issues	
Discussion	The Government response to SAGE Phase 1 established that UK policy does not include restrictions on EMF grounds on the proximity of new homes to existing lines or new lines to existing homes. But the issues might be different with these intermediate-voltage lines; specifically, routing them away from homes might be easier, as routing in general is easier. But, on the other hand, the exposures produced are lower. Hence the recognition that further investigation is needed.

9.4 Options relating to final distribution substations

As a way of ordering the options that relate to final distribution substations, DWG created the simple sequence shown in Figure 26: first consider options that apply at the stage of planning a substation, then those that apply at the stage of constructing it, then when refurbishing, and finally those that can be applied during the life of the substation when no other work is happening ("modification").

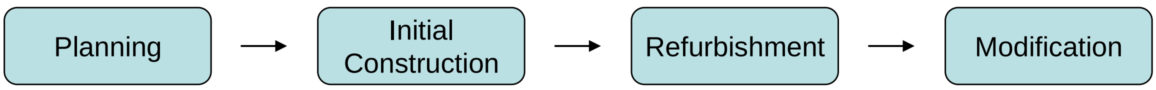

Figure 26
Sequence used for ordering the options relating to substations

9.4.1 Options that apply at the planning stage

First in the sequence of thought is that when planning a new substation, it must comply with the relevant exposure limits.

Option	**Comply with relevant exposure limits**
DWG conclusion	"Should" Endorse existing practice
Action	None needed (already ensured)

Option detail	The relevant exposure guidelines in the UK are currently, for occupational exposure, the 1998 ICNIRP exposure guidelines, and for public exposure, the 1998 ICNIRP exposure guidelines in the terms of the 1999 EU Recommendation. But this could change, so the option is described simply as compliance with the relevant limits.
Relevant information	In practice, the consequence of substation design parameters and electrical engineering is that all substations comply.
Discussion	This is, in fact, a given, because it is existing Government policy that electricity companies comply with anyway, and in practice, it is almost impossible for a substation not to comply with the exposure limits. But DWG includes this as an explicit option because it helps make sense of the remaining options

DWG considered this was the only "absolute" that could be expressed as a categorical requirement. The remaining options in this section are not as clear cut.

Option	**Reasonably practicable efforts to site substations distant from homes etc**
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	It will normally be good practice for non-EMF reasons (eg audible noise, vibration, access etc) not to site substations directly against living areas of residential properties etc. "Homes etc" is intended to cover homes, schools, libraries, and other public spaces with similar levels of occupancy.
Relevant information	Energy Networks Association document ENA TS 43-8 issue 3, "Overhead Line Clearances", specifies clearances for overhead lines to buildings etc, which also constitute the current constraint in terms of distance for substations supplied by overhead lines: **All HV conductors and also bare (i.e. non-effectively insulated) LV Conductors** Between line conductor and any object which is normally accessible = 3m (up to 33kV), 3.2m (66kV), 3.6m (132kV). Between line conductor and any object to which access is not required and on which a person cannot stand on or lean a ladder = 0.8m (up to 33kV), 1m (66kV), 1.4m (132kV). **Effectively Insulated LV Conductors, e.g. aerial bundled conductor (ABC):** Vertical distance to any surface or structure that is accessible without access equipment = 3m. Horizontal distance to any surface of a building that is accessible without access equipment = 1m. Clearance to parts of a building that are not normally accessible = 0.5m.
Unresolved issues	
Discussion	Although this will normally be good practice, the extent to which it can happen depends critically on the available space. The higher the density of the

	development the harder it will be to find space away from homes. An extreme case could be a high density development in an existing urban area where space is at an absolute premium. The wording of this option – "all appropriate efforts…" – may not be sufficiently specific in these circumstances, hence the next option.

Option	**Possible limits on fields produced in homes etc by new substations**
DWG conclusion	"Could" Further investigation needed
Option detail	It would be possible to limit the fields that new substations produce in existing homes, schools etc. In practice, it is possible that, to allow easy widespread practical application without unreasonable case-by-case effort, any restriction could be expressed as a distance rather than a field.
Relevant information	
Discussion	DWG recognises that whether this option is recommended or not would depend on what costs it carried and whether these were justifiable. Accordingly DWG recommends that a health-economics analysis should be performed and that Government should ensure this actually happens. The considerations need to include practicality, for example situations in high-density urban areas where no alternative site is available. DWG also recognises that further investigation is needed of whether this option would have ramifications, eg for existing homes near substations, or for developing new homes.

