EirGrid Evidence Based Environmental Studies

Study 1: EMF

Literature review of electromagnetic fields (EMF) and human health, and an evidence base of EMF measurements from the Irish Transmission System.

GRID25
DELIVERING IRELAND'S ELECTRICITY FUTURE

RPS

EirGrid Evidence Based Environmental Studies: EMF

Report prepared for EirGrid Plc. by RPS Group.

The following authors are gratefully acknowledged, Tom Dearing, Dr Andrew Buroni, and Daniel Smyth, all RPS Group, with external peer review from Dr Michael Repacholi.

July 2014

DISCLAIMER

RPS has used reasonable skill and care in completing this work and preparing this report, within the terms of its brief and contract and taking account of the resources devoted to it by agreement with the client. We disclaim any responsibility to the client and others in respect of any matters outside the stated scope. The opinions and interpretations presented in this report represent our reasonable technical interpretation of the data made available to us. RPS accepts no responsibility for data provided by other bodies and no legal liability arising from the use by other persons of data or opinions contained in this report.

Except for the provision of professional services on a fee basis, RPS does not have a commercial arrangement with any other person or company involved in the interests that are the subject of this report.

RPS
6-7 Lovers Walk
Brighton
BN1 6AH
T: +44 (0) 1273 546800
F: +44 (0) 1273 546801
E: rpsbn@rpsgroup.com
W: www.rpsgroup.com

Executive Summary

Project Background

EirGrid, the Transmission System Operator in Ireland, is in the process of implementing Grid25, its strategy for how the Irish transmission network will be developed in the long term to meet the challenges of increasing electricity demand and diversified generation sources. Developments under the Grid25 strategy will include upgrading existing high-voltage electricity transmission infrastructure and construction of new infrastructure, such as overhead power lines and substations.

At an early stage of this process, EirGrid has commissioned a series of literature reviews and evidence-based studies that examine the actual effects on people and the environment of the construction and operation of existing high-voltage electricity transmission infrastructure, including 110 kV, 220 kV and 400 kV overhead lines, underground cables and substations.

The results of these studies will be used to inform the planning and design of transmission infrastructure projects, ensuring that design guidelines for new transmission projects will be based upon robust data, including the most effective measures to mitigate any negative impacts identified. The findings will also enable the Environmental Impact Assessment (EIA) of such developments to focus the scope on the most significant potential impacts, and base assessments upon a high standard of existing data.

This study addresses the potential human health impacts of electromagnetic fields (EMF), and is presented in two parts: a literature review, and an evidence base of real-world EMF measurements.

Literature Review

A literature review has been conducted of the extremely low frequency (ELF) EMF health evidence base, including the position of authoritative health protection bodies and emerging research. The review complements measurements taken of EMF from high-voltage electricity transmission infrastructure in Ireland, with the combined objective of informing future grid infrastructure planning and more effectively addressing commonly raised community health concerns.

The review principally draws from extensive research collated within key documents from health protection bodies. The literature review has benefited from the advice, peer review and gap analysis of Dr Michael Repacholi, the inaugural chair of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and former EMF Task Group leader for the World Health Organisation (WHO).

The review explores a range of possible health effects from ELF EMF on human health, where the core documents developed by the International Agency for Research on Cancer (IARC) and WHO establish that the evidence for an association between ELF EMF exposure and carcinogenic effects, particularly leukaemia, is limited, and research does not rule in or out the possibility of a causal link. The evidence for other potential health effects such as Alzheimer’s, cardiovascular disease, and effects on the immune system does not support a substantive link with ELF EMF.

Extensive research has been conducted into the potential for health effects associated with ELF EMF; the 2007 WHO monograph alone draws upon around 1,000 published studies. While further research is considered desirable by WHO to investigate whether any causal mechanism underlies a possible correlation between ELF magnetic field exposure and childhood leukaemia, and whether the association is real or due to confounding factors, existing research has covered a wide breadth of topic areas, leaving limited avenues of emerging evidence.

