Investigation and Identification of Sources of Residential Magnetic Field Exposures in the United Kingdom Childhood Cancer Study (UKCCS)

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ABSTRACT

The Residential Sources Study was set up to investigate the sources of power frequency magnetic fields that contributed to average residential exposure estimates of 0.2 μT and above in the UK Childhood Cancer Study (UKCCS). The work was carried out by the National Radiological Protection Board (NRPB), now the Radiation Protection Division (RPD) of the Health Protection Agency (HPA), on behalf of the Leukaemia Research Fund Epidemiology and Genetics Unit at the University of York (EGU), as part of an extension of the UKCCS EMF Hypothesis – that exposure to extremely low frequency electromagnetic fields (specifically power frequency magnetic fields) may play a role in the aetiology of childhood cancer. The study is covered by the agreement made on 30 January 2003 between EGU as custodians of the UKCCS data, the Secretary of State for Trade and Industry, and the Energy Networks Association. There were two stages to the project; in Stage 1 the main objective was to identify power frequency magnetic field sources in the neighbourhood of the homes that might explain the UKCCS residential exposures. When there was no obvious explanation for the high exposure, the home and corresponding match were nominated for Stage 2 of the study, involving an internal inspection. At the start of Stage 1, the original UKCCS data were reviewed and verified, and 196 homes were identified for the study, comprising 83 matched case-control, high (≥ 0.2 μT) - low (< 0.2 μT) exposure pairs and 2 dual high pairs from the UKCCS analysis paper published in the Lancet, and 26 extra homes (including 8 complete pairs) that were ineligible for the analysis. In the period between March and June 2003, all the sites were visited to identify and evaluate potentially significant magnetic field sources in the vicinity of the properties. Records showing overhead and underground distribution mains circuits, and service connections, were provided by the electricity industry. The Stage 2 assessment was restricted to the homes which were occupied by the original UKCCS study homeowner and who gave written consent for participation in the Residential Sources Study. This report describes the source categories which account for elevated residential exposure in the UK Childhood Cancer Study. The findings offer an initial technical basis for possible options for mitigating EMF exposure in the UK.

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EXECUTIVE SUMMARY

The purpose of the Residential Sources Study was to identify the sources of power frequency magnetic fields that contributed to average residential exposure estimates of 0.2 μT and above in the UK Childhood Cancer Study (UKCCS).

There were two stages to the project; in Stage 1 the main objective was to identify power frequency magnetic field sources in the neighbourhood of the homes that might explain the UKCCS residential exposures; when there was no obvious explanation for the high exposure, the home and corresponding match was nominated for Stage 2 of the study, involving an internal inspection.

In Stage 1 of the study, the original UKCCS data were reviewed and verified, and 196 homes were identified for investigation, comprising 83 matched case-control, high (≥ 0.2 μT) - low (< 0.2 μT) exposure pairs and 2 dual high pairs from the UKCCS analysis paper published in the Lancet, and 26 extra homes (including 8 complete pairs) that were ineligible for the analysis. One hundred and two homes had average residential exposure estimates of 0.2 μT and above, of which 21 homes were 0.4 μT and above, and 94 homes had exposures less than 0.2 μT (Table 1). On the basis of scoping work and a pilot survey carried out with the assistance of National Grid Transco (NGT), a Stage 1 home assessment protocol was developed to identify and evaluate potentially significant magnetic field sources outside the properties. The Epidemiology and Genetics Unit at the University of York (EGU) approved the protocol in March 2003, and research staff from the National Radiological Protection Board (NRPB) now the Radiation Protection Division (RPD) of the Health Protection Agency, visited the sites between March and June 2003. Records showing overhead and underground distribution mains circuits, and service connections, were provided by the electricity industry. In Stage 1, the aim was to identify the homes where there was no obvious explanation for the elevated exposure. These homes would be investigated further during the next stage of the project by way of a protocol developed on the basis of the internal inspection of homes.

Stage 2 field trials were conducted in the homes of NRPB staff volunteers, and a risk assessment was carried out to mitigate risks associated with carrying out the internal inspection. NRPB prepared information about the study to address the informed consent requirement, and to take account of advice from NRPB's Radiation, Risk and Society Advisory Group. The Stage 2 procedures were approved in April 2004. At the end of the first stage, 119 homes were identified for possible entry into Stage 2, including 6 intermediate exposure homes (≥ 0.1 μT < 0.2 μT) and 6 homes with high net currents in distribution mains circuits or service connections. Twenty-one homes at or above 0.2 μT were excluded from Stage 2 because the exposure was adequately explained by an identified source at Stage 1. EGU was able to approach 39 homes where the original family was still in residence, and where the visit was considered appropriate in the light of personal circumstances. Stage 2 assessments were completed in the 19 homes whose

owners provided written consent. The final evaluation was based on all the available study information.

The approach of the analysis is that there is likely to be a dominant source of exposure to magnetic fields. In the 102 homes with exposure estimates at or above 0.2 μT, the most common source of the elevated exposure was connected with the final low voltage (LV) supply to the home, estimated to account for 77% of all exposures. The largest source category was possible internal wiring faults / services net currents arising from unbalanced currents, accounting for an estimated 32% of the high exposures. Twenty percent of the exposures were due to high voltage (HV) overhead lines operating at 132 kV and above. Net currents in LV distribution mains cables, accounted for 16% of the exposures, with homes often associated with short or no front gardens. The other attributable sources were LV open wire overhead lines (accounting for 4% of the exposures), operating appliances inside homes (3%), 275 kV cables (2%) and an electrified railway (1%). The remaining 22% of exposures were homes in which a number of possible LV sources could have explained the exposure, including net currents in LV distribution mains circuits and services, internal wiring, and overhead distribution mains circuits and appliances.

In the 21 homes with exposure estimates of 0.4 μT and above, LV sources taken together accounted for 57 % of the exposures (12 out of 21 homes). The most common individual source of the exposure was HV overhead lines (43 %) and possible internal wiring faults / services net currents (33%). The remaining exposures were attributable to net currents in LV distribution mains cables, and a combination of LV sources.

No 11 to 66 kV lines and cables were represented in the exposures at or above 0.2 μT and in only one situation was a local area substation possibly related to an elevated exposure. The findings of this study are also consistent with the original UKCCS conclusion that night storage heaters and underfloor heating were rare sources of elevated exposure.

The study is consistent with others that have reported an association between type of house and exposure. The most likely explanation is that terraced homes and flats tend to be located closer to LV distribution circuits than other types of homes and thus to have the potential to be influenced by load and net currents in these circuits. There is also a greater propensity for unbalanced currents to develop in terraced homes and flats, which is likely to be due in part to shared service arrangements. The potential for net currents to develop appears to be an important aspect of elevated exposure. Almost twice as many high exposure homes were located on street corners, as compared to the low exposure homes, possibly because of the greater concentration of distribution mains cables at street corners.

A number of epidemiological studies have explored whether there is a link between power frequency magnetic fields and childhood cancer. With wider availability of reliable instrumentation, most recent studies have tended to assess exposure on the basis of measurements, however distance from power lines has also been used as a proxy for exposure. If magnetic field exposure is the relevant risk factor then this study highlights the importance of measurement-based approaches over the proxy of distance from power line, as the use of a distance proxy could lead to appreciable misclassification of exposure. If, on the other hand, the risk is related to another characteristic of living near to power lines and not magnetic fields, then magnetic field measurements in population-based studies are likely to be a poor proxy for the relevant exposure.

The association between childhood leukaemia and residential power frequency magnetic fields has led to interest in possible precautionary measures to reduce exposure. The results of this study provide an initial technical basis for the research, engineering, planning and communications options which might be considered in reducing exposure to magnetic fields in homes. Assuming that the sources identified are representative of the causes of elevated exposures in homes in the UK, a number of possible options have been highlighted on which discussion of mitigation measures might focus.

CONTENTS

1 INTRODUCTION

In 2001, the independent Advisory Group on Non-ionising Radiation (AGNIR) noted the epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children[1]. Also the International Agency for Research on Cancer (IARC) concluded that there is limited epidemiological evidence that residential magnetic fields increase the risk of childhood leukaemia[2.] The basis for these views comes largely from the international pooled epidemiological study analysis of Ahlbom *et* al[3], which provided evidence for the possibility of a doubling of risk of leukaemia in children whose home was assessed to give rise to an average exposure of 0.4 μT and above. In a separate but overlapping pooled analysis published by Greenland *et al*[4], the threshold level for a possible raised risk was reported to be 0.3 μT. In 2004, the National Radiological Protection Board now the Radiation Protection Division (RPD) of the Health Protection Agency (HPA), in its Advice on Limiting Exposure to Electromagnetic Fields (0-300 GHz)[5], recommended the adoption of the EMF exposure guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). At the same time, NRPB recognised the concerns about possible effects of exposure to EMFs, in particular power frequency magnetic fields, and the view of NRPB was that Government should consider the possible need for further precautionary measures in respect of exposure of children.

In the UK the largest body of residential exposure information is available from the electromagnetic fields (EMF) part of the United Kingdom Childhood Cancer Study (UKCCS) which was published in the Lancet in 1999[6], and was included in the pooled analysis of Ahlbom *et al*[3]. The primary UKCCS analysis was based on household and school magnetic field measurements on 2226 matched case-control pairs. The study provided no evidence that exposure to magnetic fields associated with the electricity supply increases risks for childhood leukaemia, cancers of the central nervous system, or any other childhood cancer. However, it contributed little evidence on whether exposure at 0.4 μT and above increases risk. Only a small proportion of the population in the main analysis published[6] had total exposure estimates of 0.2 μT and above – 39 cases and 44 controls, and 8 cases and 9 controls had exposure estimates of 0.4 μT and above.

Although there are a number of possible approaches to characterising exposure, the metric adopted by the UKCCS investigators was the time-weighted average exposure during the year preceding diagnosis - a measure of the field strength weighted with duration of exposure at various locations. The bed, school and home non-bed exposures were estimated by measurements in the child's bedroom, living room and school, weighted for the relative time spent in these areas, as recorded in an EMF questionnaire. The exposure estimates were based on a Phase 1 assessment (P1) which applied to all study subjects and comprised in order: *i)* three 3-min spot measurements taken in the centre of the child's bedroom (SR), at the centre of the child's bed (BD), and on the centre of the child's pillow (PL); *ii)* a 90-min measurement taken in the centre of the main family room (FR); *iii)* a repeat of the three spot measurements after the 90-min measurement. In Phase 2 (P2) of the study, for all children indicated by Phase I to be in the top 10% of exposures (taken as equal to or greater than 0.1 μT) and the matched children, longer term measurements were required to give more precise exposure estimates for the elevated exposures, The P2 measurements comprised: *i)* four 3-min spot measurements taken at the centre of the family room (FR), at the centre of the child's bed (BD), at the centre of the pillow (PL) and at the bedside position (ES) to be used for the 48-hr measurement; *ii)* a 48-hr measurement taken by the side of the middle of the child's bed (ET); *iii)* a repeat of the four spot measurements after the 48-hr measurement. For both Phase 1 and Phase 2, all measurements apart from those made on the bed were performed with the instrument placed at a height of 1m from the floor in a polypropylene stand and at least 1 m from any operating appliances. Any operating appliances within 1 m of an appliance were reported in the EMF questionnaire. Resultant magnetic fields in the broadband range 40-800 Hz were measured with Emdex II magnetic field meters (Enertech Consultants Ltd, Campbell, CA).

The background field inside homes is usually defined as the ambient field away from operating appliances. The UKCCS measurement protocol was designed to reflect the influence of the background field on exposure by making measurements at least 1 m from any operating appliances, except in the vicinity of the child's bed. When possible, the measurements were made under typical overnight conditions for appliances and lights in the home. P2 measurements were made at times agreed with the appropriate electricity company as being typical for operation of the local distribution system. Where night storage heaters or underfloor heating were identified, the P2 measurements included a period when the appliance was in use. Information was also requested from the electricity companies to establish if they knew of any reason why circuits would not be operating typically, and for the homes near to high voltage power lines, line load data were requested to reconstruct historical exposure.

In November 2000, the UKCCS investigators published a subsidiary analysis of residential proximity to power lines[7]. The analysis used the information provided by the electricity companies in the form of the External Sources Questionnaire (ESQ). The questionnaire enabled the identification of power lines and other components of the electricity supply system in the vicinity of homes. The results supported the conclusions reached in the primary analysis; that is, there was no evidence that proximity to power lines was associated with increased risk of childhood cancer.

High voltage power lines are recognised to be important sources of exposure, in homes located near to them[8]. However at the time of the publication of the AGNIR report only a small proportion of the high exposures in the UKCCS could be linked to high voltage power lines near the home as reported on the ESQ. Away from high voltage lines, power frequency magnetic fields in homes are normally associated with appliances and internal electrical wiring, and external distribution and supply circuits[9]. However, few data related to the sources of elevated residential exposure in the UK exist, and the Board of the NRPB expressed the view that there was a need to understand better the factors that might result in higher residential exposures in the UK[10].

This report describes the Residential Sources Study which was set up on the basis that it is of clear interest to determine the sources of exposure on the assumption that exposure to magnetic fields might increase the risk of childhood cancer. The work is covered by the agreement made on 30 January 2003 between EGU as custodians of the UKCCS data, the Secretary of State for Trade and Industry, and the Energy Networks Association. A Study Steering Group with UKCCS, Department of Trade and Industry, Department of Health and Electricity Industry representatives, was set up to oversee the progress of the study.

The study is conducted under the arrangement for furtherance of the original UKCCS research programme, and with the agreement of the UKCCS Management Committee, the body that has the authority to make decisions on the use of the data collected. This study was conducted under the umbrella of the original study where families had given permission to be contacted again. New residents were not approached.

There were two stages to the project; in Stage 1 the main objective was to identify power frequency magnetic field sources in the neighbourhood of the homes that might explain the UKCCS residential exposures; when there was no obvious explanation for the high exposure, the home and corresponding match was nominated for internal inspection in Stage 2 of the study, involving an internal inspection.

2 STAGE 1

The main objective of Stage 1 was to identify any power frequency magnetic field sources in the neighbourhood of the homes that might explain the UKCCS residential exposures. Homes with elevated exposures that were not explained by outside sources would be identified for possible inclusion in Stage 2 of the study.

2.1 Stage 1 protocol

The objectives of Stage 1 of the project are set out in the protocol described in Appendix A, and in summary are as follows: -

- To collate verify and review the existing UKCCS EMF questionnaire, measurement and exposure data.
- To carry out site inspections for 196 high ($\geq 0.2\ \mu T$) - low ($< 0.2\ \mu T$) exposure homes.

- To acquire circuit information from the electricity industry.
- To evaluate all available information and produce individual site reports.
- To resolve the source(s) of high exposure where possible and make recommendations on the course of action in Stage 2.

2.2 Review of original data

At the start of the study, the existing UKCCS information for all homes where the average residential exposure was 0.2 μT or above, and the homes of corresponding matched children, was drawn together and checked by EGU. These included homes of 85 matched case-control pairs from the published Lancet analysis[6], and 26 extra homes (including 8 complete pairs) that were ineligible for the UKCCS analysis published in the Lancet[6] (Table 1). In this study five homes were included which had high P1 and low P2 estimates; 3 of these were from the extra homes. Of the 26 extra homes ineligible for analysis, 10 of the original occupants were not living at the house measured during the period of interest, 7 had measurements for only one of the case / control pair and 9 involved pairs where the case turned out to be ineligible for the UKCCS study (date of diagnosis outside the dates of accrual for the study). The addresses were merged with the UKCCS EMF data in an ACCESS database, and queries were used to extract summary exposure information for each address, including P1 and P2 measurements, and information from the original UKCCS EMF and External Sources Questionnaires.

Table 1 UKCCS Source homes for the Residential Sources Study

UKCCS source homes	Residential exposure < 0.2 μT	Residential exposure ≥ 0.2 μT	Totals
Original Lancet analysis	83*	87** (19)	170
Matched pairs ineligible for the Lancet analysis	11***	5	16
Individual homes ineligible for the Lancet analysis	-	10 (2)	10
Totals	94	102 (21)	196

*includes 2 P1 high, P2 low exposure homes

**includes 2 dual high exposure pairs

***includes 3 P1 high, P2 low exposure homes

() exposure estimates ≥ 0.4 μT

2.3 Network information

To supplement the Stage 1 assessment the Distribution Network Operators (DNOs) were asked to supply details about the local and regional electricity supply network for each address, showing overhead or underground cables at any voltage including distribution mains records and details of the service connection to the property. They were also asked to identify whether circuits have changed since the time of the original study measurements.

A Network Information Form was designed with assistance from NGT and sent to the appropriate DNO. DTI and the Energy Networks Association assisted in issuing and retrieving forms. The addresses were also sent to NGT so that any HV transmission circuits could be identified. The form template is presented in Appendix A.

2.4 Site visits

As part of the Stage 1 evaluation, a report was prepared for each site containing the following information: -

- Site visit and network information.
- Photographs of the property and surroundings.
- Location map.
- Measurement profiles to identify current carrying conductors in the vicinity of the home.
- Summary review of the previously held UKCCS information.
- Source assessment and Stage 2 action.

The Stage 1 site visit procedures were proposed initially on the basis of scoping work that was carried out by NRPB at six locations in south and central England. The main objective was to conduct non-intervention assessments of the 196 sites to identify sources outside the homes that might explain the UKCCS residential exposure estimates. The procedures were refined by way of a pilot survey carried out with the assistance of scientific staff from NGT. Emdex II meters were used to record the magnetic flux density profiles in the public highway passing along the boundary and perpendicular to the property of interest using a LINear Data Acquisition (LINDA) system (Figure 1).

The LINDA system is a customised measurement wheel that is used with an EMDEX II meter to record magnetic field and distance along a path. A magnetic switch mounted on the LINDA wheel sends a signal to the REMOTE jack on the EMDEX II every 0.3 m of travel. Because the EMDEX II records data at a fixed rate, the operator can walk either slowly with the LINDA wheel to produce detailed measurements over a short distance or quickly to produce more generalised measurements over longer paths. Advice on survey practices and issues such as right to privacy, confidentiality, trespass and dealing with members of the public was prepared for survey staff. Letters of authorisation were issued by NRPB. The procedures were approved by EGU in March 2003.

Between 10 March and 10 June 2003, 102 site inspections were completed in the south of England and in Wales, and a further 94 visits were undertaken in the north of England and in Scotland between 24 April and 20 June 2003. The measurements were made using Emdex II meters calibrated at NRPB using a

Helmholtz coil facility, which has an uncertainty of ± 2.5% traceable to national standards. The overall accuracy of the meter in the range 1 – 10 μT is 10% ± 0.005 μT.

Figure 1 Recording a magnetic flux density profile using the LINDA system

For each site a report was prepared consisting of: -

2.4.1 Summary review

This part of the site report contains summary exposure information for the property, including P1 and P2 measurements, and information from the original UKCCS EMF and External Sources questionnaires.

2.4.2 Environmental report

This part of the report contains general environmental information about the home, including a description of the area, the type of housing, and the components of the electricity distribution and transmission circuits that were identified either during the survey, or from the network information provided by the DNO.

2.4.3 Photographs of the property

Photographs were taken of the layout of the site and the visible local electricity circuits. The photographs provide reference information about each site, including the housing and the surrounding area.

2.4.4 Location map

Ordnance Survey (OS) Superplan digital maps were supplied by NGT for each site and used initially to assist in locating the property and in Stage 1 to annotate the position of the LINDA profiles.

2.4.5 LINDA profiles

The LINDA profiles outside the homes provided important information during Stage 1 for the assessment of potential field sources. The profiles across the front boundary of properties were used to detect possible net currents in the LV service connection to a property. The profiles perpendicular to the house boundary were used to detect net currents in the LV distribution mains cables and other current carrying conductors that pass the front of properties.

2.4.6 Summary evaluation

A summary evaluation for each site was presented in the form of a spreadsheet at the end of each site report. When a source was identified, either during the site visit or from the network information, it was recorded on the spreadsheet, with its distance from the home. The results of the Stage 1 visits were presented in a progress report to the Steering Group in October 2003[11]. The source evaluation is described in the following section.

2.5 Stage 1 interpretation

The Stage 1 information was evaluated along with the original study data, in order to identify the sources outside the homes that might explain the UKCCS P1 or P2 elevated exposure estimate.

The basis for evaluating the contribution of a particular source outside a home was to use the Stage 1 measurements to predict the field produced by the source inside the property, and compare the predicted field with the original P1 and P2 measurements. The P1 and P2 reference levels were the mean magnetic field values recorded in the Family Room and Bedroom, and for P2 the 48-hr bedside (ET) measurement also.

2.5.1 Net currents in LV distribution mains and service cables

The net current in LV distribution mains and service cables is estimated using a simple modification of Ampère's Law: -

$$I = (B \times d) / 0.2 \qquad (1)$$

Where I – net current in amperes; B – magnetic flux density in μT and d – distance from the source in m.

The contribution of a particular cable source is estimated from the maximum horizontal component of magnetic flux density aligned at right angles to the cable – when the Emdex meter is used in a LINDA system this corresponds to the field recorded by the Z coil. An adjustment is made for the approximate height of the measurement and the depth of the cable.

For a LV circuit that passes the front of a property, the current calculated in equation (1) is used to predict the field at the front and rear of the property. The distance from the source is adjusted to allow for cable depth and the estimated height of the original measurements inside the property. The horizontal offset of the meter from the LINDA wheel gives a systematic distance error of 0.1 – 0.2 m depending on how the system is used.

2.5.2 Other sources including HV cables and lines

The net current considerations described in Section 2.5.1 apply to underground cables with bundled phases. The field levels from separated-phase cables, including overhead lines, are less easy to predict. Where possible the contribution from these types of sources was estimated by extrapolation of the Stage 1 magnetic flux density profiles measured near to the property. For HV overhead lines, the line load database predictions from the original study were referred to where possible. The contribution of substations was assessed by magnetic flux density measurements at the site.

3 STAGE 2

The main purpose of Stage 2 was to investigate further the homes where external measurements provided no explanation for the elevated exposure. This section of the report describes the selection of homes for Stage 2, the process of developing the procedures for the internal inspection and the evaluation of the Stage 2 information.

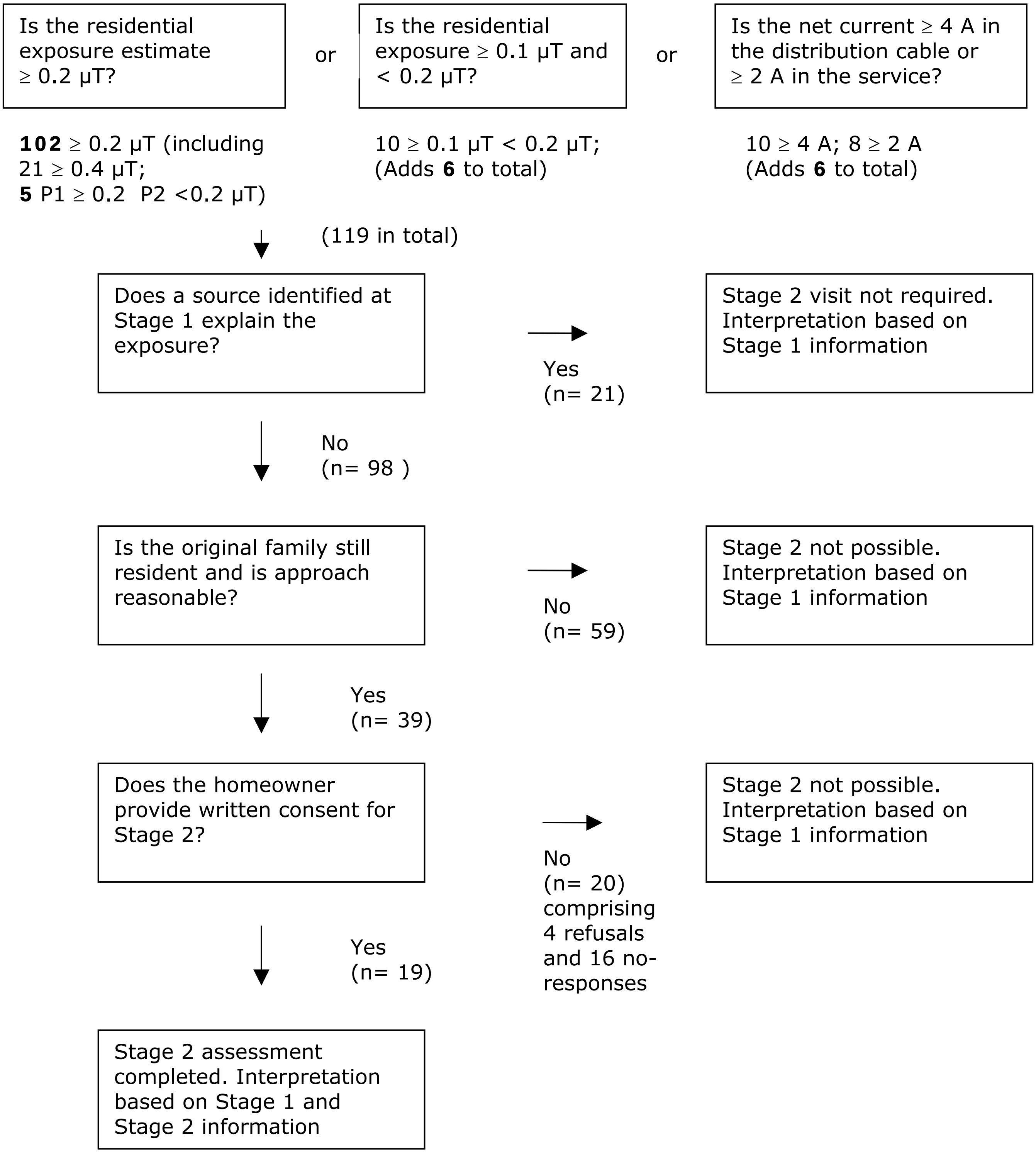
3.1 Selection of homes

During the period between November 2003 and April 2004, the Stage 1 information for each site was reviewed with the assistance of an EMF specialist from NGT.