Option	**Substation perimeter fence to include larger area**
DWG conclusion	"Don't" Ineffective
Option detail	For ground-mounted substations, require the perimeter fence to enclose a larger area
Relevant information	
Discussion	The parameter that affects the exposures produced is the distance from the equipment in the substation that produces the field to the nearest residential (or similar) property. Within this distance, the perimeter fence can be set at any point and it does not affect the field. Therefore this is not the right way to tackle the issue.

9.4.2 Options that apply at the construction stage

Option	**New substations to have compact design where reasonably practicable**
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	New substations should have compact LV Boards and, where practical, use a close-couples arrangement or compact (ie bundled) cables connecting the transformer to the LV Board.
Relevant information	It is common practice is to install a "unit" sub station, where the transformer and LV Board are bolted together ("close-coupled") and form part of a single piece of equipment, and this ensures the compact design.
Discussion	This is existing practice which should be endorsed for EMF reasons.

9.4.3 Options that apply at the refurbishment stage

When an older substation, which may well not be particularly compact, comes to be replaced or refurbished, the following options apply:

Option	**Use compact designs where reasonably practicable**
DWG conclusion	"Should" Reinforce and endorse existing practice
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	Replacing an existing substation that has a non-compact design with a new substation that does will clearly reduce exposures.
Relevant information	
Discussion	This will usually be existing practice which should be reinforced for EMF reasons.

Option	**Arrange components in the substation in the lowest-exposure layout reasonably practicable**
DWG conclusion	"Should" New proposal
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	This applies most obviously if the physical constraints of the substation (or other factors) prevent a compact design being fitted. Then the components that produce

	the greatest exposure, such as the LV Board, should be positioned within the substation as far away as practicable from residential spaces (if any). Even if a compact design is fitted, it would still be good practice to position it farther away from rather than closer to residential spaces.
Relevant information	
Discussion	This is not something that would be part of the planning or design considerations at present. It will often be readily achievable. Sometimes, however, it would carry a cost. Where that is so, DWG recognises that a health-economics analysis would be needed to assess if that cost is justifiable or not.

9.4.4 Options that apply to the modification of an existing substation

This group of options apply when an existing substation is identified as the source of elevated exposures.

If the exposure were so high as to be non-compliant with the relevant exposure limits, the DNO would be required to achieve compliance, at their cost, regardless of whether this was requested by consumers or not. However, in practice, all substations are compliant with the limits currently in force. Given that, DWG considered it would be difficult to force DNOs to take action where the field was elevated but still compliant with exposure limits. Any changes would be likely to be at the consumer's expense, but DWG felt this option should be made explicit. Hence:

Option	**DNOs to consider instances of substations producing elevated exposures when requested and offer options for reducing the exposures at the consumer's choice and cost.**
DWG conclusion	"Should" It is a new initiative to formalise this, though it would often happen anyway
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	The trigger for the DNO performing this assessment would be when the substation produced elevated exposures in a home, school, or other similar public building. A field of 0.4 μT should be used as a guide to when the exposure is "elevated".
Relevant information	
Discussion	In practice, the options which a DNO could offer would be likely to come from the options listed after this one. There will, however, be situations where no option is practicable, or where all options are so expensive as to be effectively ruled out.

The following are the options which a DNO is likely to be able to offer, at the consumer's cost and subject to practicability and operational constraints, to reduce exposures from an existing substation:

Option	**Relocate the substation**
DWG conclusion	"Could" Available at consumer's choice and cost in special cases
Option detail	
Relevant information	
Discussion	This is likely to apply most often to pole-mounted substations.

Option	**Retrofit whole substation with compact design**
DWG conclusion	"Could" Available at consumer's choice and cost in special cases
Option detail	
Relevant information	Approx. £50,000 per substation, based on complete substation replacement including ground works (i.e. new concrete plinth), HV switchgear, HV cable jointing and provision of a GRP substation enclosure.
Discussion	

Option	**Retrofit LV Board with compact design**
DWG conclusion	"Could" Available at consumer's choice and cost in special cases
Option detail	If the LV Board is replaced, this will usually mean the cables to it from the transformer are replaced also.
Relevant information	Approx. £18,000 per substation, based on replacing existing transformer and LV board but retaining existing concrete plinth, HV switchgear etc
Discussion	