Scientific research can provide evidence that something might be unsafe but cannot prove that no health effect occurs; the absence of an identified mechanism for causal effect does not in itself rule in or out the possibility of adverse health effects, but rather, has been a stimulus for ongoing research.

Existing public exposure guidelines from ICNIRP have been set based on established acute effects from EMF. They do not account for postulated possible long term health effects from extremely low frequency fields due to the uncertainty surrounding the evidence base, but do incorporate a significant reduction factor from the lowest threshold for established effects, to allow for uncertainty and for long-term exposure. It is considered appropriate by health protection bodies to remain within guidelines set to manage known health risks and where possible to further reduce unnecessary exposure.

Evidence Base

Measurements of EMF generated by a range of high-voltage electricity transmission infrastructure in Ireland have been undertaken during 2012-13. Infrastructure types measured comprised single and double circuit overhead lines at 110 kV, 220 kV and 400 kV, transformer substations at these voltages, and underground cables at 110 kV and 220 kV. Measurements were made at different times of day and year, at a series of distance intervals from each type of infrastructure. Measured magnetic field strength, which is directly dependent on the power load carried by the infrastructure item, has also been scaled to typical and high load conditions based on annual records of load for each infrastructure item measured.

The measurement results have been compared to health protection guidelines for public exposure to EMF developed by the ICNIRP, which are discussed along with the underpinning health evidence base in the literature review section.

The maximum magnetic field strength measured at all overhead lines, underground cables and substation perimeters surveyed was well below the ICNIRP public exposure reference level, set to protect public health. Based on the measured data, magnetic field strengths estimated for overhead power lines and underground cables using records of annual load are also well below the ICNIRP reference level to protect public health under typical (mean or median load) and high power load (95^{th} percentile) conditions.

The maximum electric field strength measured at all overhead lines and substation perimeters surveyed was below the ICNIRP reference level to protect public health. Underground cables produce no electric field above ground. Although the maximum electric field strength measured from the highest-voltage overhead line (400 kV) is relatively close to the ICNIRP reference level, this reference level is set on a highly conservative basis that ensures that the ICNIRP basic restriction for electric field exposure cannot be exceeded by external field strengths below the reference level.

Magnetic field strength decreased rapidly with distance from overhead lines and underground cables, as did electric field strength from overhead lines. Electric and magnetic field strength from substations at their perimeter was minor in comparison to overhead lines and underground cables, and likely to be influenced by nearby overhead lines or underground cables connecting to the substation.

Contents

Tables, Figures and Appendices

Tables

Figures

Appendices

Introduction

1 Introduction to EMF

1.1 Electromagnetic fields and the electromagnetic forces they represent are a fundamental part of the physical world. Electromagnetic forces are partly responsible for the cohesion of material substances and they mediate all the processes of chemistry, including those of life itself. EMF occur naturally within the human body (through nerve and muscle activity) and also arise from the magnetic field created by the Earth and electric fields in the atmosphere.

1.2 The sources of EMF with which this study is concerned are power frequency EMF in the frequency range below 100 kilohertz (kHz), i.e. the electric and magnetic fields produced wherever electricity is generated, distributed, or used.

1.3 As a rule, at higher frequencies the electric and magnetic fields are coupled together but as the frequency decreases, so the coupling decreases. At the frequency of 50 Hz used for electricity transmission in Ireland the electric and magnetic fields act independently. 50 Hz power-frequency EMF is sometimes referred to as extremely low frequency (ELF) EMF.

1.4 There are a number of man-made sources that generate electromagnetic fields: these include electric appliances, TV, radio, mobile phones and power lines. EMF can be divided into different bands, each having a range of frequencies that can interact in different ways with living organisms. These bands include ultraviolet radiation, visible light, infra-red radiation, microwaves, radiofrequency fields and extremely low frequency fields [1], all of which are classified as non-ionising radiation. At extremely low frequencies, which include the power frequencies of 50 Hz and 60 Hz, the electric and magnetic fields that produce electromagnetic fields are not coupled, act independently of each other and have almost no radiated energy. Unlike higher-frequency ionising radiation such as X-rays, ELF EMF does not have enough energy to break the bonds that hold molecules together and is therefore non-ionising. Figure 1.1 outlines the electromagnetic spectrum.