If a source field prediction (see Section 2.5) was greater than or equal to the original measurements the source was considered to provide a possible explanation for the elevated exposure, and the home was assigned a low Stage 2 priority. If the prediction was lower, the source was categorised as unexplained and the home assigned a high Stage 2 priority. A number of homes were assigned medium priority on the basis of interest in the original measurements i.e. P1 high: P2 low, and high net currents in LV distribution mains and service circuits. Net currents of 4 A in distribution mains cables and/or 2 A in service cable were chosen as cut-points based on the Stage 1 net current distributions (Appendix C) and published data[12,13].

Figure 2 summarises the selection process for Stage 2 homes. At the end of Stage 1, 119 homes were identified for possible entry into Stage 2, including 6 intermediate exposure homes (≥ 0.1 μT < 0.2 μT) and 6 homes with high net currents in distribution mains circuits or service connections. Twenty-one homes with exposure estimates ≥ 0.2 μT were excluded because the exposure was adequately explained by a source identified at Stage 1. EGU was able to approach 39 homes where the original family was still in residence and an approach was deemed reasonable in the light of personal circumstances.

Figure 2 The Stage 2 selection process



3.2 Stage 2 protocol

An initial protocol was presented for discussion in the progress report to the Steering Group in October 2003[11]. The protocol focused on the technical requirement of Stage 2 to identify the important source associated with the elevated exposure based on an internal inspection of the home. The protocol was refined subsequently on the basis of consideration of the UKCCS subjects, and evaluation of the homes with the NGT EMF specialist. A risk assessment was undertaken to identify and mitigate risks associated with visiting the homes. Information about the study was prepared to address the informed consent requirement for visiting the homes. Field trials were completed in the homes of NRPB staff volunteers to check and refine the procedures, and to receive feedback on the methods and the information provided about the study. The process of developing the Stage 2 protocol is summarised in Figure 3, and considered in the following sections.

3.2.1 Technical scope

The potential sources of elevated magnetic fields considered in the initial design of Stage 2 protocol were point sources such as operating appliances inside the home; net currents in electricity, gas and water mains, faults in a ring main, and lighting and wiring faults. External sources such as power lines and cables were covered by Stage 1 unless there was some temporal variability suspected.

It was concluded that each home should be subject to a series of structured and consistent measurements. Meters would be used to log the variation of the field during the visit, and more investigative measurement approaches would be used to discover sources of elevated fields as necessary.

In order to locate and identify the sources of elevated exposure the magnetic fields would be measured simultaneously inside the home and adjacent to known external sources. In order to identify possible wiring faults the magnetic field levels would be measured under various load conditions, at the same time measuring currents at various positions on the incoming supply. It would be necessary to consider the wiring arrangements in each home, and in particular to assess the service connection and earthing for the consumer's installation (e.g. termination details and cross bonding etc).

Finally, it has also been suggested that small voltages arising on grounded objects around the home provide a possible explanation for the association between homes with high magnetic field exposures and the incidence of childhood leukaemia[14]. In response, contact voltages would also be measured in this study.

3.2.2 Risk assessment

The NRPB risk assessment was an important part of the process of formulating the Stage 2 protocol. The approach taken was to identify the important risks that might be encountered in carrying out the Stage 2 site visits, assess the potential for the risks to arise, and make recommendations for appropriate action to remove or lessen the risk. Two key areas of risk were identified: -

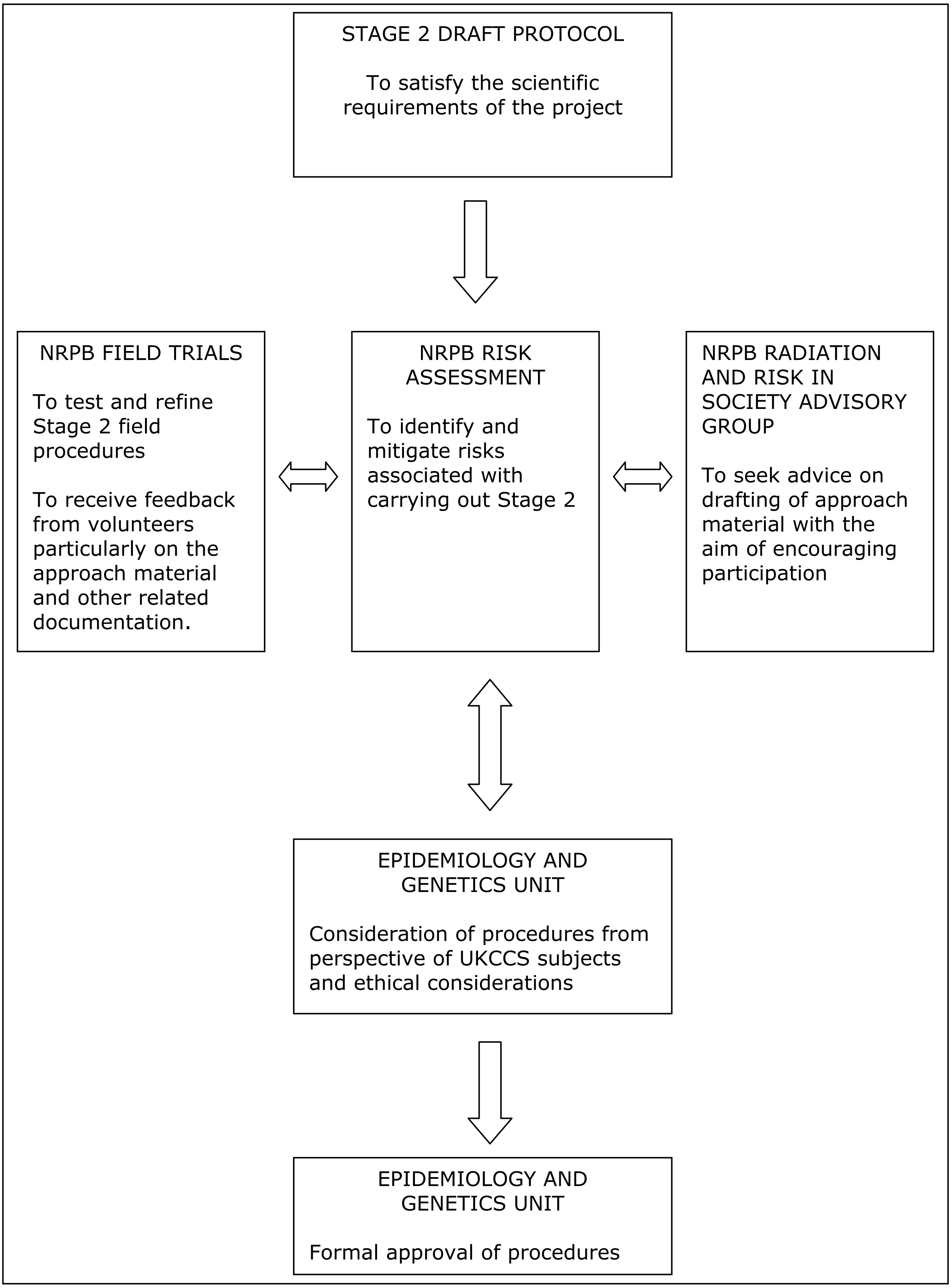
1) The advice given to homeowners in seeking informed consent. EGU agreed to approach the appropriate UKCCS families at the beginning of Stage 2. Informed consent was identified as an important requirement for NRPB's involvement in Stage 2.

2) The safety of individuals, and the possible damage to property. As the assessment involved the inspection and use of internal mains circuits, the electrical hazard to the householder and the survey staff needed to be considered.

Various information was prepared to reduce the risks likely to be encountered in the study. The information about the study prepared for homeowners needed to address the important requirement of informed consent. The families were asked to read this carefully before they agreed to participate. Other documents included Guidance Notes for Research Staff; a Wiring Report to be issued in the event of a suspected wiring fault; and a Summary of Measurements Report for the homeowners who chose to receive results.

To diminish the risks related to safety and property damage, procedural advice was given to research staff and a professionally qualified electrician was recruited on the Stage 2 research team.

Figure 3 Process of developing Stage 2 procedures



3.2.3 Field trials

Field trials were conducted in the homes of NRPB staff volunteers in order to check and refine the procedures, and to receive feedback from homeowners about the proposed methods and consent documentation. The procedures were revised to take into account the views of the volunteers. The main issues that needed to be addressed were the responsibility for safety and in the event of damage, and informed consent in relation to receiving results. NRPB accepted the responsibility for safety and accidental damage, and advice on the consequences of receiving results was made available.

3.2.4 Feedback from the Radiation, Risk and Society Advisory Group (R,RSAG)

A balance needed to be struck between measures to encourage participation in the study and measures to remove or lessen the identified risks. R,RSAG was consulted to provide advice on the drafting of information intended for study volunteers, with the aim of encouraging participation.

R,RSAG made a number of suggestions to make the information more comprehensible including more complete descriptions of the purpose of the study, the procedures and the organisations involved. The possibility of a free wiring inspection provided by the Electricity Industry, and a £50 disturbance allowance per household was added to encourage participation.

The protocol was sent to EGU in April 2004 where it was considered from the perspective of the UKCCS and the ethical arrangements for the study. Minor comments were received and the final protocol and supporting documents are presented in Appendix B.

3.3 Contact with homeowners

The underlying criteria for including homes in Stage 2 was that only original UKCCS families could be approached and that written consent was required. New residents would not be approached.

EGU checked the status of families and homes and was able to approach 39 at Stage 2 on the basis that the original families were still in residence and where the visit was considered reasonable in the light of personal circumstances. EGU began contacting households in May 2004. Families were initially contacted by telephone with those having exposure estimates $\geq$ 0.4 μT contacted first. Following this, families were sent the written information about the study (Appendix B), together with a consent form and prepaid return envelope. Two families had no telephone and were approached by post but did not respond. All but three remaining case families (whom were not contactable) were telephoned to ensure their child was well before being sent further details by post. Follow-up letters and information were sent to all families who had not responded by mid June. NRPB began contacting the families once the signed consent forms were received through EGU.

3.4 Site visits

In the period between May 2004 – March 2005, NRPB was able to visit 19 homes whose owners and occupants had provided written consent to participate in the study. The following sections describe the measurements that were made at each site. More details about the procedures are included in Appendix B.

3.4.1 Magnetic field measurements

On arrival at the home, EMDEX field logging meters were placed centrally in the family room and in the bedroom used for the original (UKCCS) measurements. The first aim was to determine the ambient exposure level, generally called the background, inside the home and establish whether the field was reasonably uniform throughout, which would tend to point to an important source outside the property. Higher field levels downstairs were used to corroborate whether the source was a distribution mains cable or overhead line. Localised fields, changing rapidly in space would be more indicative of point sources such as operating appliances located inside the home. Outside the home field-logging meters were placed as close as possible to distribution mains or service cables. The main current carrying circuits outside the house were located using the RD400 cable detector and a magnetic field meter. The Stage 1 LINDA profiles were repeated and extended where possible up to the boundary of the property. Spot measurements were then made in the corners of the rooms of interest, at least 1 m from walls and at 1 m above the floor level. These measurements were repeated with the lights switched on and with a 2 kW load placed on the nearest circuit. The electrician noted when the loads were put on circuits. Measurements were also recorded with the two-way lights (usually located on the landing or in the hall) switched on and off.

3.4.2 Electrical measurements

On arrival at the site, the positions of the incoming electricity, gas and water mains were located. In order to investigate the net currents in electricity, gas and water services, current loggers were attached at the various positions shown in Figure 4, subject to accessibility. The usual positions were the live phase conductor at a position between the meter and the main fuse (A), the live and neutral conductors in a similar position (B), the incoming service cable (C) and on the earth sheath (D). Spot measurements were also made either in the same positions to verify the readings on the meters or in other positions where logging meters could not be placed. The electrician completed a short report describing the supply characteristics and earthing arrangements for the consumer's installation. The forms used to complete the Stage 2 report are presented in Appendix B.

The instruments used to make the current measurements were Robin K2413F clamp meters and an AVO DCM300E earth leakage clamp meter. All had a measurement uncertainty of ± 0.33 % + 3 LSD traceable to national standards.

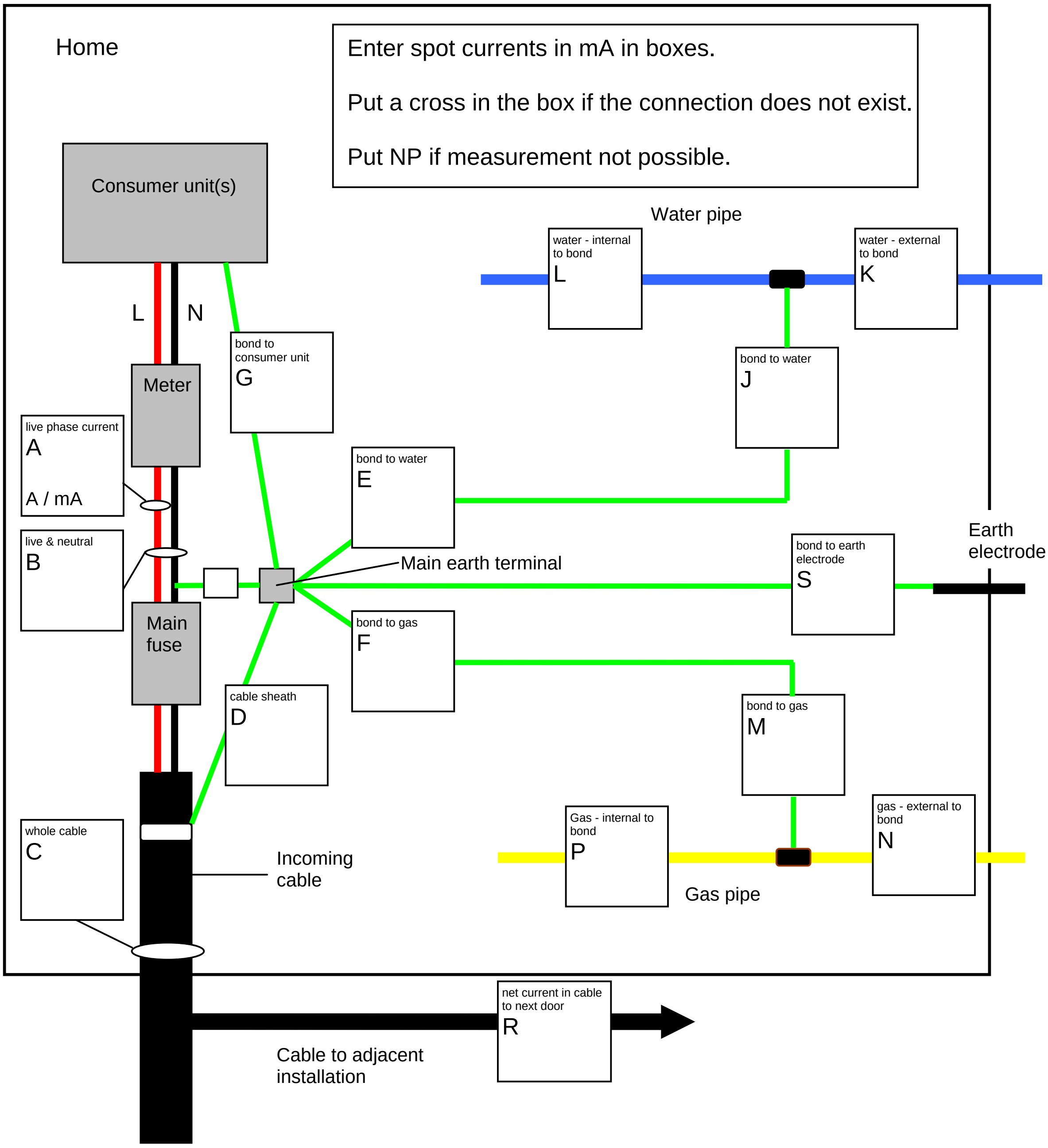
3.4.3 Open voltage measurements

Contact voltages were measured between the sink tap and plughole in the kitchen and bathroom sinks, and in the bath. The measurements were repeated with a 1 kΩ resistor connected across the meter terminals, to evaluate the source impedance and the current that would flow through a person in electrical contact with both drain and tap to be measured.

Voltages were also measured between the water pipe and electrical earth, the electrical earth and ground, the water main and ground, and the electrical earth and neutral.

The instrument used to make the voltage measurements was a Fluke 110 Digital Multimeter that had a measurement uncertainty of ± 0.04 % + 1 LSD calibrated by UK Accreditation Service (UKAS).

Figure 4 Position of current loggers and other current measurements



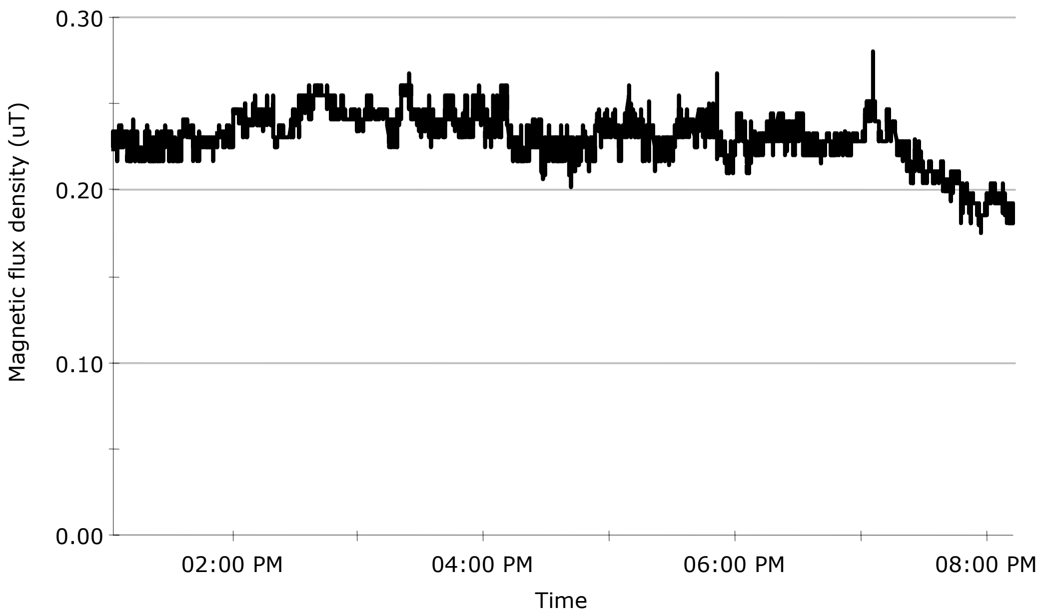
3.5 Stage 2 interpretation

The main aim of the study was to determine the important sources contributing to the elevated exposures observed in the original UKCCS study. Before addressing this question it was necessary to investigate whether or not the original P1 and P2 measurements could be replicated during Stage 2. The original UKCCS and Stage 2 measurements were compared, identifying where possible alterations to the property and / or wiring, and seasonal and diurnal effects.

In Stage 1, sources were identified outside the homes and measurements were made to assess the likely contribution to the field levels inside the home. In Stage 2 it was possible to refine the assessment by observing simultaneously the field levels inside the home.

In general reasonably uniform fields throughout the home tended to be indicative of large sources outside the home. Sources such as high voltage power lines were characterised by magnetic fields with fairly low short-term variability reflecting the relatively stable load currents that produce the magnetic fields. An example is shown in Figure 5.

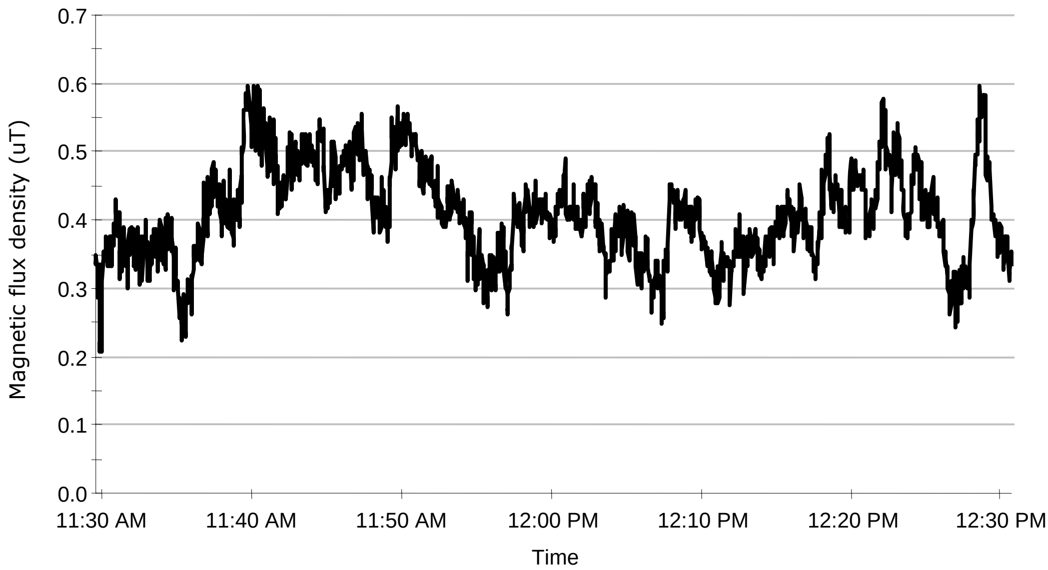
Figure 5 Magnetic field recorded in the centre of a bedroom in a home located at 105 m from a HV overhead transmission line (Mean 0.23μT, SD 0.01)



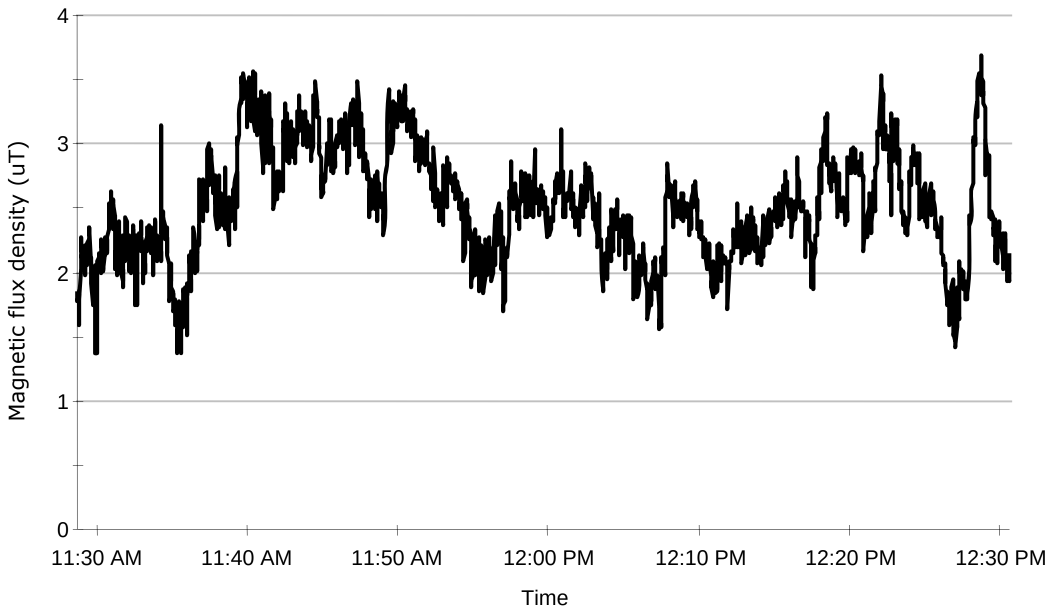
On the other hand, magnetic fields caused by net currents in distribution mains circuits tended to be more variable reflecting the complex relationship with the primary load currents. An example is shown in Figure 6.