Option	**Bundle the cables between substation and LV Board to produce more compact design**
DWG conclusion	"Could" Available at consumer's choice and cost in special cases, subject to practicability
Option detail	
Relevant information	Approx. £5000 to £7000 per substation. Bundling the cables may reduce the rating, meaning that to maintain the same rating, larger (or additional) cables have to be fitted. In some cases it is not possible to connect these larger cables to the existing transformers or LV boards.
Discussion	

Option	**Screen the fields**
DWG conclusion	"Could" Available at consumer's choice and cost in special cases
Option detail	
Relevant information	Screening magnetic fields tends to involve considerable thicknesses of metal (usually layers of aluminium and a magnetic material such as mu-metal or similar). In practice, so far, it has not been used in residential settings but has sometimes been used in office environments or technical or scientific environments where low fields are essential.
Discussion	

Option	**Any of the above as a universal retrofit option**
DWG conclusion	"Don't" Disproportionate cost
Option detail	
Relevant information	
Discussion	

In some cases a substation may be produce a particularly elevated exposure, the commonest example being where an open-design LV board is fastened to one side of a wall, the other side of which is a residential or other public area. Examples have been reported where this produces exposures of several tens of microteslas. DWG recognises there is still no basis even in these situations to require a DNO to replace the equipment concerned solely on EMF grounds, but adds the following option:

Option	**DNO to record instances of substations producing particularly high exposures so that EMF issues can be factored in to future investment and maintenance decisions for that substation.**
DWG conclusion	"Should" This is a new initiative.
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	The objective is that, even though the high exposure may not be a reason for taking action on its own, it should nonetheless influence decisions as and when they are taken for other reasons. If the exposure is not properly recorded, this will not happen. DNOs will need to create a system for recording instances of particularly high exposure such that it does indeed come to the attention of whoever later makes decisions about maintenance, refurbishment etc.
Relevant information	
Discussion	DWG intends that this option applies to instances of exposures of several microteslas or tens of microteslas rather than exposures of 0.4 μT, but leaves the

	formal definition to whoever creates the Code of Practice that would implement this.

9.5 Options relating to Training and Response

Option	**Information for the public**
DWG conclusion	"Should" This should happen
Action	Government* to ask HPA to undertake this, similarly to the information action arising from SAGE Phase 1, and consulting the same range of stakeholders. * we believe this action would fall to DH
Option detail	Information should be readily available reactively (ie when people ask questions). There are various options for proactive information as well, including websites, printed leaflets and direct mailing, all of which would have pros and cons.
Relevant information	
Discussion	Whilst DWG was clear that information should definitely be part of the approach to EMFs, it did not reach a clear view of how this should happen and what method or methods would be best used. DWG noted that a similar recommendation had been made in SAGE Phase 1 and had been adopted by Government; the action for this now lay with HPA. DWG considered that progress on this option should be monitored, by SAGE or by whatever body evolves out of SAGE.

Option	**DNOs to investigate EMF issues when notified of them**
DWG conclusion	"Should" This should happen
Action	Government* to ask ENA to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	DWG has examined and rated many options for "fixing" EMF issues. But cutting across all of these is this option which seeks to approach the issue in a different way, by ensuring that situations of elevated EMFs are taken seriously and not just dismissed or ignored.
Relevant information	
Discussion	DNOs all investigate EMF issues to some extent at present. This option seeks to make sure this happens more systematically. The following option is complementary to this one. At present volumes of EMF issues raised with DNOs, no "trigger" for the DNO to investigate is needed; DNOs are unlikely to be swamped by investigating every issue raised with them, regardless of whether the fields are in fact much elevated or not. But if the volume of issues raised increased significantly, it might be necessary

	to introduce a trigger to concentrate attention on more serious issues. The extent of the "investigation" may need defining to avoid creating unrealistic expectations.

Option	**Develop awareness within DNOs, by training of relevant staff, of how elevated exposures can be an indication of system problems**
DWG conclusion	"Should" This should happen (but recognising that development of a workable training package is needed first)
Action	Government* to ask ENA to develop such a programme and to adopt this as a Code of Practice or similar * we believe this action would fall to DECC
Option detail	Relevant DNO staff (eg, call-centre staff, field staff who might interact with the public on EMF issues, etc) should have their awareness of EMF issues raised, so that they are more alert to reports of elevated EMFs from the public and less likely to dismiss them. In particular, elevated EMFs can often be indicative of network problems (such as interrupted neutrals or undesirably high currents flowing through earth connections) and it is clearly to the DNOs advantage to pick up on early signs of such problems.
Relevant information	
Discussion	

DWG considers it is normal good practice to review the effectiveness of introducing measures like these and expects the DNOs, with other relevant parties, to conduct such a review at appropriate intervals.