Figure 1.1: The Electromagnetic Spectrum (adapted from [1])

1.5 Ionising radiation occurs both naturally and from man-made sources. Natural sources include radioactive minerals remaining from the formation of the earth and also cosmic radiation entering the atmosphere from outer space. Man-made sources include the use of radioactive material in medical settings for diagnosing and treating disease and industrial settings through radioactive waste and the use of nuclear weapons [2]. Only the high frequency portion of the electromagnetic spectrum (which includes X rays and gamma rays) has enough energy to produce ionisation.

When ionising radiation interacts with an atom it can remove tightly bound electrons from the orbit of an atom causing the atom to become charged and subsequently making it more reactive [3]. In living tissue this can cause molecules within cells to be broken apart causing either cell death or abnormal reproduction of the cell.

1.6 The EMF from power lines, electrical equipment and sunlight does not have enough energy to cause ionisation. Ultraviolet (UV) radiation provides a good example of the physical interaction between humans and non-ionising EMF, with UV radiation sitting just below X-rays (which are ionising) in the frequency range. One source of UV radiation is sunlight, where exposure stimulates vitamin D synthesis but prolonged exposure can also lead to skin damage and skin cancer. The interaction and possible health outcomes for other bands of non-ionising EMF, including ELF EMF, are not as clearly defined. However, it has been postulated that an association could exist between ELF magnetic fields and a range of health effects including cancer, cardiovascular disease and neurodegenerative disorders, thereby creating an impetus for further health research to determine the possible link between ELF field exposure and health.

1.7 In a developed country such as Ireland, essentially the entirety of the population is exposed on a daily basis to power-frequency EMF; any possibility of health risks therefore receives significant attention because even a small health risk could potentially have large public-health consequences, given the size of the exposed population.

1.8 High-voltage power transmission utilising overhead and underground cables is not the only significant source of general public exposure to EMF. Low-voltage distribution circuits, household wiring and electrical appliances are typically a major source of exposure, providing most cases of higher exposure in a residential setting [4]. However, high-voltage transmission infrastructure can continuously generate relatively strong fields in close proximity and so is of potential importance for long-term exposure, albeit at lower field strengths in a residential setting given that both electric and magnetic field strength decrease with distance from the source and that electric fields are readily screened by most building materials.

Electric Fields

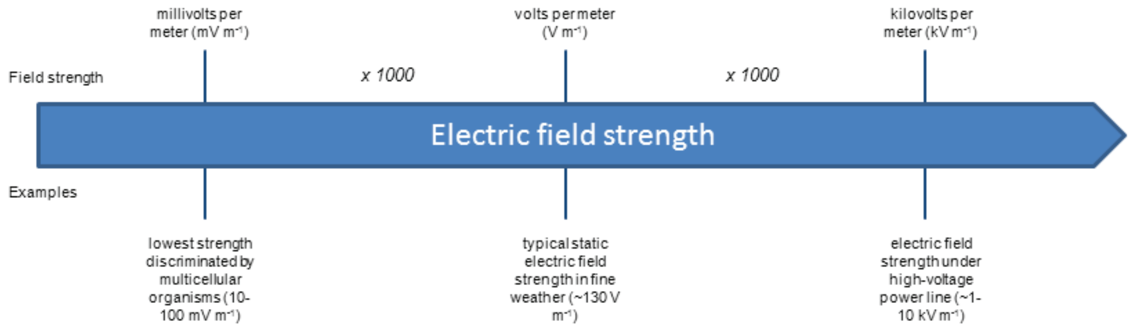
1.9 Electric fields are created in spaces between points at different voltages. Voltage (potential difference) can be described as the pressure behind the flow of electricity, analogous to the pressure of water in a hose.

1.10 Electricity in homes is at a voltage of 230 V but outside homes it is distributed at higher voltages, from 10 kV up to 400 kV. The naturally occurring atmospheric electric field at ground level is typically about 130 volts per metre (V/m) in fine weather and may rise to many thousands of volts per metre during thunderstorms.