Figure 6 Comparison of magnetic field recorded in a) the family room (Mean 0.41μT, SD 0.06) and b) outside on field logger close to a distribution main circuit

a)



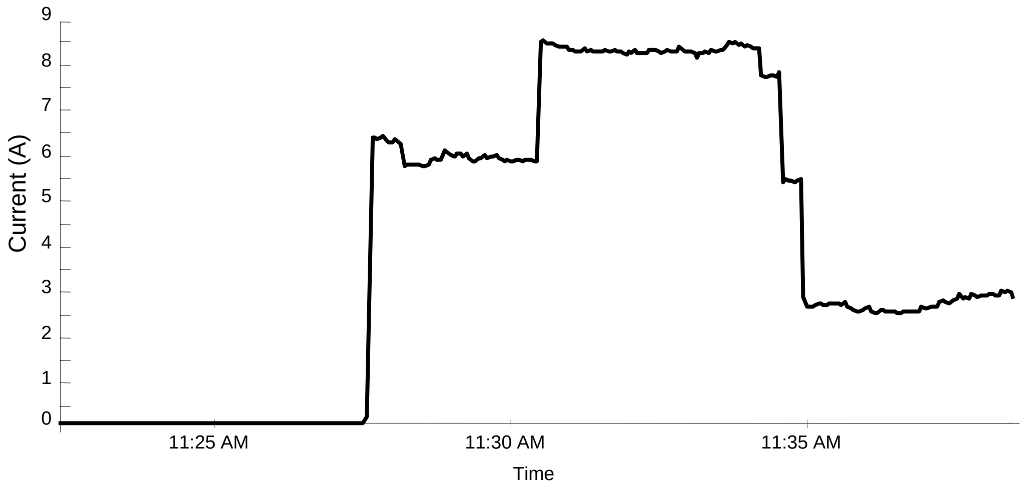
b)



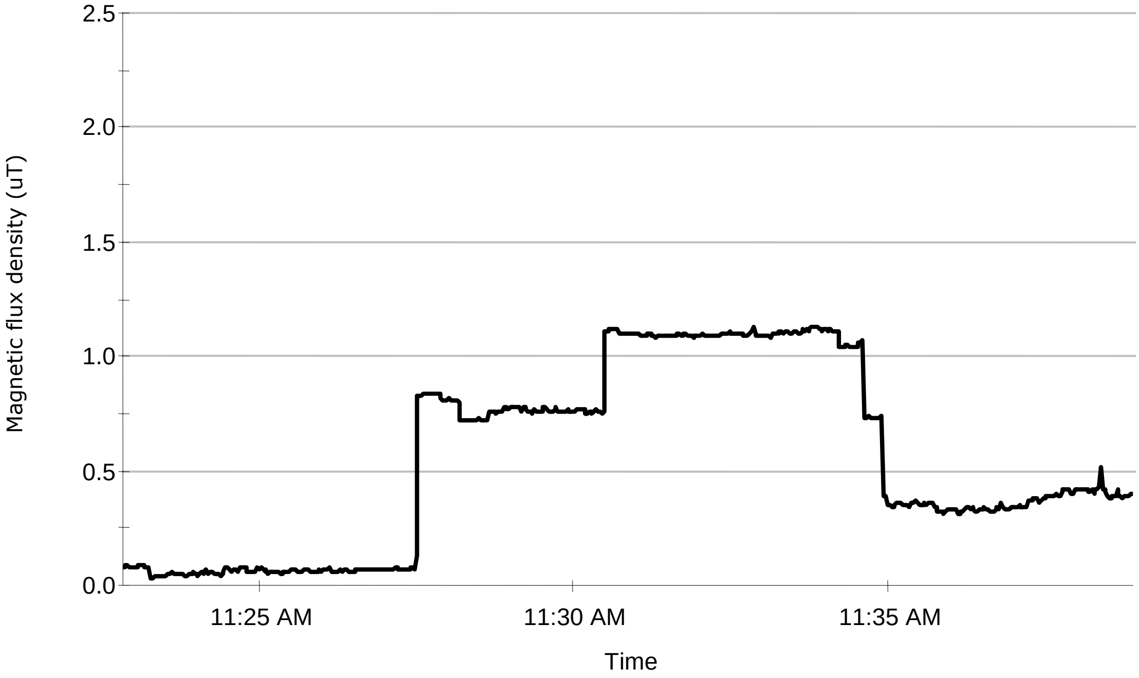
It was also possible to compare the traces from a field logger placed close to an external circuit with those from field loggers inside the home. Highly correlated traces such as those shown in Figure 6 provided evidence for the external circuit being the important source of the field inside the home.

Figure 7a) A net current of 8 A in the water pipe (approximately 3 A attributable to the 2 kW test load) recorded on the bond to waterpipe current logger; b) magnetic field levels exceeding 1 μT at the centre of the bedroom

a)



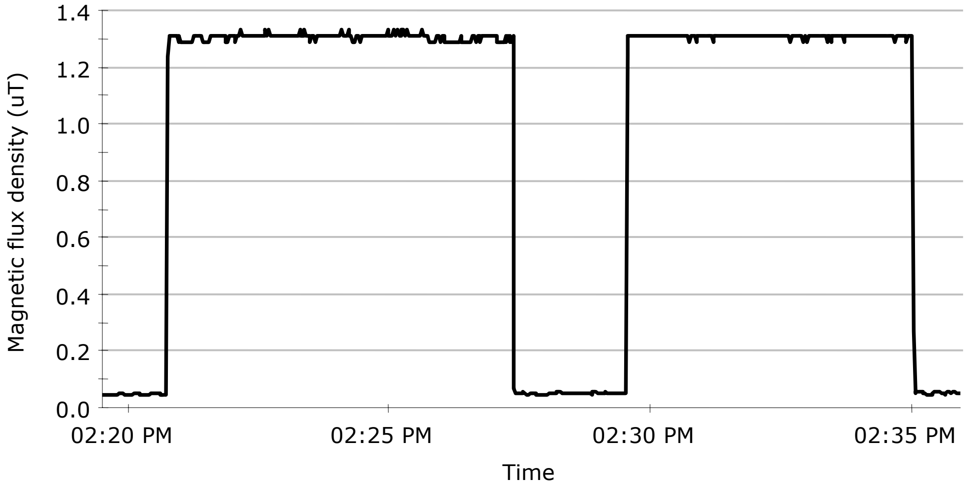
b)



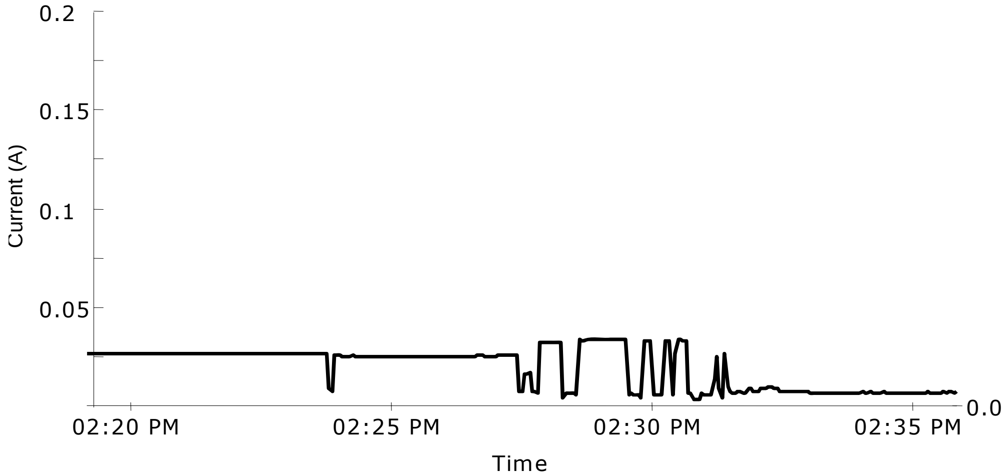
Inside the home it was possible to compare the currents recorded on the current loggers with the magnetic fields recorded on the field loggers under the test load conditions. An increase in net current accompanied by a simultaneous increase in field level suggested that net currents linked to a possible earth-neutral fault inside the home were the main sources of the elevated exposure. Figure 7 shows a situation where a net current of 8 A on the live-neutral log could be traced to a net current of 8 A on the conducting water main, and a corresponding rise of the field inside the house. If, on the other hand the field level increased and there was no corresponding increase in net current, this was more likely to reflect a ring main fault, especially if there was no earth bonding inside the home (Figure 8). The live-phase conductor, current logger trace was used as a time marker for the changing loads in the home during the Stage 2 assessment.

Figure 8 a) Magnetic field recorded in the living room when 2 kW load placed on circuit in living room at 2:21-2:27pm and 2:29-2:35pm compared with; b) net current recorded on the combined live and neutral current logger

a)



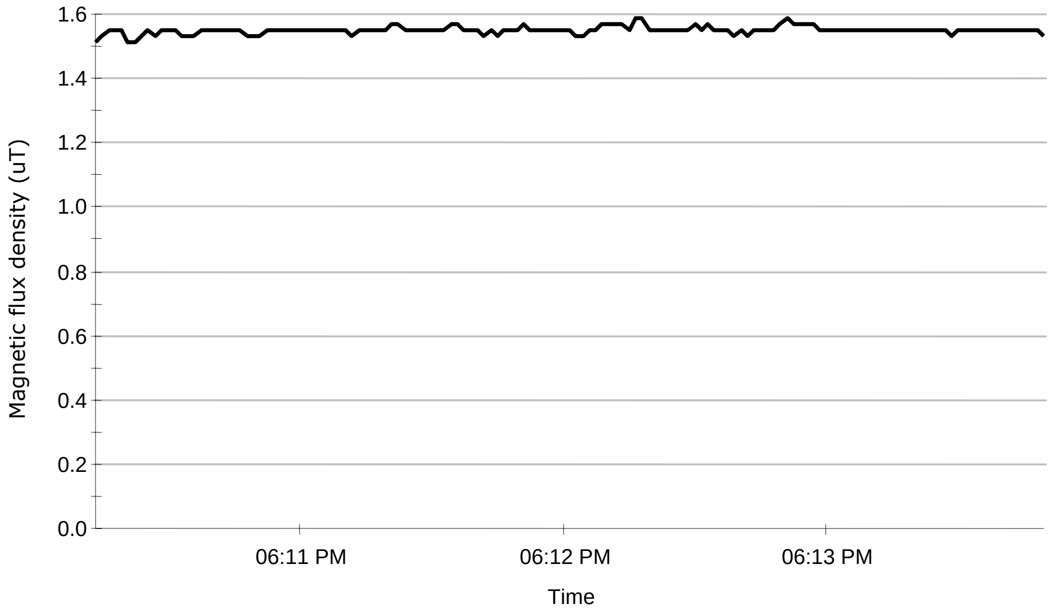
b)

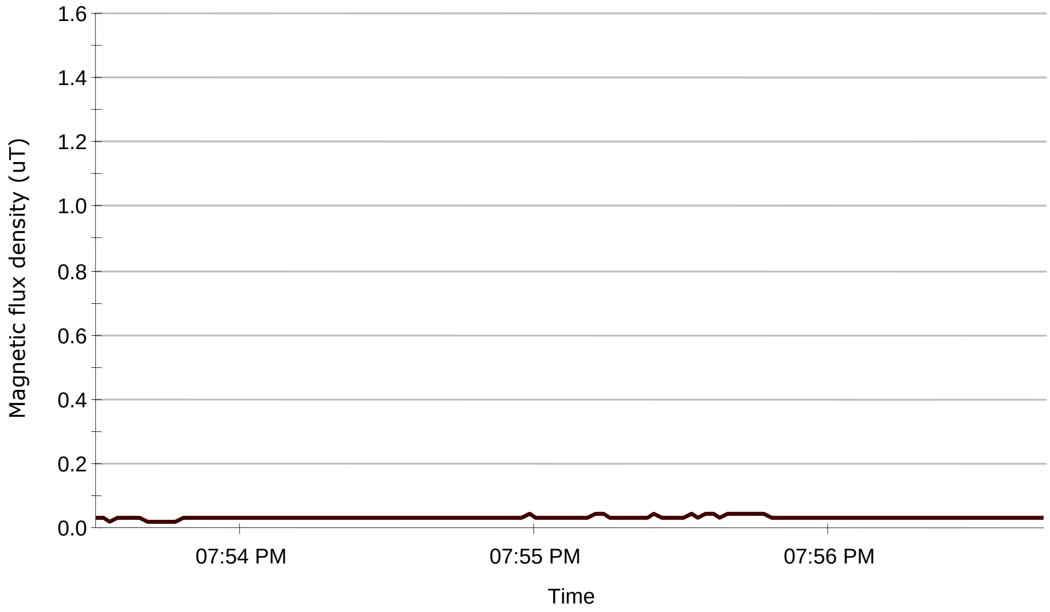


In a small number of situations isolated high P1 and or P2 spot measurements were attributed to the localised fields produced by point sources such as operating appliances in the home (Figure 9). Homeowners were asked whether any such appliance had been operating at the time of the original study measurements, and the original study EMF questionnaires were checked for any such evidence.

Figure 9 Spot measurement on bed with a) TV operating at 15 cm b) same measurement when TV was off

a)

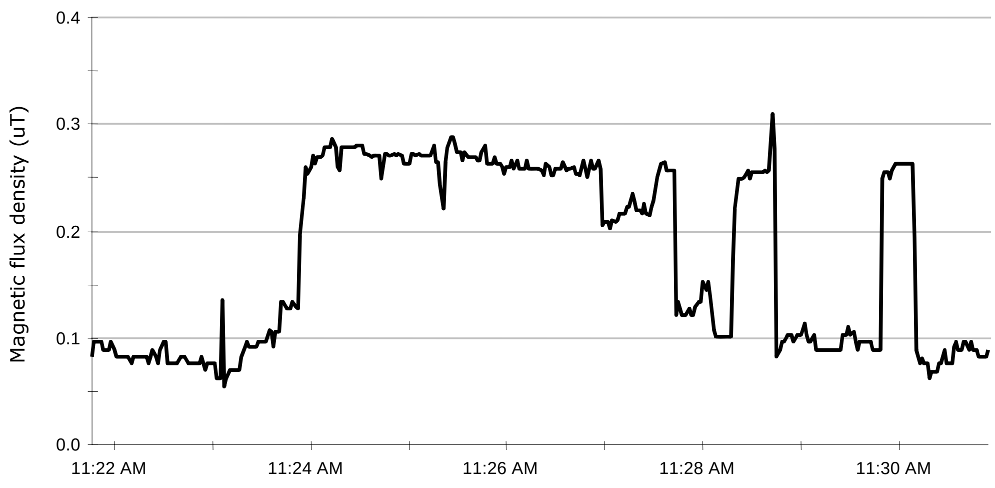




It was possible in some instances to identify a number of sources that might explain the original exposure level in the home. Figure 10 shows the magnetic flux density and current logs from a home which has been assessed to include contributions from net currents in a distribution main circuit located at 1 m from the front of the home, net currents on live-neutral conductors inside the home, and a suspected ring main fault. The effect of switching the test load on can be seen on the magnetic field and load current traces (Figures 10a and 10b). Net currents of up to 400 mA were measured at the live–neutral conductors at the service entrance (Figure 10c) but these were not enough to explain the increase in field level. Larger currents possibly associated with a ring main fault provide the most likely explanation. The trace recorded close to the distribution main cable at the front of the home is shown in (Figure 10d) and contributed to a background level of about 0.1 μT inside the home (Figure 10a).

Figure 10 a) Magnetic field recorded in living room with contributions from several sources b) live phase current trace c) Net current measured on the live–neutral conductors at the meter d) Magnetic flux density recorded close to the distribution main cable at 1 m from the front of the house

a)



b)

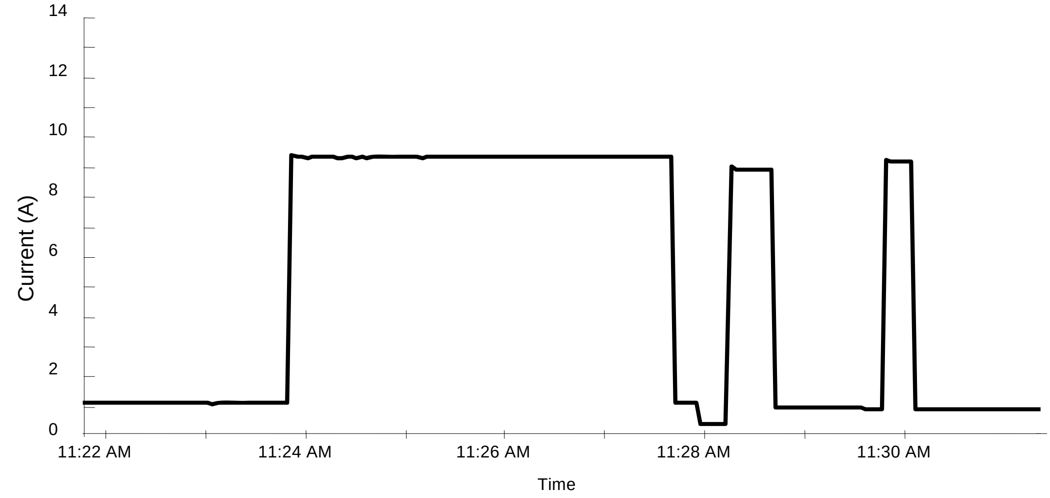
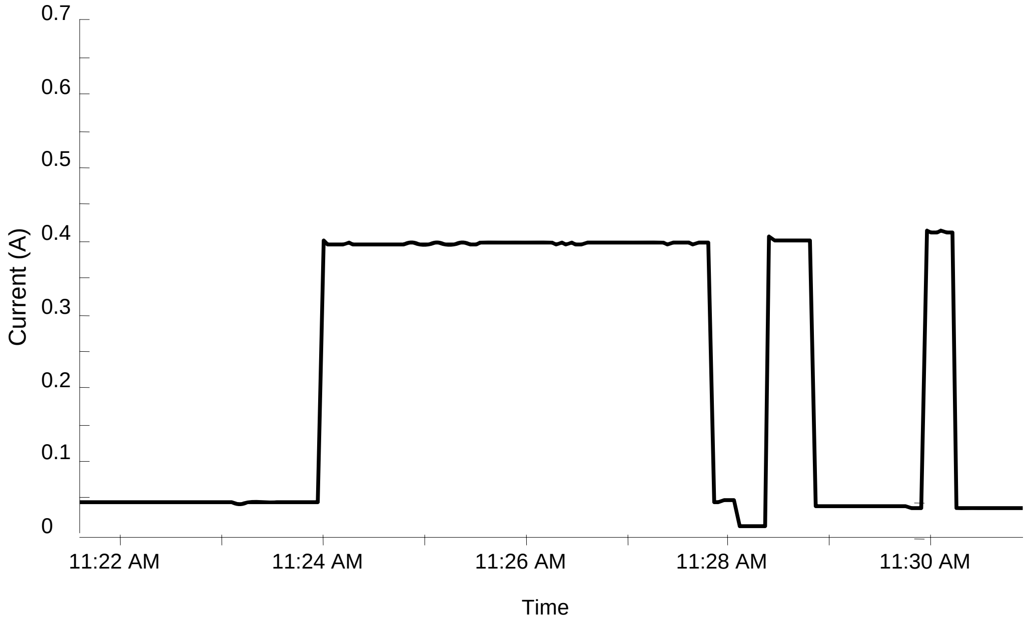
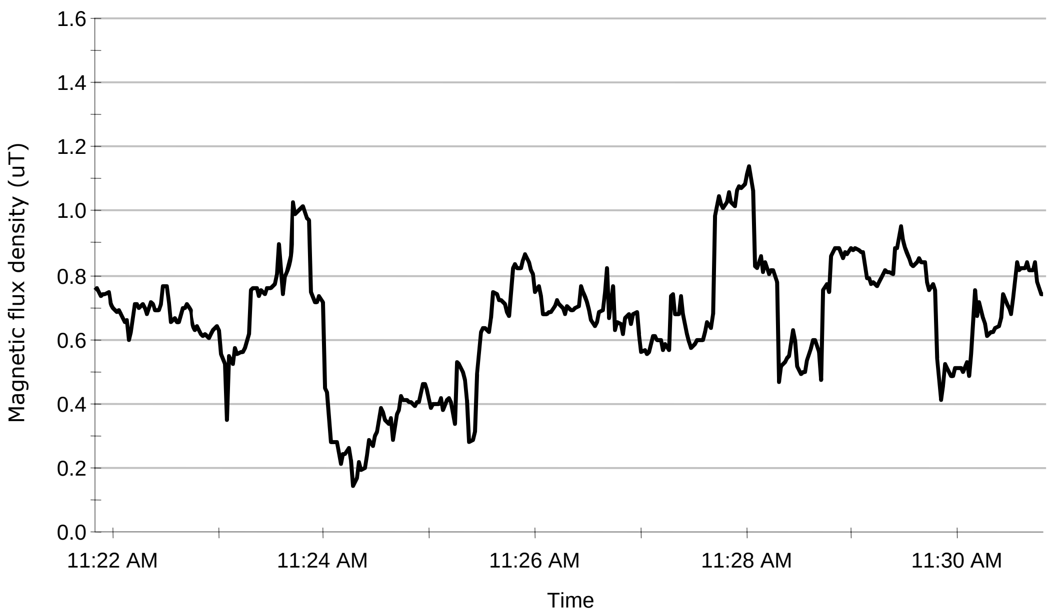


Figure 10 continued

c)



d)



4 EVALUATION OF SOURCES

This section of the report provides a summary of the sources which account for the elevated residential exposures observed in the UKCCS, based on the interpretation of the Stage 1 and Stage 2 information. In Section 4.1 the 50 Hz magnetic field sources that might influence exposures in UK homes are reviewed and Section 4.2 describes the sources from the perspective of elevated exposure homes in the UKCCS.

4.1 Source categories

Figures 11 and 12 are an overview of the main source categories that are likely to affect residential exposure in the UK.

4.1.1 Magnetic field sources outside the home

High voltage power lines are potentially important sources of magnetic field exposure in homes located near to them. The main determinants of field strength are the load current(s), the relative phasing of circuits, the spacing of conductors, and the distance from the line. Maximum flux densities of up to a few tens of microtesla can occur at ground level beneath transmission lines, however because the lines normally operate below rated conditions, the levels encountered are often no more than a few microtesla. The field level associated with power lines tends to decay rapidly, typically to no more than a few tenths of a microtesla at distances of several tens of metres from the high voltage transmission lines.

For single circuits, or double circuits with currents in the same direction and the same phase arrangement, the field decreases as the reciprocal of the distance squared. For circuits with opposite current direction or phasing, the field decreases more nearly as the reciprocal of distance cubed. In practice, because load currents in the phase conductors and the circuits are not exactly equal, the imbalance produces an additional field that for a dual circuit transposed line decays as the reciprocal of distance squared. The alternating fields produced by a transmission line also induce currents in the earth wire and the ground, which produce a magnetic field proportional to the reciprocal of distance. Net and earth wire currents tend to be relatively small compared to the load currents, but they can make significant differences to the magnetic fields at large distances from the line where the fields are smaller[15]. In general the maximum magnetic flux densities decrease as the operating voltage decreases, because currents and conductor separations become progressively smaller.

Figure 11 Breakdown of 50 Hz magnetic field sources outside the home

High voltage (HV):

- HV overhead line (400 kV, 275 kV, 132 kV, 66 kV, 11 kV)
- HV cable (275 kV, 132 kV, 66 kV, 33 kV, 11 kV)
- Substation (66 kV, 33 kV, and 11 kV)
- Electrified train line (25 kV)

Low voltage (LV):

- LV distribution main circuit
  - Overhead open wire circuit
  - Aerial bundled circuit (abc)
  - Underground cable
  - Return current in other conducting utility such as a water main
- LV service
  - Single phase / 2 phase / 3 phase supply/ shared service*
    - Overhead open wire
    - Overhead abc
    - Overhead concentric
    - Cable

*Service cable shared for one or more homes through underground cable, mural and/or under-eaves wiring)

Figure 12 Breakdown of 50 Hz magnetic field sources inside the home

Point sources:

- Appliances such as those with transformers or motors
- Service entrance equipment including meter

Line sources:

- Separate live and neutral conductors
- Net currents in wiring associated with
  - Wiring fault such as broken neutral
  - Accidental earth-neutral connection
  - Joining of neutrals from different circuits
  - 2-way switch wiring fault
- In flats where service panel is situated well within the building:
  - Separation of phase conductors
  - Proximity to internal transformers
  - Grounding of service neutral
  - Several parallel service cables (instead of one large cable)

Magnetic flux densities encountered at ground level above underground cables can be larger than those under overhead power lines carrying the same current, mainly because cables can be approached closely at ground level. A buried 400 kV cable operating at 2 kA can produce flux densities in excess of 100 μT at 1 m above ground level directly over the cable. However, because the phase conductors are more closely spaced than on the equivalent overhead line, the fields fall rapidly to background levels within a few tens of metres or so. In cables where the phase conductors are enclosed in a single metallic casing such as those typically operating at intermediate voltages of 11-33 kV, the field cancellation of load currents produces much weaker magnetic fields - usually no more than a few tenths of a microtesla at ground level. The net currents in these types of cables also tend to be small because there is only one earth connection to the neutral.