Section C: Discussions on Science

10 The work of the Science Forum

10.1 Introduction

The Science Forum (SF) was created to fulfil the need for a place within SAGE where scientific issues could be addressed and discussed openly. This followed a specific recommendation from the evaluation of the first phase of SAGE's work, where dissatisfaction had been expressed that science was not being dealt with as part of the SAGE process when it so clearly underlies the work.

The SF was not, however, convened as a scientific review body. This would not have been within the remit of SAGE, nor was the membership chosen with this purpose in mind. The SF did not attempt to review formally specific scientific papers or make any pronouncements on the science, and nothing said within the SF may be construed as "SAGE's views" of any particular scientific issue.

In fact, deliberately and perhaps unusually, the SF had no predetermined agenda, and no particular outputs in mind: it would be shaped by the needs of the participants rather than the need to deliver a product.

Its purpose was therefore to create a discussion group to promote mutual understanding and to clarify the reasons for divergent views on contentious subjects related to ELF EMFs rather than to seek consensus on these. Further, the SF has sought to tease out how different review bodies, and SAGE members, have approached the science relating to ELF EMFs and why they have arrived at different conclusions. Whilst the primary purpose of the Forum was not to produce practical recommendations to Government, the SF has begun an exploration of the process of developing public policy on EMFs in relation to risk and scientific uncertainty.

This approach may appear novel, but it was felt that it most closely represented the best method to address clearly identified need to explore why SAGE members, review bodies and governments disagree. Further, it sought to identify things that could reduce the divergence, although consensus was not necessarily achievable.

10.2 Reflections on the SAGE Science Forum

The SAGE Science Forum has achieved the following:
- an excellent chance for personal interactions;
- we are able to give process insights to people who follow us; and
- we identified two main questions: What does the science say? and What should be done about it? The SF largely tackled the former.

Membership of the Forum was open to all SAGE members and eight full-day meetings were held.

Achieving the right structural balance posed a significant challenge. In early meetings, a structured approach seemed too constrained; however it was felt that looser discussions lacked focus. The greater part of the output from SF therefore emanated from the later meetings after a number of methods had been tried and failed.

There was a second reason for the metamorphosis in the latter meetings, and that is a much greater input from the SAGE members themselves, rather than the facilitation team, in structuring the sessions. This has been a major shift, and represents one of the organic learning points to come out of this second phase of SAGE work. That is to say, that whilst members still feel very strongly about their various positions, SAGE has provided a forum for all those involved in the EMF debate to air those views and opinions in a non-confrontational way and to seek to find ways of working together collaboratively and constructively. Much of the skill and experience was already involved in SAGE, and once the heat of SAGE Phase 1 had subsided, the style of process needed to adapt to take account of the changed circumstances.

There are various outputs from the work of the SF including specialist presentations by members about science, types of studies, statistics etc. and also personal presentations, which allowed individuals to explain their "point of view". The facilitation team also carried out a face-to-face interview survey of volunteer SF participants to define the logic behind the views from individual "sectors" and major critiques of other views.

By the nature of the SF, therefore, we have no clear decisions to offer to the rest of SAGE, to Government, or to the outside world; that was not our objective. Nonetheless, the SF did provide members with an important opportunity to articulate their own views and to listen to alternative views. The SF allowed some of the "clutter" around the debate to be removed to enable the important issues to be recognised, which will be of benefit in ongoing discussions.

So we have learned from our working and talking together, and we capture some of our key learning points here, both on the differences in view and the process we have started developing for structuring the issues. We do not claim the following adds any revelatory insights to the many other people round the world who engage in similar debates on EMFs, but we offer them as the record of a very mixed group of interested people who have addressed these issues seriously over the course of half-a-dozen meetings over a year.

In general it was easier to identify the "problem" or area of disagreement than to understand the reason for it. The main lesson for groups who follow us down a similar road is the value of structured discussions. The Science Forum did this in plenary sessions, by giving individuals the floor to explain their views and by structured interviews with participants to define the decision-making processes they use. We found a commonality of decision making process/logic which nonetheless led to different conclusions.