1.11 Generally, the higher the voltage, the greater the electric field strength. However, electric fields are readily screened by most building materials and also by vegetation.

1.12 Electric field strength is directly dependent on the power line voltage, with the strongest field generated by the highest voltage power lines (400 kV). As with the magnetic field, the electric field strength measured at 1 m above ground level is also affected by conductor height for overhead lines. This is influenced by load and ambient temperature conditions, due to line sag caused by thermal expansion of the conductor material. However, the electric field strength is not as strongly dependent on load as the magnetic field strength. Figure 1.2 shows electric field strength units and examples.

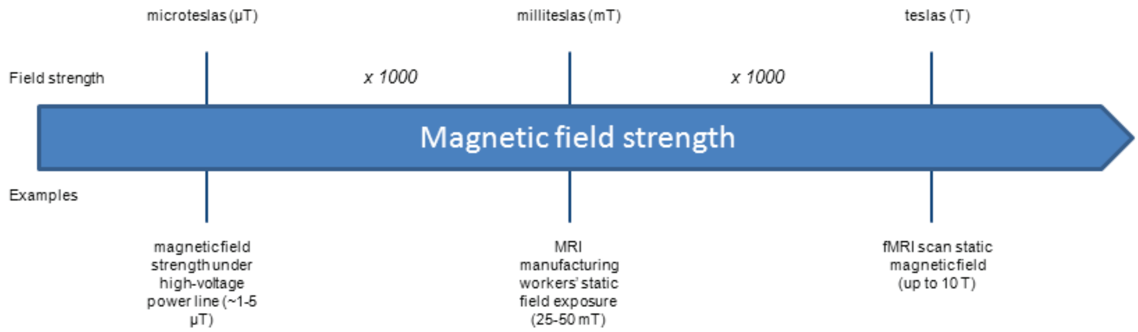
Figure 1.2: Electric field units



Magnetic Fields

1.13 Magnetic fields are produced by current, which is the flow of electricity. Current can be likened to the volume of water flowing in a hose when the nozzle is open. Anything that uses or carries mains electricity is potentially a source of power-frequency magnetic fields. The time-varying magnetic field from alternating current (AC) electricity transmission is separate to the Earth's natural (static) magnetic field, which varies between about 30 µT (microteslas) at the equator and 60 µT at the poles, being approximately 50 µT in Ireland. Figure 1.3 shows magnetic field strength units and examples[1].

Figure 1.3: Magnetic field units



[1] Note that throughout the document, magnetic flux density ***B*** (in tesla) is referred to as 'magnetic field strength', to reflect the widespread colloquial usage (rather than magnetic field strength ***H*** in A.m^{-1}). Reference levels and basic restriction equivalent external field strengths in guideline exposure limits are for the ***B*** field, expressed in tesla.

1.14 The strength of magnetic field generated by electrical equipment depends on the current carried by it: the greater the current, the greater the magnetic field. However, the field strength experienced at a given point depends on distance from the source and how the fields from different sources interact. As such, magnetic fields exist around a wide range of sources and their strength varies significantly within households, workplaces and the built and natural environment. A feature common to all such magnetic fields is that their strength decreases rapidly as the distance from the source increases.

Field Strength Calculation

1.15 Magnetic field strength *B* can be calculated using Ampère's law:

$$B = \frac{\mu_0 \, I}{2 \, \pi \, r}$$

where μ_o is the permeability of free space (magnetic constant), *I* is the current and *r* is the distance from the source (i.e. the conductor). The magnetic field strength from each source is a vector quantity (it has magnitude and direction), and when fields of different orientations are summed (e.g. for the three current-carrying phases and the earth of a single circuit power line), the result would not typically be as great as the scalar sum of their maximum strength.

1.16 This means that the load balance between circuit phases can influence the overall field strength, and can also be taken advantage of in double circuit power line designs (two circuits carried on a single set of structures) where the orientation of the phases can be transposed, such that they tend to have the greatest cancelling effect, reducing the resultant magnetic field strength. Broadly speaking, the magnetic field strength from a single current-carrying wire is inversely proportional to distance, while that from a single circuit power line is proportional to the inverse square of distance, and that from a transposed double circuit design may fall with the cube of distance, due to cancellation effects between the power phases. This means that the field strength decreases rapidly as one moves away from the power line conductors.