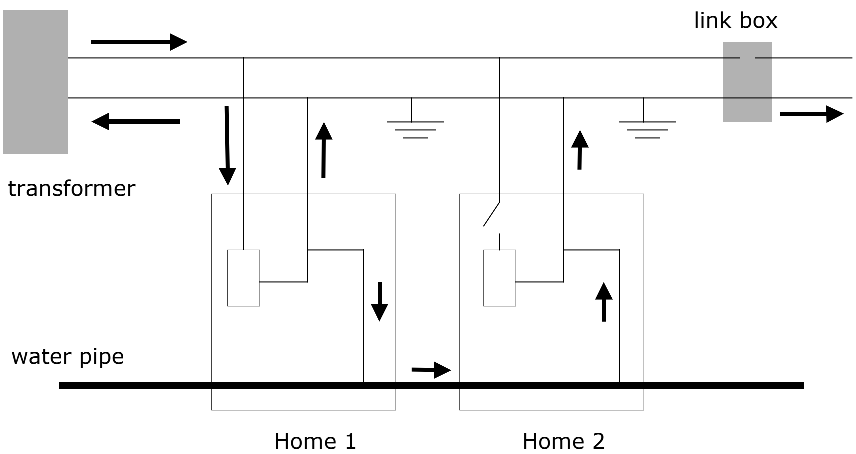
Maximum flux densities of a few microtesla have been encountered at the boundary of the local area substations that serve residential areas in the UK[16]. The levels fall rapidly to become indistinguishable from the normal domestic background level usually within a few metres or so. The maximum fields occur opposite the feeder pillar, transformer and switching units of the substation, and continue along the connecting power cables and lines.

Other important HV magnetic field sources outside the home include some of the electrically powered transport systems such as rail and tramway. The 25 kV rail system operated in the UK draws typical maximum currents of about 300 A which is expected to produce magnetic flux densities of a few tens of microtesla under the contact wire, falling to a few microtesla at tens of metres from the line and less than a microtesla at greater distances.

In the majority of homes in the UK, background power frequency magnetic fields come from currents in final distribution circuits[12]. About 15% of homes (mainly in rural areas) have overhead distribution[8]. The large majority are separated-phase overhead wiring in which magnetic fields can arise from the load currents and the field decreases as the reciprocal of the distance squared. However, as with the transmission lines, if the currents are unbalanced, magnetic fields can also arise from net currents whose fields decrease as the reciprocal of distance. About 17% of the overhead distribution mains consist of bundled conductors which produce fields similar to those from underground cables[17].

For about 85% of the UK population the final distribution is by means of underground cables, in which the individual phase conductors are no more than a couple of centimetres apart and are usually helically wound[8]. This produces almost total cancellation of the fields from balanced phase currents; however net currents are produced when the phase currents are unbalanced and when neutral currents are diverted out of the distribution cable through earth connections[9]. Live and neutral currents can become unbalanced in distribution circuits where neutrals are interconnected at a link box for circuits from adjacent substations meet (Figure 13). Net current loops can be set up in situations through neutral to earth connections when services are shared between properties (Figure 13). Neutral-to-earth connections occur as part of protective multiple earthing (PME) involving connections between the neutral and water and gas pipes. PME is applied to 64% of underground circuits and 32% of domestic consumer's installations, and neutral-to-earth connections also occur accidentally within 20% or more of homes[12]. Net currents in distribution circuits typically range from 0.1 – 10 A, with a 48-hr average in a sample of 21 circuits of 3.6 A[12]. Net currents produced by diverted neutral current vary as loads vary; however, because neutral current is proportional to the imbalance between the three phases this weakens the correlation between net currents and loads.

Figure 13 Net currents produced by diverted neutral current at a link box and through bonding of neutral inside and outside the home to other services

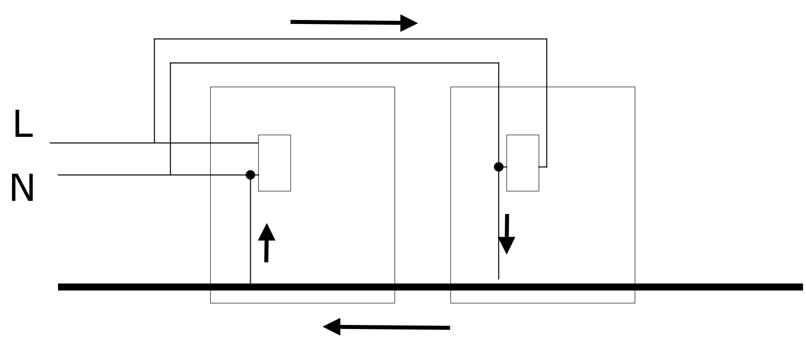


Final distribution in the UK is at 400 V phase-to-phase and most individual consumers receive one phase at 230 V, plus neutral. The large majority of service supplies to homes are via underground cables, however about 15% of homes have overhead distribution and in about one third of these the service line consists of separated conductors which leads to fields arising from net and load currents[8]. In the remaining homes the service is either underground or via aerial bundled conductors, or overhead concentric cables which are used increasingly to replace open wire arrangements. In aerial bundled conductors and overhead concentric cables, as in underground cables, the field is due to net currents which occur due to current imbalances arising from diverted neutral to earth current either in the consumer's installation or in the distribution system.

The net currents in distribution circuits are the typical source of the background field in the vast majority of homes that are not near to high voltage circuits. The net currents in water pipes and / or gas and other conducting services, and the ground itself can also add to the background fields in home. In such homes net currents can lead to markedly elevated residual field levels especially when they are close to the house such as in a service connection[8].

A small number of homes receive electricity via a shared service cable sometimes arranged as mural or under-eaves wiring. If such homes have protective-multiple-earthing or one home has a neutral-earth fault then large current loops can develop with return current diverted in water pipes and other conducting services (Figure 14). The resulting magnetic fields can be appreciable when close to the conductors of the net currents. In these circumstances the field inside a home can change rapidly due to switching of loads in a neighbouring property, and the resident would not necessarily be able to control the field levels.

Figure 14 Net current loop in shared service connection with PME



4.1.2 Magnetic field sources inside the home

The ambient level away from appliances in a home is called the 'background' and is usually attributed to net currents in the local supply and distribution circuits and in the ground[9]. Based on the UKCCS data, it is estimated that more than 97 % of UK homes have a residential background level of less than 0.2 μT. Stronger background fields usually arise from high voltage circuits located close to the home, or from unusual household wiring conditions or faults.

Inside the home, meter boxes and operating appliances represent point sources whose magnetic fields tend to decay as the inverse of distance cubed. Field levels of a few millitesla can occur close to the surface of household appliances which contain transformers, motors or heating loops, but the field strength decreases rapidly to background levels typically within 1-2 m. Some of the largest power frequency magnetic fields encountered in homes are produced by appliances, and the magnetic flux densities have been reviewed extensively elsewhere[18,19,20]. Small appliances such as clock radios tend to produce localised fields whereas larger electrical equipment can produce smaller but more extensive fields because of the position of the field source inside the equipment.

It is generally considered that for most home appliances, the time averaged field will not subject the user to appreciable additional exposure, because the field produced is very localised and the periods of use are relatively short (minutes or hours)[21]. Appliances that are used for extended periods of time such as electric blankets and underfloor heating systems, should be considered when assessing average exposure[21].

In most normal situations the electrical wiring inside homes does not give rise to any appreciable magnetic fields because the live and neutral conductors are close together in a cable and cancellation is very effective. However, a number of wiring situations can result in elevated fields, for instance: -

a) The separation of live and neutral conductors as sometimes found in older wiring, which causes poor cancellation of the load current magnetic field.

b) Accidental faults such as a broken neutral in a ring main or an earth-neutral connection, which results in unbalanced live and return current in the ring (Figure 15).

c) Incorrect wiring such as a neutral to earth connection inside the home, the joining of neutral in different radial circuits leading to net currents in both circuits (Figure 16), or wiring a two-way light switch in such a way as to produce a current loop, usually by connecting to a different neutral in part of the lighting circuit (Figure 17).

Figure 15 Fault in ring main producing imbalance in live and neutral currents (x marks break in neutral)

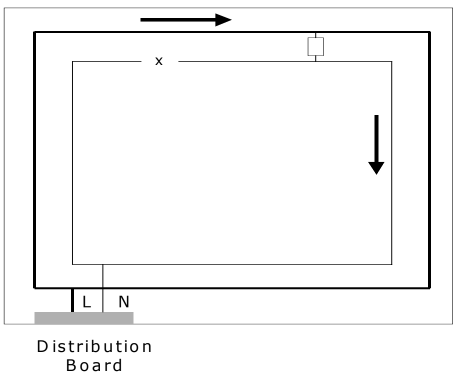


Figure 16 Wiring fault caused by joining of neutrals in two radial circuits resulting in net currents in each circuit

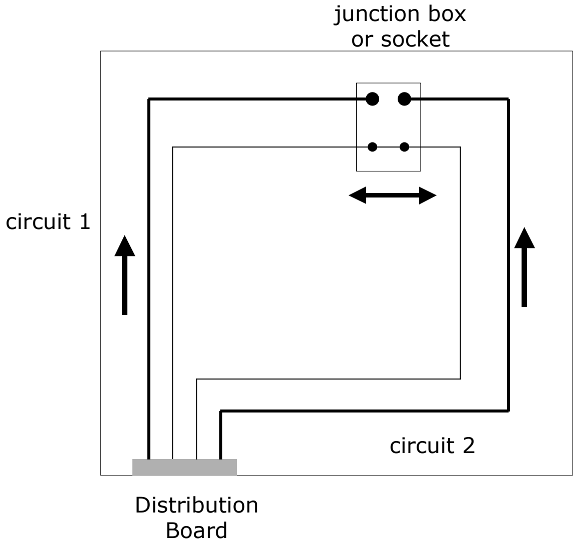
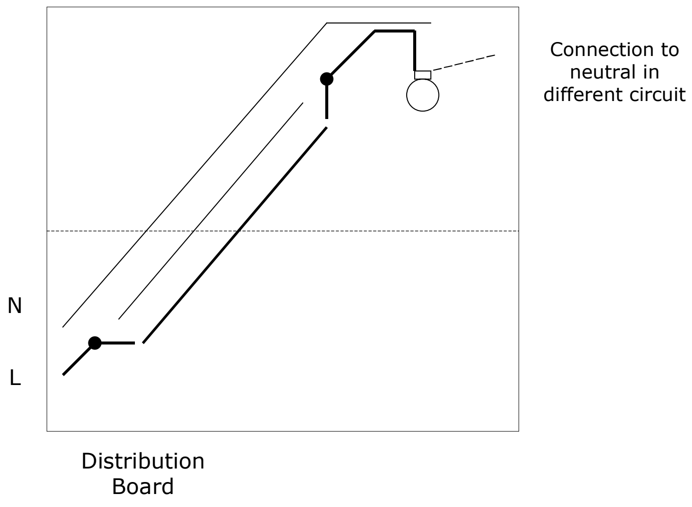


Figure 17 Two-way lighting switch fault



If the neutral and earth conductors become connected, part of the return current flows into the earth. The diversion of current from the neutral to the earth allows a proportion of the return current to return via a different route, resulting in a current loop, which is a magnetic field source. As the net current is proportional to the load current, this type of fault is detected by applying a test load to one of the circuits. A 100 mA net current in the installation with a 2 kW test load was considered to be the threshold of significance for internal net current sources during Stage 2.

Elevated magnetic fields have been reported in apartment buildings[8,22,23], and these types of residences present particular circumstances in relation to magnetic field sources. They can have a central distribution riser with separated phases leading to elevated magnetic fields arising from load currents[8]. Net currents can also occur in the distribution riser if phase currents are inadequately balanced and there is PME or interconnected circuits. Dedicated transformers and switch cabinets can lead to higher exposures as they are often installed next to, above or below areas of accommodation and can thus be approached more closely than in other types of residence. Where the service panel is installed deep inside the building the grounding of service neutral at the service panel can result in current returning to a transformer via the conducting pathways provided by structural steel, and metallic pipes and conduits[24]. The resulting net currents occur in the service line as well as the metallic pathways. Also, net currents can occur if numerous service lines are used instead of one large cable. Unless the impedances of all the sets of phase conductors are equal, and that of the neutrals are also equal, net currents arise because the neutral current in each cable will not necessarily balance the phase current in that cable[24].

4.2 Interpretation of source categories

This section of the report describes the source categories from the perspective of elevated exposure homes in the UKCCS. The interpretation is based on all the information available about the homes from the original study and that gathered during Stage 1 and Stage 2.

Figure 18 shows the summary breakdown of the source categories for the elevated exposure homes. Summary reports for each site were prepared. The approach of the analysis is that there is likely to be a dominant source of exposure to magnetic fields. This is because magnetic fields add vectorially and fields from separate sources have random phase relationships, meaning the larger source will tend to dominate.

The interpretation is based for the most part on the Stage 1 visits as it was only possible to complete a small number of Stage 2 assessments; however, the information collected generally during Stage 2 helped to improve the source interpretation in the Stage 1-only homes.

Of the 19 Stage 2 homes visited, 17 had residential exposure estimates at or above 0.2 μT, of which 3 were at or above 0.4 μT, and the remaining 2 had exposures in the range 0.1-0.2 μT.

Of the 3 homes at or above 0.4 μT, 1 was attributed to net currents in a distribution main cable at 0.5 m from the front of the house, 1 to a suspected internal wiring fault and currents in an open wire shared service (now replaced) and mural wiring, and 1 to a 275 / 400 kV transmission line located at 105 m. In the latter, on the basis of the historical operational information available and subsequent measurements, the line appears to have been operating atypically at the time of the P1 measurement,

Seven of the homes at or above 0.2 μT were assigned to the internal wiring / services net current category. The remaining homes at or above 0.2 μT were assigned to sources outside the home; 3 net currents in distribution mains cables, 2 overhead open wire distribution mains lines, one 275 / 400 kV power line, one electrified rail line, and 2 to a combination of LV sources inside and outside the home.

4.2.1 High voltage transmission at 132 kV and above

Twenty percent of the exposures at or above 0.2 μT were attributable to the fields from HV overhead transmission lines, nine lines operating at voltages at or above 275 kV, and 11 lines operating at 132 kV. The distances to 132 kV lines ranged from directly under the line to 36 m; for 275 kV lines the distances ranged between 14 and 52 m and for 400 kV lines the distances ranged between 34 m and 105 m. In the ≥ 0.4 μT exposure category, 43% of the exposures were attributed to HV power lines, 5 operating at or above 275 kV and 4 operating at 132 kV. In the ≥ 0.4 μT category, 1 home with a 400 kV line at 34 m had an exposure estimate of 1.69 μT. Two other homes in this category had exposure estimates above 1 μT, one with 275 kV line at 14 m and one with a 132 kV line at 16 m.

HV transmission cables operating at 275 kV were the most likely source of elevated field levels for two homes in the ≥ 0.2 μT exposure category. The circuits were dual cables located between 10 and 20 m of the properties, and giving exposure estimates of 0.23 and 0.37 μT. There were no instances of higher voltage cables.

4.2.2 Distribution at 11 kV to 66 kV

None of the distribution circuits operating at intermediate voltages of 11 to 66 kV were represented in the exposures ≥ 0.2 μT. A number of the homes were located close to 11 kV cables but these were not found to be important sources of elevated residential magnetic fields. There were no instances of HV power lines at less than 132 kV.

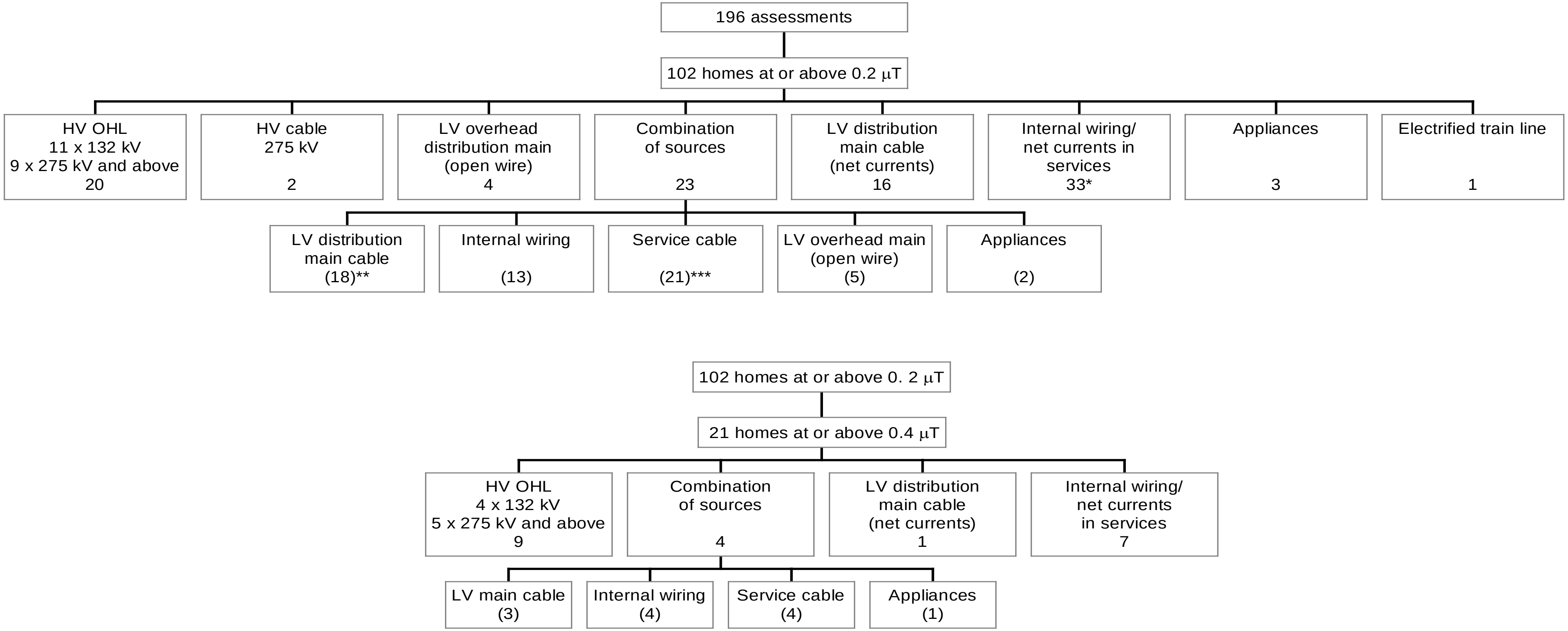
4.2.3 Substations and transformers

Substations and transformers were relatively rare sources of elevated magnetic fields in this study. Of the 4 homes identified close to substations only one had an elevated exposure of 0.2 μT or above, and it is possible that this arose from a net current estimated to be 2.9 A in a distribution main circuit located at 0.5 m from the home, rather than equipment in the substation located at 1.5 m. The other homes were all low exposures at distances of 5 m, 7 m and 12 m, outside the influence of the main components of the substations.

4.2.4 Other high voltage sources

An electrified railway was identified as the most likely source of exposure in one home located at 10 – 20 m from the side of the railway. The field was very variable possibly reflecting leakage currents associated with the line. The railway consisted of a 25 kV main line (5 rail lines supplied by overhead wires), and two suburban lines supplied by a third-rail. The magnetic flux density recorded in the home is shown in Figure 19.

Figure 18 – Breakdown of residential exposure by source category



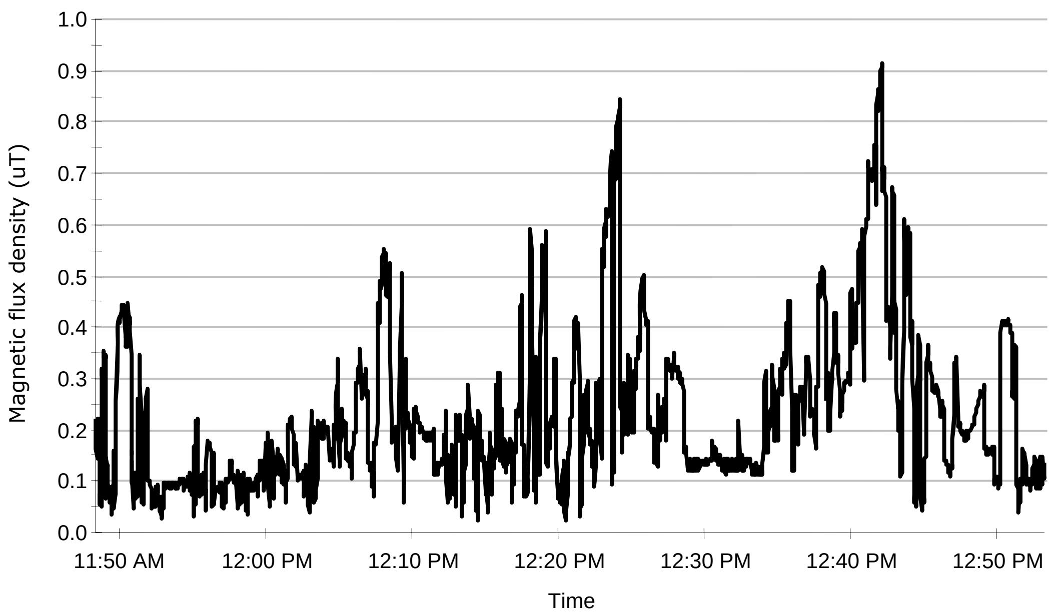
*includes 17 homes identified with shared service cables

**includes 1 aerial bundled conductor

***includes 16 homes identified with shared service cables

() the number of times reported in homes with a possible combination of sources

Figure 19 Magnetic field recorded in the family room of a home close to an electrified railway



4.2.5 LV distribution mains circuits and services

The main criterion for assigning the source as a LV distribution main or service cable was the identification of a cable sufficiently close to a house and producing a large enough net current to explain the field levels observed in the house. The other supporting criterion was the typical 'distribution mains cable net current type' trace, which is characterised by complex short-term fluctuations of the field (Figure 6).

Net currents in LV distribution mains cables were distinguished as a unique source for an estimated 16% of homes with exposure estimates at or above 0.2 μT (16 out of 102 homes). They were less important sources in the 0.4 μT or above homes, identified as the distinct source in only 1 of the 21 homes. Elevated exposures arising from net currents in distribution mains circuits were more common in homes with short or absent front gardens. In homes where the elevated exposure was attributed to net currents in distribution mains circuits, the mean distance to the cables was 2.8 m (95% CI 1.9-3.7) compared to 8.6 m (95% CI 6.9-10.3) for the low exposure homes where a distribution main cable was identified (normal distributions assumed).

Approximately 4% of homes at or above 0.2 μT (4 out of 102 homes) had elevated exposures interpreted to be most likely due to load and net currents in open-wire overhead distribution or service connection, however this type of source was not important in the homes at or above 0.4 μT (Figure 18).

Table 2 compares the net currents in mains distribution circuits of Cook et al[13] with the results in this study. The values given for this study are based on the Stage 1 predictions using the LINDA profiles which utilised an Emdex meter at 0.8 m above ground level. The statistical analysis of net currents is presented in Appendix C. For all data where values were assigned, the geometric mean current was 1.3 A (95% CI 0.7 – 2.5). The net current geometric mean for elevated exposure homes was about twice the geometric mean for low exposure homes and the difference was statistically significant at the 99% level. Seventy one percent of homes (22 out of 31) with net currents ≥ 4 A in distribution mains circuits had exposure estimates at or above 0.2 μT, compared with 45% of homes (56 out of 124) with net currents < 4 A.

For the whole population the field predicted in homes from net currents in distribution systems was only moderately correlated with the exposure (Spearman's rank correlation = 0.42; Appendix C). However the correlation improved when exposures associated with power lines, appliances, and internal wiring sources were removed from the dataset (Spearman's rank correlation = 0.79). These observations, although consistent with the interpretation that the background fields in the majority of UK homes arises from net currents in final distribution circuits[12], show that measurement of net currents is not necessarily a good way of estimating exposure.