10.3 The public-health perspective and application of health-economics methods

The group could easily identify the problems with the various viewpoints and methodologies, but were less able to approach a recommendation of how to do it better. We broadly agreed that fundamental human rights may need to be considered as well as a utilitarian approach. In formal health-economics analyses, such as cost-benefit analysis, the results depend crucially on the factors considered, eg whether the health outcome is considered only to be childhood leukaemia or a broader range of diseases. Whether Government costs alone are considered or private costs too is also an issue. In general, the more information that could be accurately encapsulated in a risk assessment the better. How to account for the views of communities is important. The group considered that more sophisticated methods may be needed, especially for low-prevalence conditions where it is difficult to achieve a favourable cost-benefit for preventive actions.

10.4 Uncertainty

The group discussed the many types of uncertainty in the science of health effects of ELF EMFs, eg whether an effect exists, the size of an effect, and the pathological mechanisms involved. This was a productive discussion in abstract but did not lead to a resolution of the differences of opinion in interpretation of the scientific evidence available.

10.5 Nature of the scientific evidence of health effects of ELF EMFs

The group agreed on the broad types of studies, and that there are fewer studies on electric fields compared to magnetic fields. The difficulties of defining a threshold for an effect when data on exposure and outcome is not known for all circumstances was also considered. Consensus could not be reached about which types of study or evidence are “the best” to define possible health effects of ELF EMFs. The concept of a simple, new, careful, bias-free study that could remove a large part of the uncertainly was discussed and this is addressed further in Section 10.11.

10.6 Nature of the science (effects and impacts)

This discussion tended to skirt round the fundamental issue of why people come to different conclusions from the same body of science without actually addressing that issue. There was a lack of consensus on whether the current evidence points to a causal link between ELF EMFs and any particular health outcome, or indeed on what would constitute evidence of causality.

10.7 Communities and risk

Led by a facilitator, the groups were aware of the evidence showing that risks of similar objective magnitude are not perceived equally by people or communities. Voluntary risks are usually tolerated at higher levels than imposed risks. Some risks have “fright factors” that make them more feared by the public and in current regulation there are already different thresholds for intervention.

Better ways to present risks more effectively to the public using "risk scales" and other approaches were supported.

10.8 Standard of proof

It was recognised that different judgements use different standards of proof ("beyond doubt" or "balance of probability"). Debate was held, without reaching a conclusion, on whether reproducible correlation without mechanism can constitute proof and trigger regulation. A discussion was held on whether society should start with the assumption that new technologies are safe, introducing them in advance of evidence as to safety, or prove safety before introduction, but no consensus was reached.

10.9 Epidemiological evidence

Epidemiology is in some ways the most direct evidence because it refers to people. However there are important obstacles to setting up good studies to minimise chance, bias and confounding leading to artefactual results. Epidemiology generally has poor power to investigate small relative risks. It is important to distinguish between good evidence but of a weak effect and weak evidence. There was discussion of why there are differing opinions about whether the relationships between ELF EMFs and childhood leukaemia (and other diseases) are causal. No consensus was reached, though it was noted that there are many associations that have been found and reported in the scientific literature but are clearly not causal.

10.10 Laboratory evidence

Although there are divergent views on the correct conclusions to draw from the existing laboratory evidence on EMFs, we were able to agree quite readily on many factors. We recognised the same broad categories of laboratory studies – on humans, animals, cells, and non-cellular chemical systems – and broadly agreed that the closer the systems investigated are to humans, the more weight should be attached to the results. Likewise, we broadly agreed that the closer the fields used are to typical human exposures the more relevant the results, and we helpfully clarified circumstances where experiments conducted with higher fields could still be relevant. We recognised that a strength of laboratory studies is the ability to control the experimental setup, but the need to control multiple parameters is also a challenge, particularly in the absence of prior knowledge as to which combination of parameters might be necessary to produce effects.

Where we differed was in our view of the existing results. Some people look at the scientific literature and see many studies reporting field effects; others look at the literature and see an absence of robust, readily repeatable results and an absence of a coherent pattern. Our discussions were nonetheless constructive for helping us understand the areas of agreement and disagreement and to set them in a broader picture.

10.11 How might future experimental results change assessments of the evidence?

We explored the proposition that a single laboratory experiment, or group of related experiments, could be set up that would have the expectation of taking all sides of the debate and moving them to one position depending on the result.

For people who currently are not persuaded of the existence of effects from the laboratory evidence, we recognised that a robust demonstration of an effect in a single experimental system should indeed change their view. We identified that in practice, people taking this view would generally be sceptical of a single experiment and would not regard it as robust, and further clarity would be needed as to what constituted a "robust" finding – how many replications, under what conditions, from which laboratories? But the principle remained that a robust finding should change views.