1.17 The electric field strength *E* can be calculated using Gauss' law for a single conductor:

$$E = \frac{\lambda}{2 \, \pi \, \varepsilon_0 \, r}$$

(although it is more complex to calculate for multiple charge-carrying wires), where λ is the charge per unit length, ε_o is the permittivity of free space and *r* is the distance from the conductor (as a cylinder). As with the magnetic field, electric field strength drops rapidly with distance from the source.

EMF and Health in Ireland

1.18 The International Commission on Non-Ionizing Radiation (ICNIRP) has developed health protection guidelines for public exposure to EMF. The 1998 ICNIRP guidelines [5] are widely adopted within the EU under the terms of a 1999 EC Recommendation (1999/519/EC). The guidelines were updated in 2010 for time-varying fields [6]. The public health protection guidelines are expressed in terms of the internal electric field or induced current density in affected tissues of the body (“basic restrictions”), and in terms of measurable “reference levels” of external magnetic or electric field strength. The reference levels are such that compliance with them will ensure that the basic restrictions are not reached or exceeded.

1.19 The most recent published reference levels (2010) are 200 μT and 5 kV m^{-1} for magnetic and electric field strength respectively, although at the present time, the standing EC recommendation for their adoption (1999/519/EC) is based upon a more stringent former reference level (1998) of 100 μT for the magnetic field and the same reference level of 5 kV m^{-1} for the electric field.

1.20 Responsibility for managing potential health impacts of EMF presently lies with the Department of the Environment, Community and Local Government in Ireland, although it is planned that this remit will be transferred to the Radiological Protection Institute of Ireland (RPII), which is itself being merged with the Environmental Protection Agency during 2013-14. In statements regarding EMF and health, the department refers to compliance with ICNIRP guideline exposure limits, although there is no specific transposition of the EC Recommendation (1999/519/EC) for adoption of 1998 ICNIRP guidelines into Irish Government policy.

1.21 In 2007 the Department of Communications, Marine and Natural Resources (DCMNR, which formerly held responsibility for EMF and health, and is now called the Department of Communications, Energy and Natural Resources, DCENR) published a review [1] of possible health effects from EMF, including consideration of the current evidence base and whether precautionary measures would be appropriate for ELF EMF exposure. It suggests that a ‘prudent’ precautionary approach would be valuable in addressing public perceptions of risk, although the evidence of actual health risks from power line EMF is weak.

1.22 EirGrid cites the ICNIRP guidelines in its approach to safeguarding public health, and commits to designing and operating the transmission network in Ireland in accordance with up-to-date recommendations of expert and independent national bodies [7] [8]. EirGrid’s strategy for route planning typically aims to avoid populated areas (on the grounds of visual / residential amenity impact), maintaining a minimum distance of 50 m from individual dwellings where feasible, and this inherently offers mitigation of residential exposure to EMF.

Literature Review

2 EMF Literature Review Scope and Key Aims

2.1 In a developed country such as Ireland, the entire population will be likely to experience ELF EMF of varying strengths on a regular and long-term basis. A large body of public health research has been conducted, especially during the last three decades, to investigate the possibility of health risks from ELF EMF.

2.2 A review of the research literature has been undertaken, with the aim of summarising the present state of scientific knowledge regarding EMF and health, placing in the context of this the resultant position of authoritative health-protection bodies. This will enable EMF from high-voltage electricity grid infrastructure comprising the transmission system in Ireland to be viewed in the light of internationally-adopted exposure guidelines and evidence that may exist for health risk at particular field strengths.

2.3 Using computer models, it is possible to calculate the EMF that would be generated by overhead power lines, underground cables or substations with a high degree of accuracy for a specific set of conditions [9]. This requires that the current, voltage, and physical arrangement of the power line (e.g. ground clearance, burial depth, spacing between phases) relative to the receptor are known.