The net currents in service cables were generally more difficult to detect because of the restricted access during Stage 1. The geometric mean current was 0.4 A (95% CI 0.2-0.8), lower than that estimated in the final distribution circuits (Table 2; Appendix C). The net currents in services were reasonably well correlated with those in the distributions circuits (Spearman's rank correlation = 0.68). Ninety-three percent of homes (14 out of 15) with net currents ≥ 2 A in the service cables had exposure estimates at or above 0.2 μT, compared with 47% of homes (62 out of 130) with net currents < 2 A.

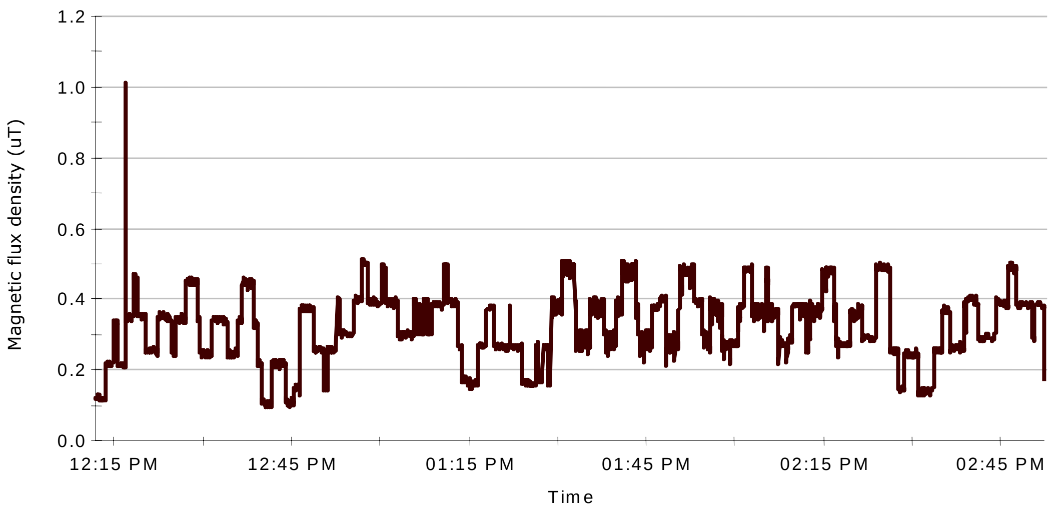
Table 2 Net currents in final distribution and service circuits

Cooke et al 1997[13]	Sample (n)	Geometric mean (A)	95% Confidence interval
Interconnected	68	1.3	0.3-6.8
Loop	10	2.3	0.7-7.1
Radial	83	0.4	0.02-5.7
Residential Sources Study			
Distribution mains	155	1.3	0.7-2.5
Exposure ≥ 0.2μT	77	2.0	1.2-3.1
Exposure < 0.2μT	78	0.9	0.5-1.7
Services	145	0.4	0.2-0.8

4.2.6 Sources inside and close to the home

The internal wiring / services net current category includes two types of sources; those related to a suspected wiring fault, and those with net currents in service cables and other conducting utilities. In practice, these types of sources were difficult to distinguish, especially in the homes without a Stage 2 assessment. In the homes assigned to this category, the magnetic flux density traces were characterised generally by large step-like changes and castellated patterns, which were shown during Stage 2 to correspond to the periods of switching on and off of appliance loads inside the home. The background field level could be flat and occasionally, superimposed on the step like changes, were short duration cycles or repetitive patterns taken to reflect the load cycling of a particular appliance.

Figure 20 A Stage 2 home with a suspected ring main wiring fault



During Stage 2 if the step changes could be shown to be restricted to appliance switching inside the home and there were no appreciable net currents detected, a ring main fault was the likely explanation. An example of a trace from one such a home is shown in Figure 20. On the other hand, if net currents were produced during the load switching, then this was more likely to reflect diverted neutral current either due to a neutral-earth fault, or in the PME homes, net current in alternative current pathways. In the Stage 2 homes with shared service cables it was possible to observe step changes independently of load changes inside the home. An example of a field trace from a Stage 2 home with net currents in a shared under-eaves service and conducting water pipe is shown in Figure 21. The trace shows step changes, and more complex variations reflecting the influence of load switching in the neighbouring homes - the pattern tending towards that of a typical distribution mains cable (Figure 6). An example of a home with shared services where the step changes were shown to be produced by load switching in a neighbouring home, is shown in Figure 22. In this situation it would not be easy to affect the exposure without changes to the shared service cable and other conducting services to divert or reduce the net currents.

In summary, it was difficult in Stage 2 to distinguish between exposures due to house wiring problems and those due to net current in the service installation or other conducting utilities. During the development of the protocol it was expected that increases in the field when a load was applied would be indicative of a wiring fault; however, similar effects were found to be caused by net currents in shared service installations and other conducting utilities, not necessarily related to a wiring fault inside the home.

Figure 21 Home with net currents identified in shared under-eaves service and conducting water pipe

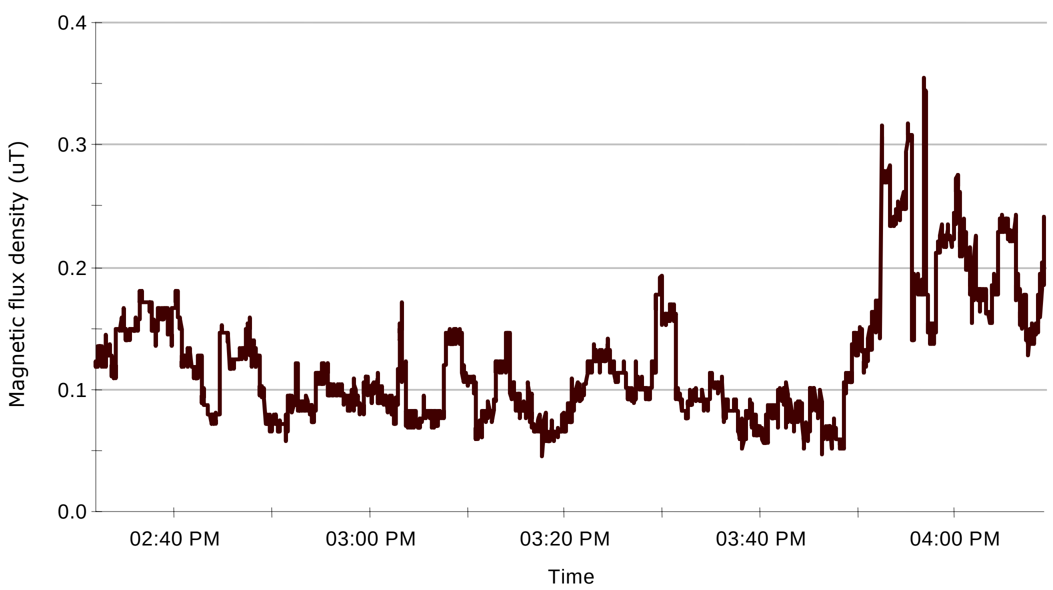
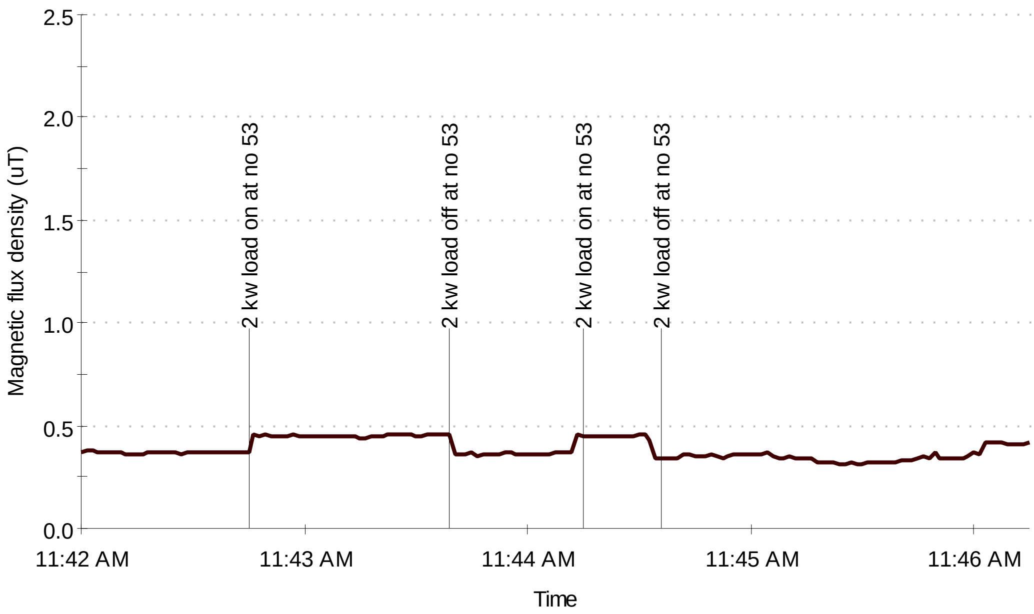


Figure 22 Magnetic flux density recorded in a bedroom of a property with PME and with service neutral and conducting water piper shared with neighbouring properties. The magnetic field increased when a test load was applied in a neighbouring home



On the basis of the above discussion, it is difficult to determine the proportion of the high exposures that were attributable to wiring faults alone. However, assuming that an internal wiring fault is the most likely explanation for the high exposure homes where there were no shared services or appreciable net currents outside the home, this accounted for 10% (11 out of 102) of the homes at or above 0.2 μT and a similar percentage (2 out of 21) at or above 0.4 μT.

Without disconnecting circuits inside the home, it was not possible during Stage 2 to ascertain the type of wiring fault. It seems likely that most were related either to faults on ring mains or neutral to earth connections. Of the seven homes at or above 0.2 μT that were assigned to the internal wiring / services net current category, 3 were distinguished as suspected ring main faults on the basis of magnetic field changes observed when loads placed on circuits; and the absence of appreciable net currents on current loggers inside the home or from cables outside the home. In the other 4 homes there was evidence of net currents either inside the home and / or in service cables and other conducting utilities, pointing towards a neutral–earth fault or a consequence of PME and shared services.

Light circuit faults were not found to be major sources of the elevated fields in the Stage 2 homes. In general the field effect of switching lights on and off was not discernible above the general variations observed in the homes. A net current of 0.4 A due to a simple light circuit fault is estimated to produce a field change of less than 0.1 μT at 1 m from the circuit, which would be difficult to detect above the normal net current variation observed in homes. A more complex lighting arrangement on a 100 V supply and based on large rectangular coils within the floor and ceiling, has been reported to produce magnetic flux densities exceeding 0.4 μT in 24% of the living space in a Japanese apartment building[25].

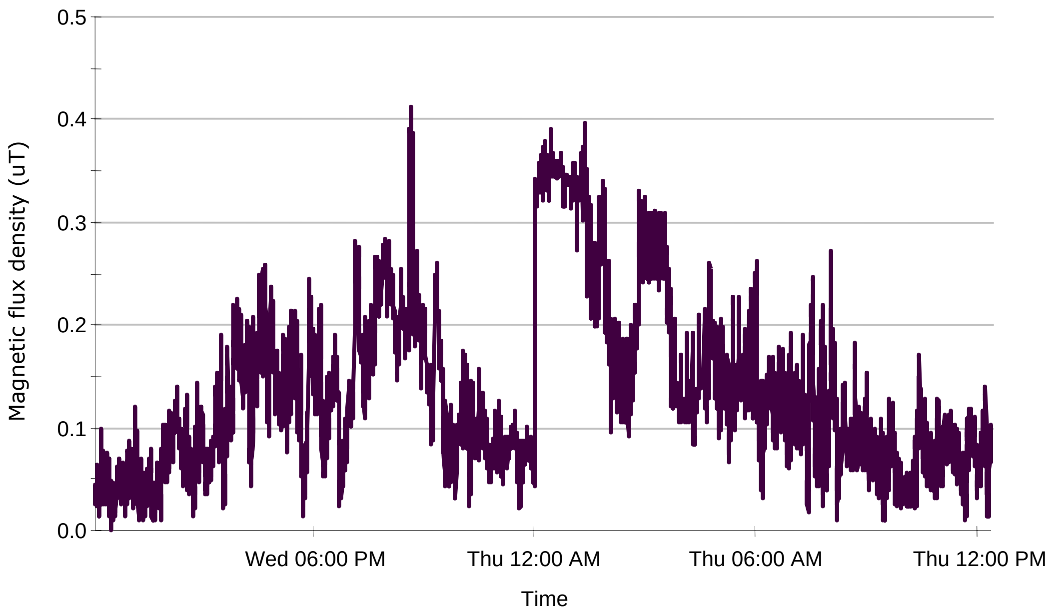
Certain appliances such as night-storage heaters and underfloor heating have previously been identified as possibly important sources of TWA exposure[21]. Although the influence of night-storage heaters could be seen in the UKCCS measurement traces of some homes (Figure 23) none of these sources were the direct cause of elevated exposures. Nineteen of the homes with elevated exposures (19%) reported the use of Economy 7 / White Meter tariff electricity, compared with 16 of the low exposure homes (18%). Five of the elevated homes reported the use of night storage heaters compared to 3 of the low exposure homes. However, in two of the homes the elevated exposures were more likely explained by high voltage power lines, and in the other three, by suspected wiring faults. None of the 196 homes investigated in the study reported the use of underfloor heating.

A small number of the high exposures were attributed on the basis of highly localised fields to be associated with operating electrical appliances. As unique sources, appliances accounted for about 3% of the exposure estimates ≥ 0.2 μT (3 out of 102 homes) but none ≥ 0.4 μT. The appliances were likely to be located within 1 m of the original measurement position.

In three of the elevated exposure homes the child's bed was reported to have been within 1 m of an electricity meter, compared with one low exposure home. However in all three cases the exposures were more likely to be explained by net currents in wiring inside the home or in shared services.

Half of the homes (17 out of 33) assigned to the internal wiring / services net current category were identified to have shared service cables, with the potential for net current loops similar to that shown in Figure 14. These homes tended to be semi-detached or terraced homes. Net currents in shared service wiring and other utility services provide a possible explanation for the association between type of house and magnetic field intensity[8,22,23] (Section 4.5).

Figure 23 Magnetic flux density recorded at bedside position in low exposure home using night-storage heaters

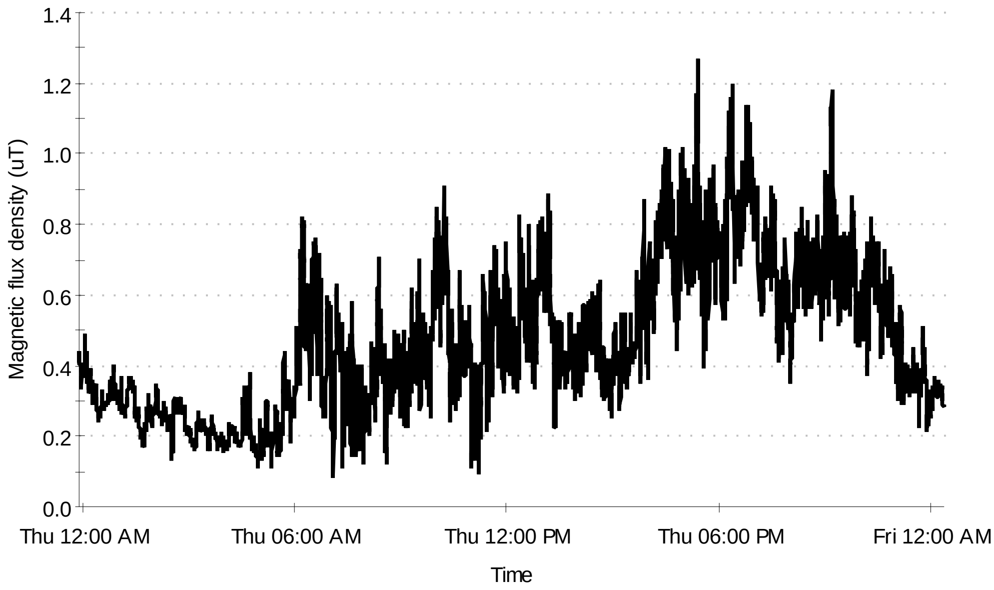


4.2.7 Combinations of LV sources

The field levels encountered in the majority of homes with elevated exposures were attributable to a single dominant source. However, in 23 homes ≥ 0.2 μT and 5 homes ≥ 0.4 μT it was unclear which particular source caused the elevated exposure, other than it was related to the final LV supply. It was likely that the exposures in these homes included field contributions from a number of possible sources, including net current sources in distribution and service cables, and from internal wiring faults. In this category the field traces tended to exhibit a mixture of step changes and the more complex variations that are typical of net current effects. An example of the magnetic flux density recorded in a home assigned to this source category is shown in Figure 24.

In this source category, seventy six per cent (16 out of 21) of the homes with net currents in service cables had shared service cables, with the potential for net current loops (Figure 14).

Figure 24 Bedside trace that may be explained by a combination of possible sources including an internal wiring fault, net current in a distribution main cable at 3 m and in a shared service cable



4.3 Contact voltages

Recent studies in the USA have suggested that relatively modest contact currents (~ 18 μA) can lead to induced electric fields, averaged across tissue such as bone marrow, greater than those due to ambient magnetic fields, leading to a possible explanation of the associations of magnetic fields with childhood leukaemia[14]. In Stage 2, measurements were taken both of open circuit voltage and with a 1 kΩ resistor in place. The majority of homes had plastic pipes and although open circuit voltages were recorded initially at tap to drain positions, the voltages fell to levels below the resolution of the meter with the 1 kς resistor in place. Small voltages with the 1 kΩ resistor were recorded in three homes only; in the first home, 3 mV was measured at the kitchen sink; in the second, 12 mV and 14 mV at the bath and bathroom sink, and in the third, 7 mV was measured at the bath. Assuming a total body resistance of 2.5 kΩ[26] and the same value back to the circuit ground[14], for a total resistance of 5 kΩ, the largest contact current estimated at the tap to drain position in this study is 2.8 μA. Although based on a small sample, the Stage 2 measurements suggest that much lower levels of contact current are likely to be encountered in UK homes as compared with homes in the USA[14] where the average contact current, based on a computer model of a 40 house, single-unit, detached dwelling neighbourhood. is estimated to be about 11 μA[14].

4.4 Stability of exposure estimates

One of the questions that arises in the UKCCS EMF study is how stable were the exposure estimates with respect to time. In this study, it was possible to compare the Stage 2 field levels measured in the home with measurements made in the original study up to ten years previously. The most directly comparable measurements are the 90-min average Family Room measurement during Phase 1 (P1FR), with the 2-hr average Family Room measurement during Stage 2 (ST2FR). The measurements were moderately well correlated (Pearson's correlation 0.57; Spearman’s correlation 0.6). The distribution of the P1 measurements tended towards normality, whereas the Stage 2 measurements were skewed towards lower values. In Table 3 the measures are cross-tabulated using the original study cut-points, and at the level at which the risk is hypothesised. The Stage 2 measurement includes short periods when the lights and the 2 kW load were switched on. In general the categorisation held well suggesting that under most circumstances the exposure estimates are likely to good indicators of long term average exposure. The results are consistent with reported correlations of 0.6-0.7 for P1 measurements repeated up to 4 years between measurements[6]. There was no particular pattern in terms of sources assigned to explain the exposures. Three of the 5 most stable measures above 0.2 μT were attributed to net currents in final distribution circuits and two were related to suspected ring main faults. In the two least stable P1 measurements, one exposure was attributed to a wiring fault and the other was considered to be related to a change in the overhead service connection to the property.

Table 3 Cross-tabulation of Phase 1 and Stage 2 Family room measurements

	P1FR < 0.1 μT	0.1 μT ≤P1FR< 0.2 μT	0.2 μT ≤P1FR< 0.4 μT	P1FR ≥ 0.4 μT
ST2FR < 0.1 μT	1	2	2	
0.1 μT ≤ST2FR < 0.2 μT		5	2	
0.2 μT ≤ST2FR < 0.4 μT			3	2
ST2FR ≥ 0.4 μT				2

4.5 Type of residence

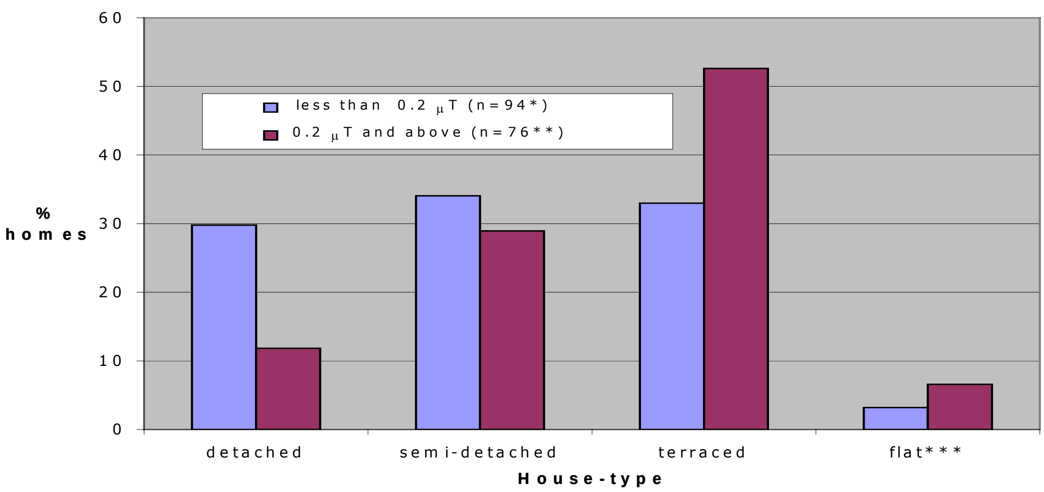
This study is consistent with the findings of other studies[8,21,22] in that there is an association between type of house and exposure. Fifty-three percent of the homes in the elevated exposure category were terraced homes, compared to 33% in the low exposure category, and almost twice as many flats were associated with high exposures as with low exposures (Figure 25). Seventy five percent of detached homes were low exposure homes.

There is a tendency for terraced homes and flats to be located closer to LV distribution circuits than in other types of homes and thus to have the potential to be influenced by load and net currents in these circuits. There also appears to be a greater propensity for unbalanced currents to develop in terraced homes and flats, due in part to shared service arrangements. There was no significant difference between the distances to the nearest distribution mains circuits in high and low exposure terraced homes, 5.2 m (95% CI 3.4-7, n=33) and 6 m (95% CI 3.5-8.5, n=26) respectively. However the net currents were sufficiently large in 25% of the elevated exposure homes, such that these circuits were assigned as the main source of the elevated exposure. The potential for net currents to develop appears to be an important aspect of elevated exposure. Fifty percent (21 out of 40) of the high exposure terraced homes were assessed to have shared service cables compared to 28% (8 out of 29) of the low exposure homes (excluding corner properties), also possibly suggesting net currents as an important source of high exposure. The figures are uncertain as the status of the service, shared or otherwise, was not easy to determine from many of the maps provided at Stage 1.

There were 7 LV open wire distribution circuits reported for the high exposure terraced homes (4 considered to be sufficiently close as to be an important source of exposure), compared with 5 such circuits for the low exposure homes (2 sufficiently close to influence the exposure in the home).

Finally, almost twice as many high exposure homes were located on street corners, as compared to the low exposure homes (12 *cf* 6 homes), possibly because of the greater concentration of distribution mains cables at street corners (All but 2 of the homes were supplied by mains cables).

Figure 25 Comparison of house type and exposure



*includes 5 P1 high P2 low exposure homes

**excludes HV power line, appliance and electric rail exposure homes

***includes 1 converted flat in low exposure category and 2 in high exposure category

4.6 Implications for EMF epidemiology

A number of epidemiological studies have explored whether there is a link between power frequency magnetic fields and childhood cancer. Earlier studies suffered from a lack of measurement-based exposure assessments. With the wider availability of reliable instrumentation, most recent studies have tended to assess exposure on the basis of measurements (see Ahlbom *et al*[3] for summary), and this approach has generally been regarded as providing a substantially improved basis for the epidemiology[1]. A number of studies have used distance from HV power lines as an alternative marker of exposure[27,28,29]. These studies must take into account the possibility that, if any such link were established, it might not be due to fields from the power lines but rather some other characteristic of living near to power lines.