Some people who are currently persuaded of the existence of effects may base that view on a single mechanism or endpoint, but most generally feel that the evidence comes, not from a single experiment, but from a number of experiments on different systems. A negative result from a single experiment could at most persuade an individual against that particular effect, and would not logically lead to an overall switch of view because it would not address all the other experimental results. A negative finding from a single, well-designed, strong experiment should have some influence on their degree of certainty, depending on how important they viewed that specific experimental system, but should not usually be expected to change their overall judgement. We also recognised that scientists from any viewpoint can have an initial reaction, when faced with unexpected experimental results, that the experiment was the wrong one or that it had been conducted wrongly.

There is therefore an asymmetry, in that a single robust positive finding should change people's judgement but a single robust negative finding should not, or not to the same extent. But we recognised that this asymmetry partly reflects the reality of the scientific process, that a negative result in one experimental system does not disprove positive results in other systems.

An important point to emerge is that for people who currently see a number of experimental findings of EMF effects they find persuasive, there is one type of new evidence that would lead to a reassessment: this is a demonstration of how those apparent EMF effects were in fact being produced by a non-EMF cause.

Finally, we had examined this idea of a single designated experiment as a test of what it should take to make people change their minds, and it was a helpful exercise in that context. But we recognised that science does not generally proceed through a single experiment in isolation, however perfect it might be. Rather, a good view of the bigger picture is necessary, as both acute and chronic effects are important in this area and cross-generational impacts may also be relevant, as well as the very real possibility that, if EMFs have an effect, it is in conjunction with other agents.

10.12 Why do different review bodies come to different conclusions from the same body of scientific evidence?

Some members of the group have strong and differing views on this issue. However we did define a number of factors underlying the differences, some of which would be amenable to be addressed/improved in future reviews:

- some reviews have pre-determined agendas;
- the methodology may not be explicit;

- the reviews use different study-quality weightings and have different approaches to inclusion of non-peer-reviewed material; and
- reviews would be more likely to gain universal acceptance if the body doing the review is well recognised, the methods used are justified and transparent, and the process of selecting the people doing it is open and credible.

10.13 Precaution

The group found it easier to define the problem than propose a solution to the central question of "how much precaution does the current evidence justify?" It was noted that there are legal constraints to the application of precaution. Precaution must be proportionate but we already know there seems to be inconsistency between different types of possible hazards.

There are different standards of proof for different purposes or in different contexts. These are clearly defined in the legal arena: eg "beyond reasonable doubt", "balance of probabilities". They are often less clearly defined in the scientific context. "95% confidence" is used for the purely statistical aspects of evidence, but when looking at the overall evidence, looser phrases such as "established", "strong evidence", "possibility" are often used. It is obvious that different levels of scientific proof would warrant different levels of action, and the decision about what level of action to take involves social and political factors as well as the purely scientific. The group considered this could be part of the reason for seeming inconsistencies between different hazards, and this could fruitfully be explored more systematically.

Putting more information into the public domain, as recommended by SAGE Phase 1 is low cost, but can raise anxiety, a health risk in itself. The group felt that there may be merit in more discussion of risk-assessment and risk-management methods in future SAGE work.

10.14 International Exposure Limits

We considered a summary of how other countries have interpreted the concerns about the health impacts of EMFs into regulation and precautionary limits and targets. There is a wide variation and several countries have put in place local arrangements and conditions, including different levels of exposure for different sections of the population, and for different periods of time, for example. No country we are aware of has levels much higher than ICNIRP, but in a variety of instances lower values have been imposed. It would be useful to investigate why levels differ, and to ascertain what exposure limits, if any, are in place for countries that were not listed, especially such as Turkey, Russia, and the African and Arab states.

However, it was not possible, in the time available, to drill down into a sufficient level of detail to understand the reasons for these differing exposure limits. We agreed to continue to investigate this issue of how other countries interpret and deal with EMF hazards, looking at health-economics processes such as cost-benefit analysis in particular, and to go deeper rather than broader. We recommend that this area should form part of an ongoing engagement process.

10.15 Summary of specific topics discussed

The issue of ELF EMF health effects is a very complex area of science and while underlying issues remain uncertain it was difficult to reach firm conclusions or recommendations. Examples of these underlying issues include:

- the level of precaution justified by the evidence;
- which factors are taken into account in health economics analyses; and
- which review bodies provide the most reliable conclusions.