2.4 However, a key theme that has emerged in the public sphere of dialogue regarding EMF and existing or proposed high-voltage electricity transmission infrastructure is that it is essential to address public perceptions of health risk, in addition to managing actual risk. Perceived risk and anxiety regarding health (or other effects) can itself induce stress that can lead to adverse health outcomes [10].

2.5 This literature review aims to present the current scientific health evidence base, including the position of authoritative health protection bodies and any newly emerging evidence, to aid public understanding of the potential for health impacts from EMF. Allied to this, an extensive catalogue of EMF measurements from operational grid infrastructure have been made, to provide evidence of EMF strength under real-world conditions. The results are given in the Evidence Base section of this study.

2.6 This review covers extremely low frequency EMF (in the range of >0 Hz to 100 kHz) associated with power lines. Electric and magnetic fields exist wherever electricity is generated, transmitted or distributed in power lines or cables. As noted, a wide body of literature exists regarding the possible effects of ELF or 'power-line frequency' EMF on human health. The majority of this research investigates possible health effects associated with magnetic fields.

2.7 The report structure first gives an overview of the extensive literature reviews conducted by national and international health protection bodies, providing an understanding of the subject area and key health outcomes without unnecessary repetition of work already conducted. The studies included within this authoritative evidence base are outlined in the following section of this document. However, the milestone publication is taken to be the 2007 World Health Organisation

(WHO) monograph on extremely low frequency fields, which provides the definitive review of the scientific evidence base to that date.

2.8 A search of scientific literature presented by the wider scientific community post-2007 was conducted in 2012, in order to determine how the current evidence base aligns with the position held by authoritative groups and whether newly emerging evidence has changed the existing consensus regarding risk from power-frequency EMF.

2.9 A further literature search focusing on epidemiological studies of childhood leukaemia published in 2013-14 is also presented, as this had been the principal topic of interest for possible health impacts identified in the review.

2.10 Finally, the concluding section considers any remaining uncertainties in the evidence regarding ELF EMF and human health.

3 Authoritative Health Literature

Introduction

3.1 There are a number of review documents available regarding the potential health effects of ELF EMF, prepared by national and international health protection bodies. Particular regard has been given to the 2007 WHO monograph and 2002 IARC monograph which cover a wide range of topic areas and present the main body of evidence.

3.2 Extensive research including *in-vitro*, *in-vivo* and epidemiological studies has been conducted regarding ELF EMF and health. A wide-ranging body of evidence has been established, especially during the most intense period of research in the last three decades. Overall, the documents referenced in this study draw from and build upon this extensive evidence base: the WHO monograph alone references approximately 1,000 papers, demonstrating the breadth of published evidence considered within these authoritative reviews.

Methodology

3.3 The following review in this chapter documents present the key body of evidence from advisory health bodies and the remainder of this section provides an overview of the information contained within these documents:

- World Health Organisation (WHO, 2007) in Environmental Health Criteria Monograph 238: Extremely Low Frequency Fields;
- International Agency for Research on Cancer (IARC, 2002) monograph on static and ELF EMF fields;
- The UK Health Protection Agency Advisory Group on Non-ionising Radiation (HPA AGNIR, 2006);
- International Commission on Non-Ionising Radiation Protection (ICNIRP, 1998, 2010), ELF Guidelines;
- UK Childhood Cancer Study (UKCCS Investigators, 2000, 2010);
- Department of Communications, Marine and Natural Resources (DCMNR, 2007) report on health effects of EMF;
- Chief Scientific Advisor's review of recent investigations into health effects of EMF exposure from power lines (O'Sullivan, 2011); and
- Scientific Committee on Emerging and Newly Identified Health Risks, Health Effects of Exposure to EMF report (SCENHIR, 2009).

3.4 Chapter 4 focuses on peer-reviewed literature published after the comprehensive 2007 WHO review, to provide an up-to-date summary of the evidence base focusing on emerging studies in the key areas of interest.