The Residential Sources Study has shown that for residential exposure estimates at or above 0.4 μT, less than 50% were attributable to HV overhead lines operating at 132 kV and above. Therefore, if the risk factor was related to some characteristic of HV overhead power lines but not magnetic fields, then magnetic field measurements would be a poor proxy for the relevant exposure, and measurements in population-based studies in the UK would tend to yield false positive exposures. If magnetic field exposure were the relevant risk factor, the distance-based studies would be expected to have low sensitivity in that only a low proportion of truly exposed subjects would be detected.

The Residential Sources Study highlights the importance of measurement-based approaches over the distance from power line proxy if magnetic field exposure is the relevant risk factor.

4.7 Sources of uncertainty

There are a number of uncertainties that affect the interpretation presented in this report.

An important element of uncertainty is attached to the source interpretation which relies heavily on assessment of the ambient magnetic field encountered in the vicinity of the homes; a number of different source arrangements could produce similar magnitude magnetic fields, and it has been necessary to make assumptions about how sources operated, and what type of field might be produced. The field measured in the home is likely to include contributions from a number of unknown sources and although it is straightforward to calculate the field produced by one particular source, the inverse problem is more difficult to resolve.

The main basis for the interpretation is that it is only necessary to consider the field produced by circuits which are the closest sources, as most other sources will be sufficiently far away for the magnetic field they produce to be negligible. The approach is that there is likely to be a dominant source of exposure to magnetic fields; because magnetic fields add vectorially and fields from separate sources have random phase relationships, the larger source will tend to dominate.

In Stage 1 the magnetic fields in homes were calculated from the net current estimated in the distribution cable and it was not possible to take account of the field arising from the corresponding return current(s) elsewhere.

In the homes with suspected wiring faults, it was not possible at Stage 2 to investigate the exact nature or position of a wiring fault. It is also possible that undetected net currents in conducting services influenced some of the exposures.

In this study it has only been possible to take partial account of the effect of the time variation in circuit currents, including diurnal, daily and seasonal variability. Power frequency magnetic fields are known to vary in time broadly following the variation in use of electrical power. However fields arising from net currents are much more variable over time and this has led to the suggestion that the best way of assessing average magnetic fields in residences remains direct measurements over at least 24 hrs[12]. The measurements made in this study were limited in duration to two hours on a day convenient for the homeowner. The measurements were also made several years after the original measurements.

Finally, the interpretation presented in this report is dependent largely on the information collected during Stage 1. Only a small proportion of the homes was available for the Stage 2 assessment; however, the information collected during Stage 2 was useful in consolidating the interpretation of the Stage 1 - only homes.

5 POSSIBLE EXPOSURE REDUCTION

This section of the report considers the findings of the study in terms of possible measures to mitigate exposure. The predominant sources of elevated exposure in UK homes, based on the results of this study, are summarised in Figure 26 and 27.

Published expert scientific reviews have identified only one reasonably consistent epidemiological finding of an adverse health outcome associated with exposure to EMFs at levels lower than exposure guidelines: that is an apparent increased risk of childhood leukaemia with time-weighted average exposure to power frequency magnetic fields above 0.4 μT[30]. In 2003, the WHO held a workshop to develop a common framework for application of the Precautionary Principle to health issues, in particular in the context of electromagnetic fields[30]. A document on Precautionary Framework for Public Health Protection is currently being updated following numerous comments[31]. The Precautionary Principle is a concept that allows flexible approaches to identifying and managing possible adverse consequences to human health even when it has not been established that an activity or exposure constitutes harm to health. The objective of precautionary measures within the framework is to minimize potential risks from new technologies or other potential risk factors, without losing potential benefits. In its review of scientific evidence for limiting exposure to electromagnetic fields, NRPB concluded that it is important to consider the possible need for precautionary measures with respect to exposure of children to power frequency magnetic fields[30].

The Residential Sources Study provides an initial technical basis for consideration of the research, engineering, planning and communications options to mitigate exposures in UK homes. It is unclear what aspect of the exposure should be controlled, if any, and in contrast to the UKCCS, the pooled analysis of Ahlbom et al[3] was based partly on a geometric mean metric, which is likely to reflect more stable elevated exposures, and the analysis is less likely to be influenced by statistical outliers. The elevated exposures in the pooled analysis do not necessarily embrace all such exposures featured in the UKCCS analysis. In Table 4, various possible field mitigation options have been highlighted based on the findings of this study, and their efficacy has been considered in terms of reducing exposure in the population at or above 0.2 μT. The basis for the impact on population exposure is the breakdown of exposure by source category presented in Section 4.2. The table might apply equally to new or existing facilities. Assuming that reducing time-weighted exposure would reduce risk, the largest reduction would most likely be achieved by improving wiring inside the home and reducing net currents in service cables. At or above 0.4 μT the main reduction would be from reducing the fields from HV power lines, and by restricting the level of net currents and improving wiring within the home. Whilst all the sources of exposure are not represented in the published UKCCS analysis, the sample is likely to be broadly representative of the exposure circumstances likely to be encountered in the UK. It is recognised that within the precautionary framework there are a number of factors to be considered in selecting appropriate action, including strength of scientific evidence, technical feasibility, economic costs and benefits, and various social and political inputs; these are beyond the scope of this report.

Figure 26 Sources of power frequency magnetic fields contributing to exposure at and above 0.2 μT in UK residences (n =102)

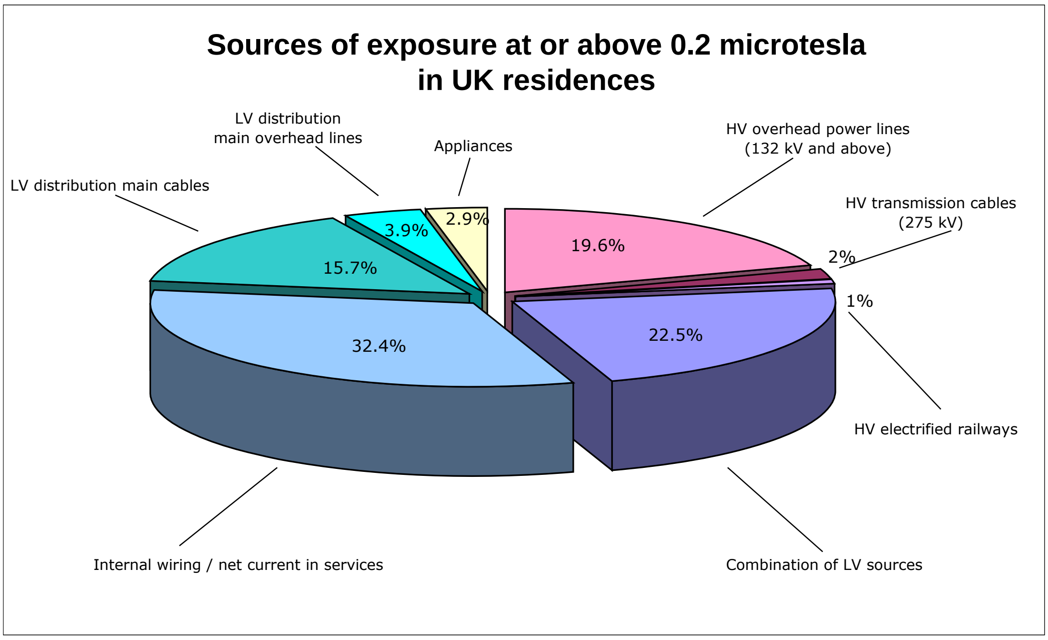


Figure 27 Sources of power frequency magnetic fields contributing to exposure at and above 0.4 μT in UK residences (n=21)

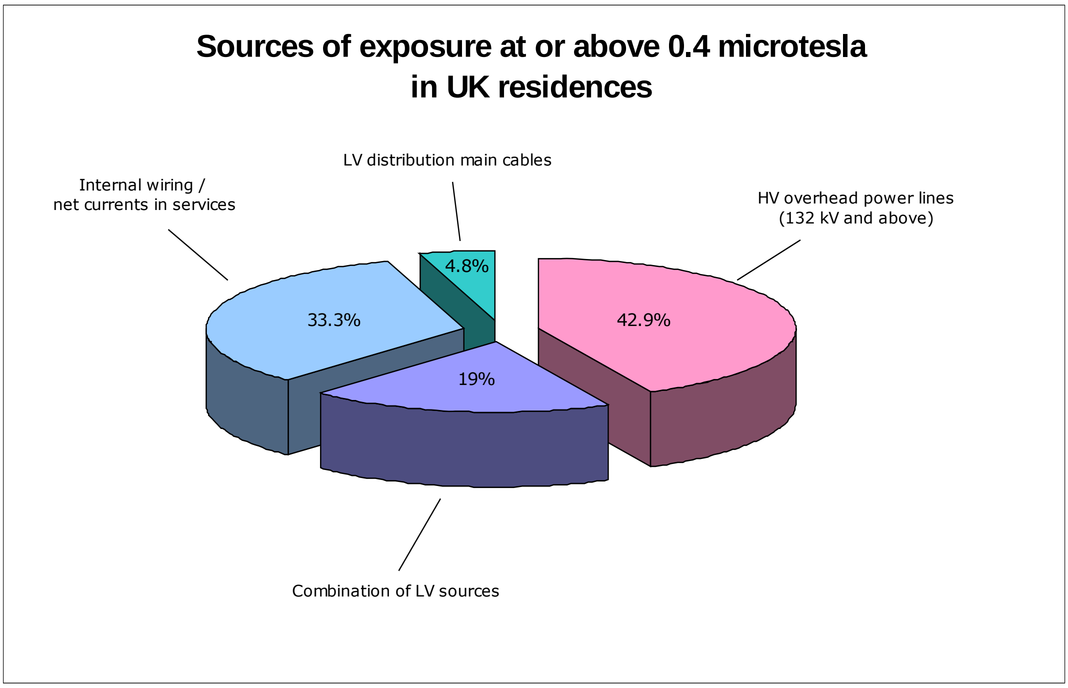


Table 4 The efficacy of various possible options to mitigate exposure in the population at or above 0.2 μT in the UK, based on the results of this study

Source	Options	Impact on proportion of population exposed ≥ 0.2 μT
Internal sources / services	Improving wiring / service installation and removal of faults	Up to 55 % reduction
	Changes to design of appliances	Up to 5% reduction
	Relocation of appliances based on voluntary measures	Up to 5% reduction
LV distribution mains	Laying new cables further away from homes	Not always feasible but up to 34% reduction
	Changes to wiring to reduce net currents	Up to 34% reduction
	Using cables rather than overhead lines	Up to 9% reduction
HV power lines (132 kV and above)	Burying power lines	Up to 20% reduction
	Routing new lines away from homes or siting of homes away from power lines	Up to 20% reduction
	Passive or active shielding	Up to 20% reduction
	Other engineering options to reduce fields (phase transposition, ground clearances etc)	Up to 20% reduction
HV cables (275 kV and above)	Routing new cables away from homes or siting of homes away from power lines	Up to 2% reduction
HV Distribution (11-66 kV)	Burying power lines	Minimal impact
	Routing new lines away from homes or siting of homes away from power lines	Minimal impact
Distribution Substations (11-66 kV)	Build new substations away from homes	Minimal impact

6 CONCLUSIONS AND RECOMMENDATIONS

The Residential Sources Study was set up to investigate and identify the sources of power frequency magnetic fields that contributed to average residential exposure of 0.2 μT and above in the UKCCS.

During Stage 1 of the study, external inspections were made of 196 homes in England, Scotland and Wales of which 102 homes had UKCCS exposure estimates ≥ 0.2 μT. One hundred and nineteen homes, including 12 intermediate exposure or high net current homes, were nominated for the Stage 2 assessment, involving an internal inspection. Twenty-one homes ≥ 0.2 μT were excluded because the exposure was adequately explained by a source identified at Stage 1. EGU was able to approach 39 homes where the original families UKCCS were still in residence and a visit was considered to be reasonable in the light of ethical considerations. Stage 2 assessments were completed in the 19 homes whose owners provided written consent.

In the homes with exposure estimates at or above of 0.2 μT, the largest source category was possible internal wiring faults / net currents in services accounting for an estimated 32% of homes (33 out of 102). HV power lines were the next most common individual source identified, representing 20% of the exposures (275 kV lines and above - 9%, 132 kV lines - 11%). Net currents in LV distribution mains cables, accounted for an estimated 16% of the homes (16 of 102), in homes often associated with short or no front gardens. The remaining individual sources distinguished were LV open wire overhead lines (4%), appliances (3%) 275 kV cables (2%) and an electrified train line (1%). In 22% of the exposures, a number of possible LV sources were likely to have contributed to the exposure, including net currents in LV distribution mains cables and services, possible internal wiring faults, LV overhead distribution mains and appliances. In the ≥ 0.4 μT category, the most common source of exposure was HV overhead power lines (43 %), consisting of four 132 kV lines and five 275 kV and above lines. Suspected internal wiring faults / net currents in services accounted for an estimated 33% of exposures, the remaining attributable to net currents in LV distribution mains cables, and a combination of other possible LV sources.

The study confirms the findings of others, that there is an association between type of house and exposure. The most likely explanation is a tendency for terraced homes and flats to be located closer to LV distribution circuits than other types of homes and thus to have the potential to be influenced by load and net currents in these circuits. There also appears to be a greater propensity for unbalanced currents to develop in terraced homes and flats which is likely to be due in part to shared service arrangements. The potential for net currents to develop appears to be an important aspect of elevated exposure. Almost twice as many high exposure homes were located on street corners, as compared to the low exposure homes, possibly because of the greater concentration of distribution mains cables at street corners.

There are a number of limitations to the study. The interpretation is based largely on the Stage 1 visits and it was only possible to complete a small number of Stage 2 assessments. An important element of uncertainty is attached to the source interpretation which relies heavily on assessment of the ambient magnetic field encountered in the vicinity of the homes; a number of different source arrangements could produce similar magnetic fields, and it has been necessary to make assumptions about how sources operated, and what type of field might be produced. It was only possible to take limited account of the diurnal, daily and seasonal variability.

A number of epidemiological studies have explored whether there is a link between power frequency magnetic fields and childhood cancer. With wider availability of reliable instrumentation most recent studies have tended to assess exposure on the basis of measurements, however distance from power lines has also been used as an alternative measure of exposure. If magnetic field exposure is the relevant risk factor, then this study highlights the importance of measurement-based approaches over the proxy of distance from power line. If, on the other hand, the risk is related to another characteristic of living near to power lines and not magnetic fields, then magnetic field measurements in population-based studies are likely to be a poor proxy for the relevant exposure.

Considerable interest has focused on the application of precautionary measures in relation to reducing exposure to power frequency magnetic fields. The findings of this study offer an initial technical basis for consideration of possible exposure mitigation measures in the UK. A number of areas have been highlighted based on the results of this study. Further work would require a comprehensive evaluation of the technological feasibility of the options identified. This should be carried out in collaboration with the electricity industry.

7 ACKNOWLEDGEMENTS

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APPENDIX A STAGE 1 PROTOCOL

A1 Objectives

This protocol covers the following STAGE 1 objectives: -

1) To collate verify and review the existing UKCCS EMF questionnaire, measurement and exposure data.

2) To carry out site inspections for 196 high-low exposure homes.

3) To acquire additional circuit details from the Electricity Industry.

4) To evaluate the information and produce individual site reports.

5) To resolve the source(s) of high exposure where possible and make recommendations on the course of action in Stage 2.

A2 Procedures

A2.1 Data compilation and review

a) Supply addresses and measurement and questionnaire details for the 85 matched case-control pairs and the additional homes. All information to be checked. A record of corrections will be kept for consideration later in the study.

b) Review original UKCCS information using the **Data Review Form**, which records the following information: -

- The address including post-code and OS grid location.
- The time-weighted average values for P1 and P2 measurements.
- The P1 90-min measurement in the Family Room (FR) and P2 48 hr extended measurement at the bedside (ET).
- The P1 and P2 exposure estimates.
- Key information from the P1 EMF questionnaire, including information on appliances and neighbouring residential power sources.

- Key information from the original P1 External Sources Questionnaire (ESQ) reported by the Distribution Network Operators (and NGT questionnaires if appropriate).

c) Obtain site-centred location maps accurate to 10 m to prepare for site visits.

A2.2 Network information

The aims of obtaining additional network information are as follows: -

1) To obtain details of the HV transmission circuits, HV and LV distribution circuits (including the LV service drop) near to the home.

2) To identify whether circuits have changed since the time of the original study measurements.

The Electricity Industry will be asked to complete a **Network Information Form** for each property. Contact with the Distribution Network Operators (DNOs) will be facilitated through NGT and the Energy Networks Association. The form will be used to: -

- Obtain information / maps on HV transmission and distribution networks in the local neighbourhood.
- Obtain a detailed circuit plan for each property (1:1250 or better)
- Obtain details of the current carrying sources circuits passing the property and information about the local earthing practice.
- Identify any changes to circuits since the time of the original measurements.

NGT will assist NRPB in the interpretation of the information and seek clarification from the industry if necessary.

A2.3 Site visits

All homes will be visited at Stage 1 in order to identify transmission, distribution and supply circuits in the vicinity of the home, and validate the original information reported on the External Sources Questionnaires. The current sources near the home will be identified if possible, including the visible electrical circuits and buried circuits. The service connection to the property will be described. Other possible sources of high magnetic fields will also be identified. The site work will be carried out according to a Code of Practice agreed between LRF EGU and NRPB.

A2.4 Procedures

Obtain a detailed site-centred plan for each site accurate to 10 m, and resolve the boundaries of the property (OS Superplan maps or network maps supplied by the Distribution Network Operators at a scale of 1:1250). Record the following information for each property on the **Site Report Form**: -

- Date of visit, meter no., last calibration date, and the time of the survey.
- A description of the local neighbourhood and type of housing, including what is behind the property. Record digital photographs (see Code of Practice).
- Description of visible HV transmission and distribution circuits in the local neighbourhood including distances.
- Description of the LV distribution and service connections.
- Confirmation of previously reported sources on the ESQs.
- Details of electrical equipment near to property including reference numbers. Measure field levels associated with such equipment.
- Record on the plan the positions of the cables and measurement profiles described below (provide sketches as necessary).

A2.5 Stage 1 site measurements

The aim of the survey measurements is to locate and identify individual current-carrying circuits in front of a property and assess whether the field levels associated with these can lead to elevated levels (0.2 μT or greater) inside the property. To do this it is necessary to measure the magnetic field arising from the source and to obtain an estimate of distance from the source.

1) Use a RD400 / RD4000 cable detector to locate and obtain a depth estimate for the main current sources in front of the property.

2) Use the LINDA Measurement System to measure profiles at right-angles and parallel to the property. Use the name convention listed on the Site Visit Form. The procedures should be standardised where possible. For corner plots also measure profiles at right angles to the side of the property.

3) Try to allow for short-term variability by observing min/max values when taking readings in the fields by making repeat measurements.

4) Record the starting and stopping positions, and direction of profiles accurately in the field notes and on the site plan. Use event buttons if necessary. Record distances and make sketches as necessary.

A3 Stage 1 Evaluation

The main aim of Stage 1 is to identify sources located outside the home that explain the high exposures. The Stage 1 evaluation will draw on the following three sources of information: -

- The original UKCCS measurement data and questionnaire information.
- The electricity network information.
- The site visit results.

The Stage 1 evaluation will consider the following: -

- The probable source of high exposure and any secondary source candidates.
- The homes for Stage 2 inspection prioritised as high, medium and low according to the Stage 1 findings.

A4 Stage 1 Pilot Survey

On 5th March 2003, NRPB staff visited three sites in the Didcot (OX11) area for the purpose of testing the STAGE 1 procedures. The following objectives were defined beforehand: -

- To collect information about the type of housing, the local environment and the electricity supply (also validating original supply information about the site).
- To determine the measurements needed to identify current carrying sources outside a property and evaluating whether these could give rise to high field levels inside a home.
- To gain experience in the use of the EMDEX II / LINDA System and RD400/4000 Cable detector.
- To define the deliverables for each site visit.

The pilot study sites were as follows: -

Site 1 - Barley Fields

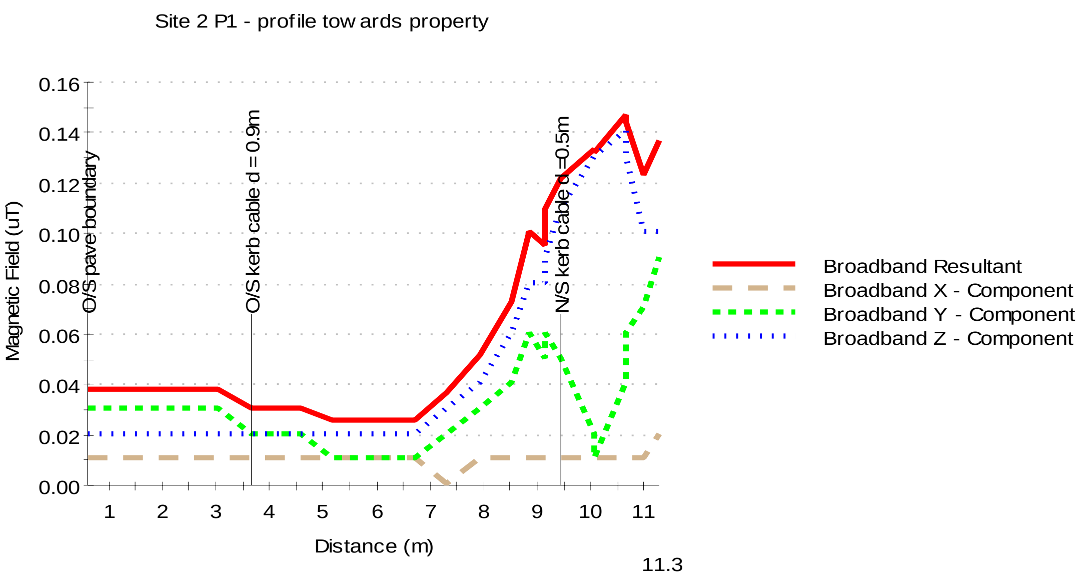
Site 2 – Slade Road (through road)

Site 3 - Wensum Drive (near to HV transmission line).

Staff from NGT accompanied NRPB on the survey and provided advice on the procedures. NGT also provided EMDEX II LINDA systems and cable detectors for the purposes of the study.

A property was selected at each site. Cables in front of the properties were located and depths estimated using the RD400 cable detector. Magnetic flux density measurements were made along profiles perpendicular to and across the front of the properties. The information recorded on the Site Visit Form was also considered.

An example of a LINDA field-distance plot recorded at Site 2 is shown below.



A5 Site Visit Form

STUDY ID		Date of visit	Time of survey
NEIGHBOURHOOD DESCRIPTION		Meter No	Last calibration
Urban ☐	Suburban ☐	Rural ☐	Semi-rural ☐
Notes:			

PROPERTY				
Flat ☐	Terraced ☐	Semi-detached ☐	Detached ☐	Other[specify] ☐
Notes:				

ELECTRICITY SUPPLY o-originally reported, c-confirmed, n-new observation

TRANSMISSION CIRCUITS [275kV and above] YES ☐ NO ☐ CHECK ☐

	OVERHEAD LINE ☐o ☐c ☐n	CABLE ☐o ☐c ☐n	SUBSTATION ☐o ☐c ☐n
Voltage			
Distance			
No circuits			
Conductors per bundle			
Circuit reference			
Company			
Notes:			

DISTRIBUTION CIRCUITS [11kV – 132kV] YES ☐ NO ☐ CHECK ☐

	OVERHEAD LINE ☐o ☐c ☐n	CABLE ☐o ☐c ☐n	SUBSTATION ☐o ☐c ☐n
Voltage			
Distance			
No circuits			
No conductors per bundle			
Circuit reference			
Company	Contact	Tel	
Notes:			

LV DISTRIBUTION [230/400V]

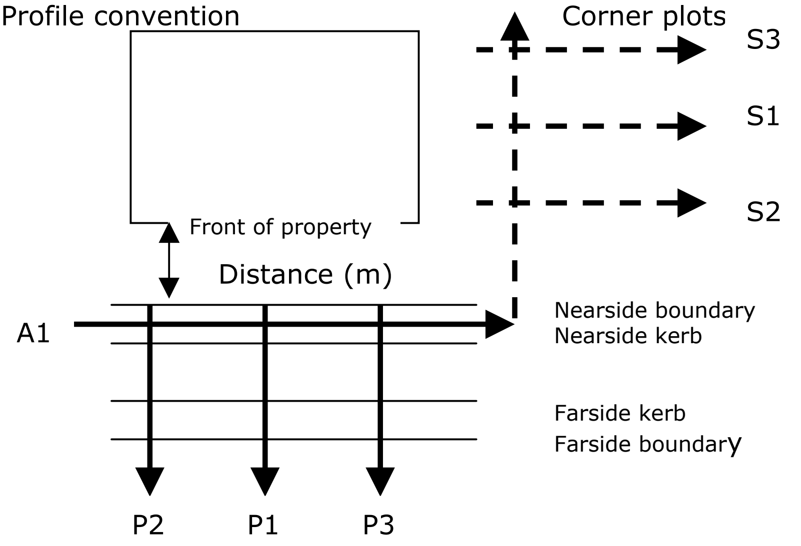
	OVERHEAD LINE ☐o ☐c ☐n	CABLE ☐o ☐c ☐n
Voltage		
Distance		
Circuit reference		
Company		
Notes:		

LV SERVICE CONNECTION	Overhead ☐o ☐c ☐n Undereaves ☐o ☐c ☐n Mural attachment ☐o ☐c ☐n	Underground cable ☐o ☐c ☐n
Notes:		

Sketch of site

Cable No	Position	Depth (m)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Profile convention



Profile	Run No	E1	E2	E3	E4	E5	E6	E7	E8
P1									
P2									
P3									
A1									
S1									
S2									
S3									

DIGITAL IMAGES				

SUMMARY COMMENTS:

A6 Network Information Form

The purpose of this questionnaire is to identify all current-carrying circuits passing near to the property identified below. Please answer all the questions as fully as possible. Try to ensure that all the information provided is accurate and complete. Do not leave boxes blank. Please provide maps and sketches if appropriate. Copy pages for more than one circuit.