It was not possible, in the time available, to decide on all these issues as well as debate and discuss the specific example of ELF EMF health effects. The obvious conclusion would be that the wider issues should be considered as well, before a group like the SAGE science forum could reach useful conclusions.

Section D: Next steps for SAGE

11 Intended further activities

SAGE came into being in 2004 out of a confluence of motivations:

- a desire by some stakeholders to create a better model for communications on the EMF issue;
- a desire by some stakeholders to influence Government policy on EMFs; and
- the need for Government to implement the then NRPB's recommendation to consider precautionary measures.

Those same motivations still remain and therefore there is still a will for SAGE (or something like it) to continue. However, the context of SAGE has evolved since 2004:

- Government are still committed to SAGE. But the delay in the Government response to SAGE Phase 1, the fact that not all the recommendations from SAGE Phase 1 were implemented or even pursued with enthusiasm, and the fact that while some Departments'/Administrations' attendance at SAGE meetings have been exemplary, others appear less committed, all point to the reality that either or both of the EMF issue or SAGE as an approach to dealing with it are not the highest priority for Government.
- For stakeholders with a clear agenda about introducing precautionary measures, SAGE has been disappointing.
- Several stakeholders, in some cases those with strong views in one direction or another, have voted with their feet and no longer attend SAGE.
- For most if not all stakeholders, there is a sense that SAGE is a very time-consuming process.
- The motivation of many stakeholders, including one of the three funders, the electricity industry, is centred on the EMFs produced by the power system. SAGE has now dealt, at least as a first pass, with the three technical areas into which EMFs from the power system were initially split: power lines, house wiring, and distribution. The last of the four areas originally envisaged, "transport and others", would be a marked shift in interest.

Accordingly, the SAGE participants intend that the process should continue, but in an evolving way.

Among the specific subjects that SAGE has already identified as worthwhile to consider further are, in the technical area:

- **exposures from substations at higher voltages than the final distribution substations considered in this Assessment;**

and, arising from the work of the Science Forum:

- **how appropriate risk-management policies are chosen, including health-economics considerations such as cost-benefit analyses;**
- **how, and more importantly why, different countries have responded to the same scientific evidence with different policies; and**
- **the communication of these issues.**

These discussions would take place in the context of the body of science concerning both childhood leukaemia and also other health outcomes.

SAGE asks Government to:

- **reconfirm that Government does indeed want SAGE to continue;**
- **say whether there are particular policy issues that Government wants SAGE to consider (to complement SAGE's own thinking about what it should look at next); and**
- **confirm that Government will consider seriously whatever advice may emerge from SAGE in future.**

We will monitor the extent to which SAGE's recommendations, from both this Second Interim Assessment and the First Interim Assessment, are implemented. It will fall to DH to take a lead in helping us with this.

Section E: Supplementary Material

12 List of SAGE participants

DWG: member of Distribution Working Group
SF: regularly attended Science Forum meetings (this group did not have defined membership)
PG: member of Process Group

		DWG	SF	PG
Adrian Todd	Kilmorack Community Council	Y	Y	
Alan Preece	Bristol University			
Alasdair Philips	Powerwatch	Y	Y	
Alison Edwards	Department for Communities and Local Government			
Andy Hood	Western Power Distribution	Y		
Anne Silk	Independent Health Researcher		Y	
Anthony Barker	Institution of Engineering and Technology		Y	
Arthur Johnston	Scottish Government			
Barry Hall	Council of Mortgage Lenders			
Brenda Short	Powerwatch		Y	
Caroline Blakely	CHILDREN with LEUKAEMIA			
Caroline Hampden-White	CHILDREN with LEUKAEMIA	Y	Y	Y
Caroline Paterson	Stirling Before Pylons			
David Collier	Facilitator	Y	Y	Y
David Dossett	British Electrotechnical and Allied Manufacturers' Association			
David Renew	National Grid		Y	
Denise Libretto	Department of Energy and Climate Change			
Derek Blatt	Royal Institution of Chartered Surveyors			