Mechanism of Action

3.5 The generic term ‘electromagnetic field’ can be defined as a field of force generated by electrical charges or magnetic fields. Power lines are a source of ELF EMF, but do not have enough energy to cause ionisation in tissues that could result in direct cell damage. However, at very high field strength (above international guidelines) ELF fields can induce electric fields and currents in tissues that can result in involuntary nerve and muscle stimulation [1].

3.6 In 2007 WHO published a review of the scientific literature on the biological effects of exposure to ELF EMF [11]. This is part of its series of Environmental Health Criteria monographs that assess information on the relationship between exposure to environmental pollutants and human health.

3.7 The review considers frequencies in the range from >0 Hz to 100 kHz, with the majority of studies considered focusing on power-frequency (50 or 60 Hz) magnetic fields. A number of biophysical mechanisms have been postulated, with three possible key mechanisms identified at low field strengths suggested, principally:

- induced electric fields in neural networks whereby electric fields interfere with synaptic transmissions;
- an increased concentration of free radicals at low magnetic field strengths that are thought to contribute to a number of disease states including neurodegenerative disorders; and
- an increased detection of change in magnetic fields through magnetite crystals in organisms.

3.8 The WHO report concludes that the three direct mechanisms outlined above do not seem to be plausible causes of the potential for increased disease incidence at the exposure levels generally encountered by people. The lower bound level for effects on neural network transmission is thought to be 10-100 mV m^{-1} as electric fields below this cannot be discriminated by multicellular organisms. It is suggested that power frequency field strengths lower than the geomagnetic field strength of approximately 50 μT are unlikely to be of biological significance for the free radical pairs mechanism. Furthermore the presence of trace quantities of magnetite crystals in humans does not confer an ability to detect the geomagnetic field and therefore this is unlikely to have an effect on human health. However, the absence of an identified mechanism cannot in itself rule in or out the possibility of adverse health effects; rather, it has been a stimulus for ongoing research.

3.9 In addition to biophysical mechanisms, WHO reviewed the possible link between exposure to low frequency EMF and an increased risk of cancer, cardiovascular disease, and neurodegenerative disorders and also possible changes in neurobehaviour, the neuroendocrine system, the immune system, reproduction and development. Each potential health pathway is summarised below.

Cancer

3.10 The possibility that exposure to ELF EMF leads to an increased risk of cancer has been widely researched. In 2002 IARC classified ELF magnetic fields as ‘possibly carcinogenic to humans’.

However, this should to be set in context: ‘possibly carcinogenic’ is the least probable of the three categories used by IARC to indicate that an agent could be carcinogenic. To clarify, an example of another well-known agent in the same category is coffee, which may increase the risk of urinary bladder cancer, while at the same time be protective against bowel cancer.

3.11 The IARC monograph examines a range of studies on the carcinogenicity of ELF EMF including cancer in adults, children and studies using experimental animals. It highlights two pooled analyses, based on nine and fifteen studies respectively, that found a two-fold excess risk of leukaemia at ELF magnetic field strengths above 0.4 μT and a 1.7-fold risk for exposure above 0.3 μT. However, similar conclusions could not be drawn for electric fields. This association may in part be explained by selection bias where studies either receive a low response rate or use historical data and subsequently assess a very low number of exposed subjects. The mechanism of action is thought to be via ELF fields enhancing damage from other sources and interfering with factors that play a role in late stage tumour development as opposed to causing direct genetic damage [12]. In the same report IARC concludes that the carcinogenicity to humans of static electric and magnetic fields and ELF electric fields is not classifiable.

3.12 The UK Childhood Cancer Study (UKCCS), a very extensive study of possible causes of childhood cancers, found no association between measured power-frequency magnetic field exposure and risk for any malignancy. The study also considered residential proximity to electricity supply equipment, distances to high voltage lines, underground cables, substations and distribution circuits, concluding that there was no evidence that proximity to electrical installations in the UK is associated with increased risk of childhood leukaemia or any other cancer [13]. By contrast, a further UK-based study conducted by the Childhood Cancer Research Group (CCRG), often referred to as the ‘Draper study’ (after former CCRG Director Gerald Draper), initially found (in 2005) a statistically significant increase in relative childhood leukaemia risk for children living within 200 m of a high-voltage (275 kV or 400 kV) power line, or a significant but lower risk for those born within 200-600 m, compared with those living or born at >600 m distance [14]. A further review of this data in 2010, which included calculation of magnetic field strength (rather than relying on distance), found that the findings were consistent with a possible increase in risk for exposure of >0.4 μT reported in other pooled analyses, although the number of cases with that exposure level was too low for this finding to be statistically significant [15]. The calculation of field strength showed that this level of exposure would extend to approximately 50 m from the power lines, undermining the apparent evidence of increased risk at a distance of up to 600 m.