Section 1 – Property of interest – UKCCS to complete
Section 2 – Circuit details - DNO to complete

Section 1 Address of Interest – to be completed by UKCCS

STUDY ID:	
LOCATION	
Address 1:	
Address 2:	
Address 3:	
Postcode:	
Grid ref:	
Phase 1 (2 hrs from following start time)	Phase 2 (48 hrs from following start time)
Date: Time	Date: Time:

Previous electricity company:

Contact Person:

Section 2 – to be completed by the Distribution Network Operator

2.1 Contact details

Electricity company: Contact name:

Phone: Fax: E-mail:

If necessary can we contact you directly to discuss the circuit details? Y☐ N☐

2.2 Distribution mains and service connection
Please provide a large-scale map showing the distribution mains (415 V) passing the property and the service drop. Map available? Y ☐ N☐

2.2.1 Distribution mains in front of property
Please indicate which of the following applies:-

a) Overhead line
Distance to closest point on boundary (m) and on house (m)

☐ Phase separated (open wire) No of phases ☐ ABC

Are the phase cables attached to the property? Y ☐ N☐ DK☐
Please provide sketch or diagram if necessary.

b) Underground cable
No of phases

Describe the cable layout and construction (provide sketch or diagram if necessary)

Depth (m) Distance to closest point on boundary (m) and on house (m)

c) Are the phases generally balanced? Y ☐ N☐ DK☐
Please describe if necessary

2.2.2 Service connection to the property
Indicate the type of service drop by ticking one of the following:-

☐Aerial bundled conductor (ABC) ☐ Under-eaves attachment ☐ Mural attachment

☐ Underground cable

Please provide a sketch or diagram of the service connection to the property and the junction with the distribution mains. Sketch/diagram available? Y ☐ N☐

2.2.3 Earthing practice
Please indicate the type of earthing system that applies:-

Local earth rod ☐ PME ☐ Non PME ☐ Don’t know ☐

2.2.4 Circuit Typicality
Please confirm that none of these circuits have changed (configuration or load) since the time of the original study measurements (see section 1).

Changes ☐ No changes ☐ Don’t know ☐

Please describe any change(s) and date(s):

2.2.5 Other current-carrying circuits passing the house
Please list and give distances of other current carrying circuits passing in front of the house:-

2.3 High voltage circuits
Provide a map showing any high voltage (>415 V) circuits located within 400 m of the property
Map available? Y ☐ N☐

2.3.1 Underground cables
Please identify any high voltage cables within 50 metres of the property:-

Circuit details: ☐ Single ☐ Dual Voltage (kV) Rating (kA)

Depth below surface (m)

Phase arrangement: ☐bundled ☐ separated

If separated give phase separation (m) Provide a sketch or diagram if necessary.

Distance from property (m)

2.3.2 High voltage overhead lines
Please identify any high voltage overhead lines within 400 metres of the property:-

Circuits: Single ☐ dual ☐ Voltage (kV) Rating (kA)

Distance to centre of property (m)

For dual circuits
Phase arrangement: Transposed☐ Untransposed ☐ Provide sketch if necessary.

2.3.3 Substations and transformers
Identify any transformer within 100 m of the property: -

Name Location Distance from property (m)
Primary voltage Circuits: Underground ☐ Overhead ☐

Secondary voltage Circuits: Underground ☐ Overhead☐

2.3.4 Typicality
Please confirm that the above circuits have not changed since the date of the original measurements?

Changes ☐ No changes ☐ Don’t know ☐

Please describe any change(s) and date(s):

APPENDIX B STAGE 2 PROTOCOL

B1 Objectives

The aim of STAGE 2 is to locate the key source(s) inside and/or outside the home that cause(s) the high exposure (0.2 μT or greater). STAGE 2 involves measurements inside and outside the property.

The LRF EGU will determine which homes can be visited. STAGE 2 is restricted to the case-control high-low subjects who are the original homeowners, and who have given written consent for participation in the study. In seeking agreement to participate LRF EGU will seek informed consent from householders. The procedure for obtaining informed consent is briefly described below; the approach procedure will have to be flexible depending on individual circumstances. Surveys in homes will be conducted according to a Code of Practice agreed between LRF EGU and NRPB.

NRPB staff will carry out each STAGE 2 survey, and the time in each home is expected to be up to 2 hours. LRF EGU and NGT personnel might also attend site visits.

The procedures described below cover the practical aspects of the STAGE 2 survey work. Trials will be carried out by NRPB at the beginning of STAGE 2, to determine the precise survey methods. NGT staff will assist in these trials.

B2 Protocol

B2.1 Site visit preparation

a) LRF EGU staff approach homeowners on an individual basis, taking account of individual family circumstances. Information about the study is given and informed consent for participation sought. Convenient days and times for NRPB staff to visit, including preferred method of contact by NRPB staff to arrange an appointment (for example letter, telephone call) is ascertained. A contact name and telephone number at LRF EGU is given to all homeowners approached.

b) LRF EGU sends contact details of consenting homeowners to a named contact at NRPB.

c) NRPB contacts the homeowner and arranges a suitable time for the site visit. The contact will be made about one week beforehand. The homeowner will receive information from LRF EGU about the study. NRPB will describe the practical aspects of the work to the house owner so that inconvenience is minimised (section B2.2 below). The maximum time for completion of the visit will be 2 hours.

d) The STAGE 1 site report will be reviewed to become familiar with the site and likely current carrying sources located near to the home.

B2.2 Site visits

Initially standardised measurement procedures will be used, to facilitate comparison between high and low exposure homes. More investigative approaches will then follow if necessary.

B2.3 Initial standardised procedure

The standardised measurements will determine the ambient exposure level and establish whether the field is uniform throughout the house, which might suggest that the important source is outside the home. Localised fields, changing rapidly in space would be expected to be more indicative of point sources located inside the home.

a) On arrival at the home position logging meters centrally in the Family Room and at the bedside position and start recording the field. Try to establish if furniture in rooms has been re-arranged since the time of the original UKCCS measurements.

b) Measure the centre and corner-room magnetic field levels in each room of the house using a hand-held meter and event markers. (Measurements should be made at least 1 m from walls and at 1 metre above the floor level).

c) If possible switch off the power to the home to determine whether a high field is coming from an internal or external source. This should not be done without consulting the homeowner.

d) If possible investigate the net currents in electricity, gas and water mains. Record the net current flowing on the service connections to the house. In the case of the electricity mains use a clip-on ammeter to measure the net current at three positions, in the complete cable (beyond the connection to the earth sheath), in the earth sheath, and the live and neutral conductors together.

e) Locate and note the position of the incoming electricity, gas and water mains.

f) Identify the earthing arrangements for the distribution network (where the earth electrodes are, if any) and for the consumer's installation (e.g. termination details and cross bonding etc).

g) Try to establish if the house has been re-wired since the time of the original measurements.

h) Register the above information on an appropriate (STAGE 2) report sheet, including date of visit, meter identity numbers, positions, calibration dates, and the time of the survey. Sketch a plan of each level of the home, including the position of the electricity meter, and appliances that are close to the original UKCCS measurements. These should include appliances such as night-storage heaters, central heating pumps, clock radios, immersion heaters, bell transformers, fluorescent lights, burglar alarms, and fish tank pumps.

B2.4 Identifying specific sources

The standardised measurements will provide information about the likely sources of high fields at the time of the survey. Consideration should be given to the following: -

a) External sources

These sources have largely been considered during STAGE 1. Check field levels in the home. Uniform fields throughout the home might be indicative of sources outside the home.

b) Point type sources such as appliances.

High fields may be encountered close to certain appliances. Record the fall-off rates and positions on the STAGE 2 Site Report Form. Check the usage pattern and whether the appliance existed at the time of the original measurements.

c) Faults in ring mains

Elevated fields close to walls can be indicative of net currents in a ring main arising from a wiring fault. Try to measure the field in the centre of rooms with and without dummy loads. The field will increase under load conditions if there is a ring main fault.

d) Lighting and wiring faults

Record the field with and without lights switched on. In particular check two-way lighting, which can produce high fields under certain wiring conditions.

B2.5 Measurements outside the home

If possible repeat the STAGE 1 LINDA profiles and extend these up to the property boundary. Outdoor measurements should be arranged after the indoor work has finished. Permission should be sought to make measurements in the garden as necessary.

B2.6 Contact Voltage Measurements

If possible during the visit contact voltages will be measured as described below: -

a) Tap to drain at kitchen sink and bath.

Using a DVM, measure the voltage between the metallic part of the plughole and the tap. Then connect a 1 kΩ resistor across the meter terminals and measure the voltage again. This pair of measurements will enable the source impedance and the current that would flow through a person in electrical contact with both drain and tap to be measured.

Repeat these two voltage measurements at the kitchen sink.

b) Water pipe to electrical earth

Locate the point where the water main enters the home and find the point where the bond to the electrical earth is connected. Attach one probe of the DVM to this point. Using a standard mains plug with a wire attached only to the earth pin, make a connection to the electrical earth at a nearby electricity socket. Measure the voltage between these two connections. Repeat the measurement with a 1 kΩ resistor connected across the meter terminals.

c) Measurements involving ground rod

Take a metal stake and hammer, choosing a suitable location outside the house, hammer the stake into the ground. Connect a reel of wire to the stake at one end and to the DVM at the other end and connect the other meter terminal to the electrical earth pin. Repeat this with a 1 kΩ resistor connected across the meter terminals.

Connect the voltmeter to the stake and to the water main and again measure the voltages with and without the 1 kΩ resistor.

These measurements have three degrees of priority. The measurements in the bathroom and kitchen (A) are the most important. The voltages between electrical earth and water main (B) are the next most important and are little extra trouble. The measurements involving the ground rod are also useful but discretion will be needed about whether there is time to do them.

B3 Information about the study

Residential Sources Study

THE UNIVERSITY of York

DEPARTMENT OF HEALTH SCIENCES

EPIDEMIOLOGY & GENETICS UNIT

National Radiological Protection Board

Information for those taking part

What is the study?

We are researchers who are interested in the sources of magnetic fields in people's homes. We are inviting you to take part in a study which will give us a better understanding of this. The following information explains the research in more detail and what it would involve for you. Please take time to read through the information carefully and discuss it with friends and relatives if you wish. Please ask the study co-ordinator (Pat Ansell, telephone 01904 321890) if there is anything that is not clear or if you would like more information.

What is the purpose of this research?

In the UK Childhood Cancer Study (UKCCS) we found that not all the homes with higher exposures were associated with obvious features of the electricity supply system such as high voltage power lines. We do not know why this is and in this study we are trying to find why. This may or may not be of benefit to you, but the study will provide valuable information for society in general.

Why have I been chosen?

You are being asked to take part because you previously participated in the UKCCS. We have selected a sample of the participants in that study to investigate how exposure to magnetic fields at home depends on sources such as appliances, and internal and external wiring circuits.

Do I have to take part?

We hope you will be able to find the time to help us, but you are under no obligation to take part in the research. If you think you might like to take part please complete and return the enclosed consent form and post it in the pre-paid envelope. You are free to leave the study at any point without having to give a reason.

What will happen if I decide to take part?

Once we have received your consent form we will contact you to arrange a time when we come to your home to make the measurements. We will record the magnetic field inside and outside your home, using small meters, some left on stands and others hand-held by the researchers. Inside your home we will make measurements in the living room and one of the bedrooms, hopefully in the positions used in the original study. We will need to switch lights on for short periods during the visit, and to plug equipment into the mains. The measurements outside the property will stretch from the road up to the edge of the property, and we may wish to make measurements in your garden, although we will seek permission first.

A qualified electrician will look at the electrical wiring, and water and gas pipes inside the house, and make a number of electrical measurements at various locations around the property. We may need to take photographs of wiring in and around the house, however, we will ask before doing so.

How long will the visit take?

The visit will take no longer than two hours. You will be contacted by phone about one week before to arrange a suitable time for our visit. The visit will normally take place during working hours between 0900 and 1700hrs Monday-Friday, although we can arrange an alternative time if necessary.

Do I need to be present during the visit?

It would be helpful if you are present during the visit to answer questions about your home. We are able to offer you a disturbance allowance of £50, to allow for any inconvenience caused to you in arranging for our visit. At the end you will also be asked to complete a short questionnaire so that you can make comments if you wish.

Is the work an electrical wiring inspection?

We do not make a formal wiring inspection; however, if during the course of the work we suspect that there is an electrical fault, we will tell you about it. In some circumstances there may be the possibility of a free wiring inspection.

What happens if my home is damaged during the visit?

It is very unlikely that there will be any damage and we will make very effort to work safely in your home; however, we will cover the cost of any accidental damage of your property or goods. If there is damage please let the researcher know so that he can make a note of the incident and take photographs if necessary. At the end of the visit you will be asked to confirm there was no damage.

Is the work safe?

The procedures are relatively simple and do not present a hazard to you or the researchers; however, we do ask you to supervise any children in the house whilst we are working and to keep pets out of the way where possible.

What happens after the survey?

We hope to publish the findings of the study in a journal where all homes will be treated anonymously. A summary of the results for your home can be provided on request; however, you may be asked to pass on this sort of information if you sell your house. If you are unsure about the potential consequences of knowing the results you should contact your solicitor or local Citizen's Advice Bureau.

Who is doing the study?

The work is being carried out by researchers from the National Radiological Protection Board (NRPB) on behalf of the Epidemiology and Genetics Unit (EGU) at the University of York, who are responsible for the UKCCS data. The work is funded by the Department of Trade and Industry and the Energy Networks Association.

The NRPB's aim is to find out about the protection of mankind from radiation hazards, and to provide information and advice about protection from radiation hazards either of the community as a whole, or of particular sections of the community.

About EMFs in homes

What are power frequency magnetic fields?

EMFs arise from electricity, which is carried to appliances in the home by overhead and underground cables that form part of the electricity supply and distribution system. Power frequency magnetic fields are caused by electricity flowing through wires, cables and appliances.

What are the sources of power frequency magnetic fields in people's homes?

There are many potential sources of power frequency magnetic fields in homes, such as electrical appliances, household wiring, power lines and the electricity supply. The highest levels encountered in homes usually occur close to appliances in use and electrical wiring. Sources outside the home such as power lines and distribution circuits can also contribute to the fields measured in the home. Magnetic field levels may increase to a few microtesla (μT) close to domestic appliances or in homes beneath power lines. The lower background levels away from appliances usually come from distribution circuits outside the home.

What magnetic field levels are encountered in UK homes?

The background magnetic field levels encountered in UK homes are typically in the range 0.01–0.2 μT. It is estimated that about 0.5% of the UK population (1 in 200) have average residential exposures at or above 0.4 μT. The UK Childhood Cancer Study suggests that not all of the homes in the UK in which exposures were elevated were associated with obvious features of the electricity supply system such as high voltage power lines. This study has been set up to find out what causes the variability in levels of magnetic fields in homes.

How are people protected from possible health effects of EMFs?

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) have published guidelines on restrictions on exposure to EMFs that aim to ensure the avoidance of established adverse effects on people's health. Power frequency magnetic fields produce electrical currents in the body. Currents if sufficiently high inside the body can affect the control of movement and posture, memory, reasoning and visual processing. However the magnetic fields normally encountered in homes are such that the currents are much lower, and do not cause these effects. For power frequency magnetic fields, the ICNIRP reference level for public exposure is 100 μT.

Why is there concern about EMFs?

There has been some concern about the possibility of adverse health effects at lower levels of exposure to electromagnetic fields – notably cancer. The issue has been addressed by the independent Advisory Group on Non-ionising Radiation (AGNIR) under the chairmanship of Professor Sir Richard Doll, which provides advice to the Board of NRPB. AGNIR published its report on Extremely Low Frequency (ELF) Electromagnetic Fields and the Risk of Cancer in 2001. The review of experimental studies by AGNIR gives no clear support for a causal relationship between exposure to ELF EMFs and cancer. There is, however, some epidemiological evidence that suggests that there may be an association between average home exposure to magnetic fields at or above 0.4 μT and raised levels of childhood leukaemia. However, there is no clear reason why exposure to EMFs should cause cancer and the findings may be due to factors not accounted for in the way the data have been collected. NRPB's view is that currently the evidence is not strong enough to justify a firm conclusion that such fields cause leukaemia in children.

What will measurements in my home tell me?

The measurements are representative of the magnetic fields in your home at the time of the visit, and these can be compared directly with the ICNIRP exposure guidelines.

Can power frequency magnetic fields be reduced?

It is not always clear what factors result in elevated exposures in people's homes, which is the reason for this study. In some cases it may be possible for individuals to take simple, cheap effective measures to reduce exposure levels. In other cases the field is an inherent feature of a particular electricity supply system and it would be more difficult and expensive to reduce field levels.

More information

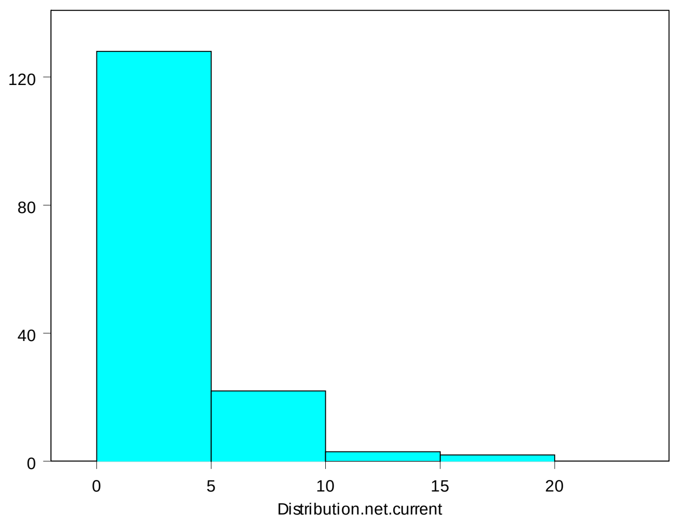
For more information on EMFs see NRPB's At-A-Glance Leaflet and or visit the website at http://www.nrpb.org.

APPENDIX C NET CURRENT STATISTICS

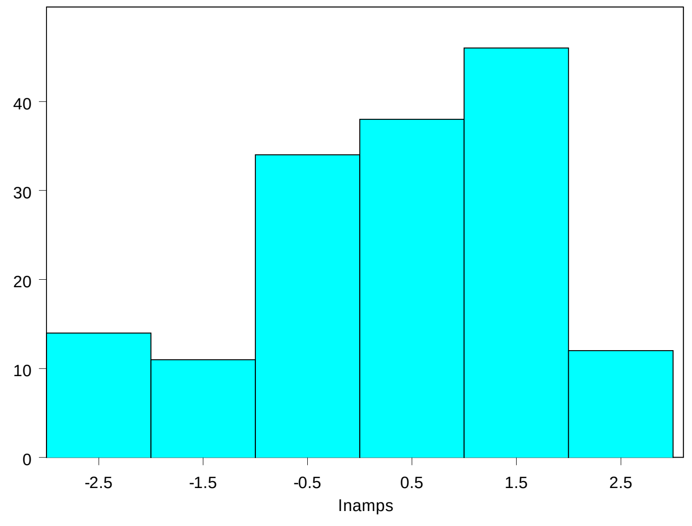
C1 Net currents in distribution mains cables

All homes where net current value assigned (N=155), based on Stage 1 LINDA profile assessments

```
 Distribution.net.current
     Min:   0.060000
 1st Qu.:   0.660000
    Mean:   2.673290
  Median:   1.750000
 3rd Qu.:   3.560000
     Max:  17.309999
 Total N: 155.000000
    NA's :   0.000000
Std Dev.:   2.995032
```

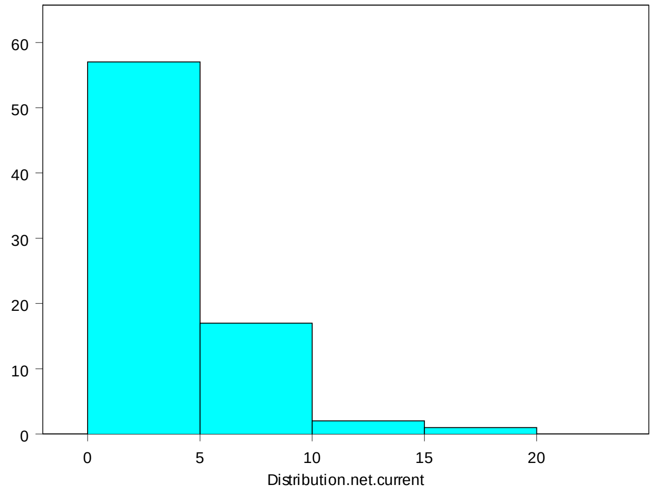



```
Log-transformed data
lnamps
     Min:  -2.8134107
 1st Qu.:  -0.4165496
    Mean:   0.2955678
  Median:   0.5596158
 3rd Qu.:   1.2691921
     Max:   2.8512843
 Total N: 155.0000000
    NA's :   0.0000000
Std Dev.:   1.3677610
```

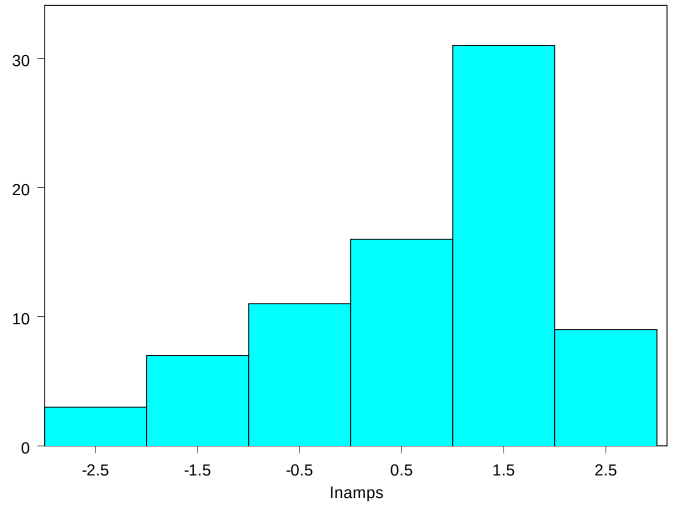


High exposure homes where net current value assigned (N=77), based on Stage 1 LINDA profile assessments

```
 Distribution.net.current
      Min:  0.060000
  1st Qu.:  0.910000
     Mean:  3.438312
   Median:  2.880000
  3rd Qu.:  5.000000
      Max: 17.309999
  Total N: 77.000000
    NA's :  0.000000
 Std Dev.:  3.221065
```

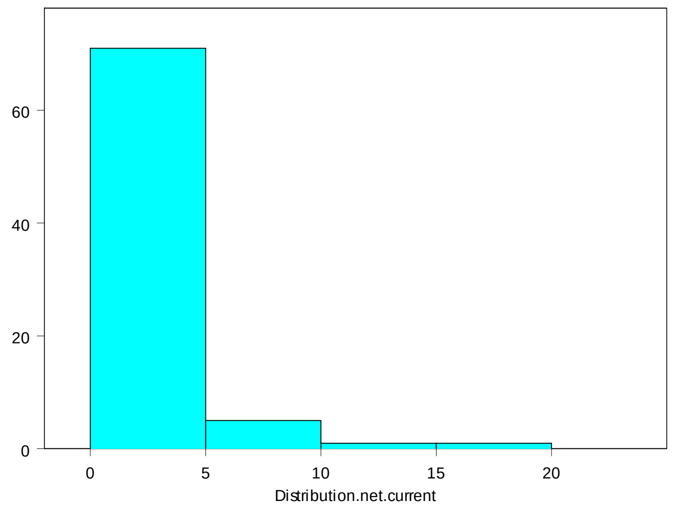



```
Log-transformed data
lnamps
      Min:  -2.81341074
  1st Qu.:  -0.09431065
     Mean:   0.67018686
   Median:   1.05779033
  3rd Qu.:   1.60943791
      Max:   2.85128434
  Total N:  77.00000000
    NA's :   0.00000000
 Std Dev.:   1.27427573
```