		DWG	SF	PG
Geoffrey Stokes	Institution of Engineering and Technology			
Graham Barber	Institution of Engineering and Technology			
Graham Philips	Electromagnetic Radiation Research Trust	Y	Y	Y
Hector Pearson	National Grid			
Howard Price	Chartered Institute of Environmental Health			
Jackie Bennett	Council of Mortgage Lenders			
Jill Meara	Health Protection Agency	Y	Y	Y
John Swanson	National Grid	Y	Y	Y
Jonathan Stopes-Roe	Department of Health			
Michael Jayne	Nottingham Trent University / Royal Institution of Chartered Surveyors			
Mike Clark	Electrical Safety Council			
Mike Dolan	Mobile Operators Association		Y	Y
Mike O'Carroll	Independent			
Nigel McMahon	Department of Health, Social Services and Public Safety Northern Ireland			
Nigel Westaway	Facilitator	Y	Y	Y
Patricia Keep	Department of Health	Y	Y	Y
Paul Bicheno	Institution of Engineering and Technology	Y		
Peter Roberts	Energy Networks	Y	Y	
Peter Wilkinson	Facilitator		Y	Y
Richard Hughes	Association of Manufacturers of Domestic Appliances		Y	
Rod Robson	Department of Enterprise, Trade and Investment Northern Ireland			
Roger Coghill	Coghill Research Laboratories	Y	Y	
Ross Hayman	National Grid			
Sally Sims	Oxford Brookes University			
Simon Turner	Facilitator	Y		

		DWG	SF	PG
Steph Tuffee	Golder Associates			
Stephen Wall	Welsh Assembly Government			
Steve Davies	Department of Energy and Climate Change			
Stuart Conney	Department of Health	Y	Y	Y
Theresa Donohue	Department of Communities and Local Government			
48		15	19	10

SAGE is funded equally by the Department of Health, CHILDREN with LEUKAEMIA, and the electricity industry (the electricity industry share is split with two-thirds coming from National Grid and one-third from Energy Networks Association). When it has been necessary for the Funders to meet, DH has been represented by Stuart Conney and Pat Keep, CHILDREN with LEUKAEMIA by Caroline Hampden-White, and the electricity industry by John Swanson.

13 Acronyms and abbreviations

AC	Alternating Current
ACE	Association of Consulting Engineers
ALL	Acute Lymphocytic leukaemia
ALS	Amyotrophic Lateral Sclerosis, the commonest form of Motor neurone Disease
AM	Arithmetic Mean
AMDEA	Association of Manufacturers of Domestic Electrical Appliances
BERR	Department for Business, Enterprise and Regulatory Reform (no longer in existence)
BIS	Department for Business, Innovation and Skills
BRE	Building Research Establishment
BS	British Standard
BSI	British Standards Institution
CIBSE	Chartered Institute of Building Service Engineers
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)
DECC	Department for Energy and Climate Change
Defra	Department of Food and Rural Affairs
DH	Department of Health
DNO	Distribution Network Operator
DTI	Department of Trade and Industry (no longer in existence)
DWG	Distribution Working Group (within SAGE)
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)
EPRI	Electric Power Research Institute
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)
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
MCB MF MND MOA	Miniature Circuit Breaker Magnetic Field Motor Neurone Disease Mobile Operators' Association
NCRP NFU NI NICE NRPB	National Council on Radiation Protection and Measurements (US body) National Farmers' Union Northern Ireland National Institute for Health and Clinical Excellence National Radiological Protection Board (now part of HPA)
ODPM Ofgem	Office of the Deputy Prime Minister, now DCLG Office for Gas and Electricity Markets
PLP PME	Power Lines and Property (SAGE Working Group) Protective Multiple Earthing
QALY	Quality Adjusted Life Years
RCBO RCD RCM RCMS RF RIA RIBA RICS RPD	Residual Current circuit Breaker with Overload protection Residual Current Device Rate of Change Metric Rate of Change Metric Standardised Radio Frequency Regulatory Impact Assessment Royal Institution of British Architects Royal Institution of Chartered Surveyors Radiation Protection Division (of HPA)
SAGE SF	Stakeholder Advisory Group on ELF EMFs Science Forum (within SAGE)
T THD TWA	Tesla (unit of magnetic field) Total Harmonic Distortion Time Weighted Average
UKCCS	United Kingdom Childhood Cancer Study
V V/m or V m^{-1}	Volt (unit of electrical potential difference) Volt per metre (unit of electric field)
WHO	World Health Organization
μT	Microtesla (unit of magnetic field)

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 Assessment represents a record and a distillation of the discussions that have taken place within SAGE. Although reflecting a large degree of agreement, 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. 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 are a part of the process, informing the debate and supplying 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 this Assessment, as that is a matter for Government as a whole to consider once it has received the Assessment.

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