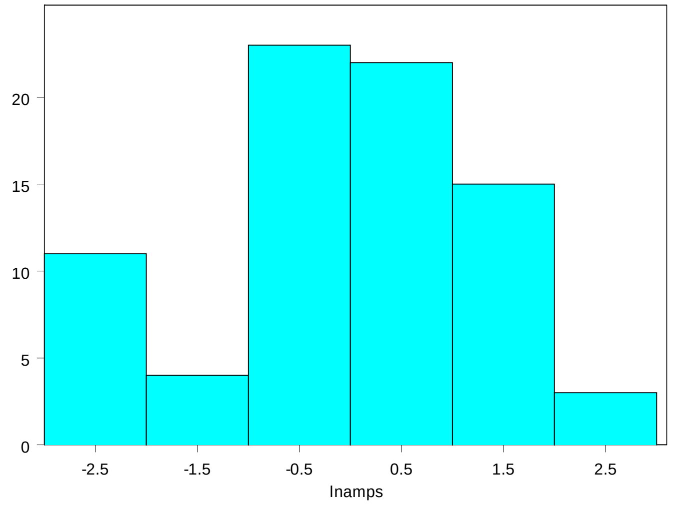


Low exposure homes where net current value assigned (N=78), based on Stage 1 LINDA profile assessments

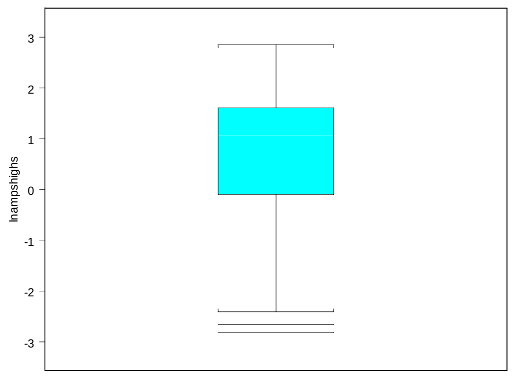
```
Distribution.net.current
     Min:  0.060000
 1st Qu.:  0.577500
    Mean:  1.918077
  Median:  1.000000
 3rd Qu.:  2.425000
     Max: 15.630000
 Total N: 78.000000
    NA's :  0.000000
Std Dev.:  2.556737
```

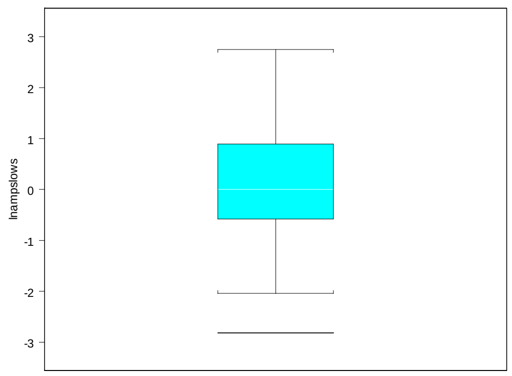



```
Log-transformed data
lnamps
     Min:  -2.81341074
 1st Qu.:  -0.55037274
    Mean:  -0.07424852
  Median:   0.00000000
 3rd Qu.:   0.88577368
     Max:   2.74919215
 Total N:  78.00000000
    NA's :   0.00000000
Std Dev.:   1.36380717
```



Comparison of net currents in high and low exposure homes (Log-transformed data)



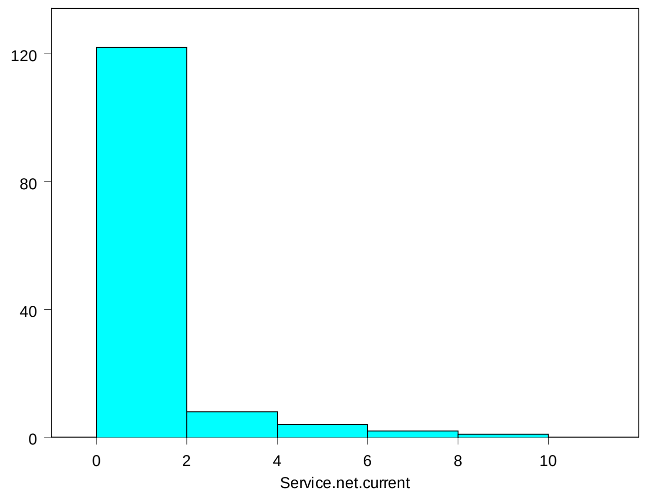



```
Wilcoxon rank-sum test

data:  x: lnampshighs in highlowcomparison , and y: lnampslows in
highlowcomparison
rank-sum normal statistic with correction Z = 3.7375, p-value = 0.0002
alternative hypothesis: true mu is not equal to 0

Wilcoxon rank-sum test

data:  x: lnampshighs in highlowcomparison , and y: lnampslows in
highlowcomparison
rank-sum normal statistic with correction Z = 3.7375, p-value = 0.0001
alternative hypothesis: true mu is greater than 0
```

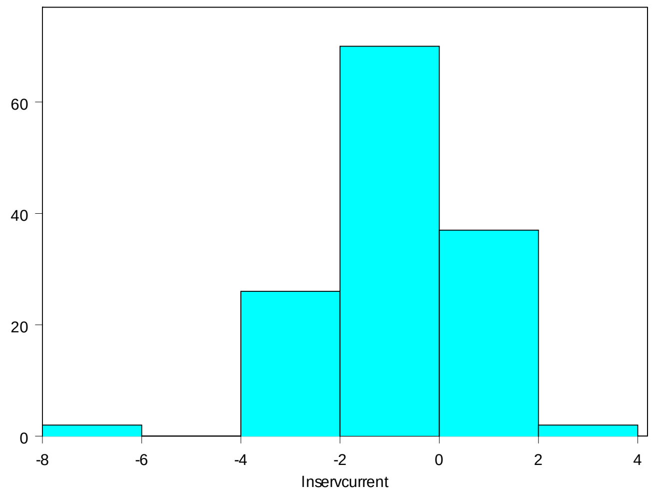
C2 Net current in service cables

All homes where net current value assigned (N=145), based on Stage 1 LINDA profile assessments

```
Service.net.current
      Min:          0.0010000
  1st Qu.:          0.1800000
     Mean:          0.9197931
   Median:          0.3600000
  3rd Qu.:          1.0800000
      Max:          8.3999996
  Total N:        145.0000000
    NA's :          0.0000000
 Std Dev.:          1.4352127
```




```
Log-transformed data
lnservcurrent
      Min:   -6.90775528
  1st Qu.:   -1.71479839
     Mean:   -0.91130147
   Median:   -1.02165121
  3rd Qu.:    0.07696108
      Max:    2.12823166
  Total N:  145.00000000
    NA's :    0.00000000
 Std Dev.:    1.40044182
```



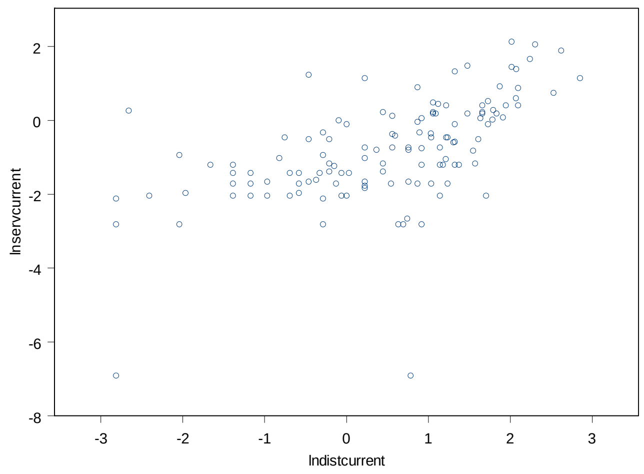
Correlation of net currents in distribution mains and service cables (n=145)

Distribution and service circuits where values of net currents both assigned

Log transformed data

Spearman's rank correlation

data: distribution and service
normal-z = 7.8771, p-value = 0
alternative hypothesis: true rho is not equal to 0
sample estimates:
rho
0.6754596



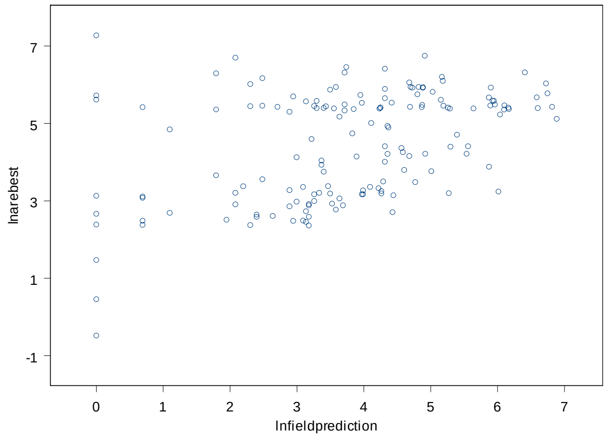
C3 Correlation of field predictions from net currents in distribution mains and UKCCS exposure estimate

All data where net current value assigned (n=155)

Log-transformed data

Spearman's rank correlation

data: prediction and exposure
normal-z = 5.1974, p-value = 0
alternative hypothesis: true rho is not equal to 0
sample estimates:
rho
0.4188184

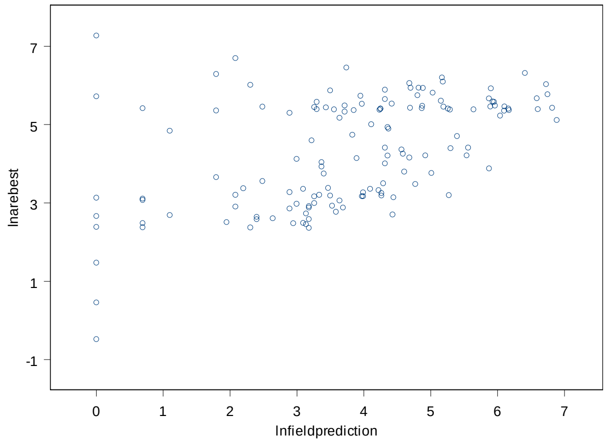


Power line- and appliance–related exposures removed (n=141)

Log-transformed data

Spearman's rank correlation

data: prediction and exposure
normal-z = 6.0815, p-value = 0
alternative hypothesis: true rho is not equal to 0
sample estimates:
rho
0.5139831

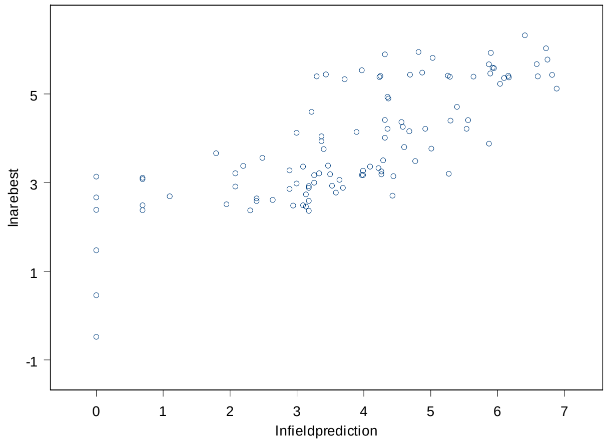


Powerline-, appliance- and internal wiring-related exposures removed (n=106)

Log-transformed data

Spearman's rank correlation

data: prediction and exposure
normal-z = 8.0541, p-value = 0
alternative hypothesis: true rho is not equal to 0
sample estimates:
rho
0.7860085



APPENDIX D DESCRIPTION OF LV CIRCUITS

D1 Introduction

This appendix provides clarification of the terms used in the report. The information is compiled from a number of published sources including the Institution of Electrical Engineers Wiring Regulations [1] and the Electricity Safety, Quality and Continuity Regulations [2], and from informal communication with engineers in the electricity industry.

The LV distribution system in the UK is three-phase, though most domestic consumers require only one phase plus neutral [3]. 400 V refers to the RMS voltage between any two phases in a distribution main whereas 230 V refers to the RMS voltage in one particular phase. The load current is the current drawn by the consumer. If the phase conductors are separated, magnetic fields are produced due to poor cancellation in the same way as in transmission lines. Net currents arise in unbalanced circuits where the neutral current returns along the neutral of a different circuit. Where metallic pipes provide the water service, the network of piping can result in a low impedance path, which is used by the return current in preference to the neutral conductor supplied by the utility [3].

D2 Distribution main and service connections

Distribution main - the connection between the supply transformer and service line. The distribution main may consist of a three phase four-wire, two phase three-wire, single phase three-wire or single phase two-wire construction. In the old TN-S system the main consisted of 5 conductors; 3 phase conductors, a neutral and an earth. Since 1974, and the introduction of the TN-C system and Protective Multiple Earthing (PME), the distribution main consists of 4 conductors; 3 phase and a combined neutral and earth (CNE) conductor [3]. PME networks and their application have been described elsewhere [4, 5, 6].

Service line - the line from the distribution mains to the supply terminals of a single customer or 2, 3 or 4 customers occupying a single property [1,2]. In the TN-S system, three conductors enter the premises; one phase a neutral and an earth. In the TN-C system the service line consists of two conductors; one phase and a neutral to which the consumers earth terminal is bonded. The current on any particular service line is usually restricted to < 100 A. In rare cases where residences may require additional power, such as rural areas without gas for instance, the service line may consist of two phases 180^{o} apart, allowing the delivery of more power. In such cases the line might consist of three separated conductors.

D3 Overhead lines

Overhead distribution main - the overhead line used for the 400 V final distribution main. In the UK about 15% of homes (mainly in rural areas) have an overhead distribution main [7]. In most cases the conductors are separated by 150 to 300 mm and there is a magnetic field produced by the phase current. The phase current field falls as $1/r^2$ whereas the net current falls as 1/r [7]. Close to a line the phase-current generated field tends to be dominant whereas as the distance increases the net current field begins to dominate.

In some older terraced properties, two or three phases and a shared neutral conductor, may be attached to a home and feed along under the eaves of several properties, or as mural wiring, with single phase take-offs to each home.

Overhead service – the overhead line that connects the distribution main and the home. The majority of overhead service lines to domestic properties comprise one phase and one neutral conductor. Neutrals are wired in similar ways to those of underground circuits and thus net currents exist for the same reasons. Two or three phase service connections to individual domestic properties are rare but do occur in properties with unusual load requirements such as heated swimming pools or large boilers.

Open Wire – a term used to describe overhead separated non-insulated conductors. It may apply to mains distribution circuits or service lines. About one third of homes with overhead supplies have a service connection consisting of separated conductors [7]. This leads to magnetic fields arising from the load (phase) current in the service connection. In the remainder of cases the service connection is either underground or consists of overhead bundled conductors.

Concentric Cable - a cable arrangement consisting of a neutral conductor enclosing but insulated from a central phase conductor. When used as a service line the magnetic fields produced are similar to those produced by underground service cables. The magnetic fields due to phase currents are negligible due to effective cancellation but fields due to net currents can occur.

Aerial Bundled Conductor (ABC) – normally refers to a modern mains cable consisting of insulated wrapped phase conductors and a neutral conductor. Magnetic fields produced by these are similar to those from underground distribution main cables. Magnetic fields due to phase currents are negligible due to efficient cancellation but fields due to net currents can occur.

Pole Mounted Transformer (PMT) – the transformer which normally connects a HV (11 kV) line with a distribution main line.

Under-eaves wiring – refers to the attachment of service line(s) to a property or properties, which is installed under the eaves of one or more properties.

D4 Definitions from the IEE Wiring Regulations

Bonding conductor – a protective conductor providing equipotential bonding.

Bunched - cables are said to be bunched when two or more are contained within a single conduit, duct, ducting or trunking or if not enclosed, are not separated from each other by a specified distance.

Cable ducting – an enclosure of metal or insulating material, other than conduit or cable trunking, intended for the protection of cables which are drawn-in after erection of the ducting.

Circuit - an assembly of electrical equipment supplied from the same origin and protected against overcurrent by the same protective devices(s).

Conduit - a part of a closed wiring system for cables in electrical installations, allowing them to be drawn in and / or replaced, but not inserted laterally.

Current-carrying capacity of a conductor - the maximum current which can be carried by a conductor under specified conditions without its steady state temperature exceeding a specified value.

Design current (of a circuit) - the magnitude of the current (rms for ac) to be carried by the circuit in normal service.

Distribution board – an assembly containing switching or protective devices (e.g. fuses, circuit-breakers, residual current devices) associated with one or more outgoing circuits fed from one or more incoming circuits, together with terminals for the neutral and protective circuit conductors. It may also include signalling or other control devices. Means of isolation may be included in the board or may be provided separately.

Duct - a closed passage way formed underground or in a structure and intended to receive one or more cables, which may be drawn in.

Earth - the conductive mass of the Earth, whose electric potential at any point is conventionally taken as zero.

Earth electrode - a conductor or group of conductors in intimate contact with, and providing an electrical connection to Earth.

Earth electrode resistance - the resistance of an earth electrode to Earth.

Earth fault current - a fault current which flows to Earth.

Earth concentric wiring - a wiring system in which one or more insulated conductors are completely surrounded throughout their length by a conductor, for example a metallic sheath, which acts as a PEN conductor.

Earthing – connection of the exposed-conductive-parts of an installation to the main earthing terminal of that installation.

Earthing conductor - a protective conductor connecting the main earthing terminal of an installation to an earth electrode or to other means of earthing.

Electrical installation - an assembly of associated electrical equipment supplied from a common origin to fulfil a specific purpose and having co-ordinated characteristics.

Fault - a circuit condition in which current flows through an abnormal or unintended path. This may result from an insulation failure or the bridging of insulation. Conventionally the impedance between live conductors or between live conductors and exposed or extraneous-conductive-parts at the fault position is considered negligible.

Fault current - a current resulting from a fault.

Fuse – a device which by melting of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time. The fuse comprises all the parts that form the complete device.

Highway - any way (other than a waterway) over which there is public passage and includes the highway verge and any bridge over which, or tunnel through which the highway passes.

Insulation - suitable non-conductive material enclosing, surrounding, or supporting a conductor.

Leakage current – electric current in an unwanted conductive path under normal operating conditions.

Live part - a conductor or conductive part intended to be energised in normal use, including a neutral conductor but, by convention, not a PEN conductor.

Main earthing terminal - the terminal or bar provided for the connection of protective conductors, including equipotential bonding conductors, and conductors for functional earthing if any, to the means of earthing.

Neutral conductor - a conductor connected to the neutral point of a system and contributing to the transmission of electrical energy.

Overcurrent - a current exceeding the rated value. For conductors the rated value is the current-carrying capacity.

PEN conductor - a conductor combining the functions of both protective conductor and neutral conductor.

Phase conductor - a conductor of an ac system for the transmission of electrical energy other than a neutral conductor, a protective conductor or a PEN conductor.

Protective conductor - a conductor used for some measures of protection against electric shock and intended for connecting together any of the following parts: 1) exposed-conductive-parts 2) extraneous-conductive-parts 3) the main earthing terminal 4) earth electrode(s) 5) the earth point of the source, or an artificial neutral.

Protective multiple earthing (PME) – an earthing arrangement found in the TN-C-S systems, in which the supply neutral conductor is used to connect the earthing conductor of an installation with Earth, in accordance with the Electricity, Safety, Quality and Continuity Regulations 2002.

Residual current - the algebraic sum of the currents in the live conductors of a circuit at a point in the electrical installation.

Ring final circuit - a final circuit arranged in the form of a ring and connected to a single point of supply.

Switchboard - an assembly of switchgear with or without instruments, but the term does not apply to groups of local switches in final circuits.

Switchgear - an assembly of main and auxiliary switching apparatus for operation, regulation, protection or other control of an electrical installation.

System - an electrical system consisting of a single source of electrical energy and an installation. For certain purposes of the Regulation types of system are identified as follows, depending on the relationship of the source and of exposed-conductive-parts of the installation, to Earth:

TN system - a system having one or more points of energy directly earthed, the exposed-conductive-parts of the installation being connected to that point by protective conductors.

TN-C system – a system in which neutral and protective functions are combined in a single conductor throughout the system.

TN-S system – a system having separate neutral and protective conductors throughout the system.

TN-C-S system – a system in which neutral and protective functions are combined in a single conductor in part of the system.

TT system - a system having one point of the source of energy directly earthed, the exposed-conductive-parts of the installation being connected to earth electrodes electrically independent of the earth electrodes of the source.

IT system - a system having no direct connection between live parts and Earth, the exposed-conductive-parts of the electrical installation being earthed.

Wiring system - an assembly made up of cable or busbars and parts which secure and, if necessary, enclose the cable and busbars.

D5 Definitions from the Electricity Safety, Quality and Continuity Regulations 2002

Consumer's installation - the electric lines situated upon the consumer's side of the supply terminals together with any apparatus permanently connected or intended to be permanently connected thereto on that side.

Distributing main – a low voltage electric line which connects a distributor's source of voltage to one or more service lines or directly to a single consumer's installation.

Electric line – any line which is used or intended to be used for carrying electricity for any purpose and includes, unless the context otherwise requires -

a) any equipment connected to any such line for the purpose of carrying electricity; and

b) any wire, cable, tube, pipe, insulator or other similar thing (including its casing or coating) which surrounds or supports, or is associated with, any such line.

Generating station - those parts of any premises which are principally used for the purposes of generating electricity.

High Voltage (HV) - any voltage exceeding low voltage.

Low Voltage (LV) - in relation to alternating current, a voltage exceeding 50 volts measured between phase conductors (or between phase conductors and earth), but not exceeding 1000 volts measured between phase conductors (or 600 volts if measured between phase conductors and earth), calculated by taking the square root of the mean of the squares of the instantaneous values of a voltage during a complete cycle.

Network - an electrical system supplied by one or more sources of voltage and comprising all the conductors and other equipment used to conduct electricity for the purposes of conveying energy from the source or sources of voltage to one or more consumer's installations, street electrical fixtures, or other networks, but does not include an electrical system which is situated entirely on an offshore installation.

Neutral conductor - a conductor which is, or is intended to be, connected to the neutral point of an electrical system and intended to contribute to the carrying of energy;

Overhead line - any electric line which is placed above ground and in the open air.

Phase conductor - a conductor for the carrying of energy other than a neutral conductor or a protective conductor or a conductor used for earthing purposes.

Protective conductor - a conductor which is used for protection against electric shock and which connects the exposed conductive parts of equipment with earth.

Service line - an electric line which connects either a street electrical fixture, or no more than four consumer's installations in adjacent buildings, to a distributing main.

Substation - any premises or part thereof which contain equipment for either transforming or converting energy to or from high voltage (other than transforming or converting solely for the operation of switching devices or instruments) or for switching, controlling or regulating energy at high voltage, but does not include equipment mounted on a support to any overhead line.

Supplier - a person who contracts to supply electricity to consumers.

Supply - the supply of electricity.

Supply neutral conductor - the neutral conductor of a low voltage network which is or is intended to be connected with earth, but does not include any part of the neutral conductor on the consumer's side of the supply terminals.

Supply terminal - the ends of the electric lines at which the supply is delivered to a consumer's installation.

Support - any structure, pole or other device, in, on, by or from which any electric line is or may be supported, carried or suspended and includes stays and struts, but does not include insulators, their fittings or any building or structure the principal purpose of which is not the support of electric lines or equipment.

Switching device - any device which can either make or break a current, or both.

Underground cable - any conductor surrounded by insulation which is placed below ground.

D6 References

1. IEE Wiring Regulations, 16th Edition, The British Standard Requirements for Electrical Installations, BS 7671 (2001).

2. The Electricity, Safety, Quality and Continuity Regulations 2002. Statutory Instrument No.2665.

3. Rauch GB *et al*. A comparison of International Grounding Practices and Associated Magnetic Fields. *IEEE Trans. on Power Delivery*, **7**, No 2 (1992).

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5. Use of PME Earth Terminals on Overhead Distributors, D Fathers, IEE Power Engineering Journal, December 1994, pp 261-264.

6. Engineering Recommendation G12/3. Requirements for the Application of Protective Multiple Earthing to Low Voltage Networks, The Electricity Association (now Energy Networks Association) (1995).

7. Merchant CJ *et al.* Exposures to Power-frequency fields in the Home. *J. Radiol. Prot.*, **14**, No 1, 77-87 (1994).