3.13 Whether ELF EMF presents a risk of cancer has been further considered in the 2007 DCENR report stating that some epidemiological evidence indicates that where the average exposure exceeds 0.3 μT to 0.4 μT the incidence of childhood leukaemia could double [1]. However, the exposure of children in Europe to ELF magnetic fields is generally much lower than this, averaging 0.025 μT to 0.07 μT. If the increased risk from exposure of 0.4 μT were real, it could theoretically be responsible for approximately one case of childhood leukaemia in Ireland every two to five years [1] [16]. This would be equivalent to approximately 0.4% to 1.4% of childhood leukaemia cases, based upon the typical incidence rate of 35-55 cases of childhood leukaemia per year in Ireland [1].

3.14 Hypothetical effects with such a low frequency of occurrence would be very difficult to detect with any reasonable level of certainty [16]. Furthermore, ICNIRP notes that the existing scientific evidence base is too weak to establish that there is a causal relationship between prolonged exposure to low frequency magnetic fields and an increased risk of childhood leukaemia or for this evidence to form the basis of exposure guidelines [17].

3.15 The European Commission SCENIHR produced an update in 2009 to its 2007 opinion on the health risks from EMF. In keeping with the IARC monograph, the SCENIHR evaluation of scientific evidence concluded that ELF magnetic fields are a possible carcinogen and could contribute to an increased risk of childhood leukaemia [18]. However, it is noted the studies on which this conclusion has been based have weaknesses within their methodology such as low participation numbers and the use of proximity to power lines to determine exposure as opposed to magnetic field strength measurements. SCENIHR recognises the need for further research and independent replication of studies in order to ensure robust results [18].

3.16 In contrast to the results for leukaemia, the IARC monograph found no consistent relationship in studies for childhood brain tumours or cancers at sites linked with residential ELF EMF [12]. This is consistent with the UKCCS pooled analysis of ten studies on ELF magnetic fields and childhood brain tumours, which concludes that the results provide little evidence for an association [13].

3.17 With regard to the residential exposure of adults, the IARC monograph concludes,

"Although there have been a considerable number of reports, a consistent association between residential exposure and adult leukaemia and brain cancer has not been established. For breast cancer and other cancers, the existing data are not adequate to test for an association with exposure to electric or magnetic fields" [12] (page 333).

3.18 The 2007 WHO monograph established that the findings of studies published subsequent to the IARC monograph considerably weakened the evidence for an association between ELF exposure and breast cancer. The monograph also concludes that the evidence for other childhood cancers, adult brain cancer and adult leukaemia remains inadequate [11].

3.19 Melatonin is a hormone secreted by the human body that influences a range of physiological functions including sleep patterns, and may offer some protection against breast cancer development. Hypotheses exist which suggest that EMF exposure could affect melatonin production in the body, thereby influencing the risk of cancer. The IARC monograph highlights six laboratory studies that have investigated the influence of magnetic field exposure on endocrine functions in humans exposed to 50 Hz or 60 Hz magnetic fields. Overall, five of the six studies reported no effects. One study found a possible delay and reduction in night-time melatonin concentrations; however, a number of concerns have been raised regarding the experimental design and statistical analysis of this study [12].

3.20 In 2006 the UK HPA produced a report investigating whether EMF can affect the production or action of melatonin and subsequently whether this alters the risk of breast cancer. The HPA concluded that,

"*Investigations using cells, animals and humans have not given consistent or convincing evidence that EMF exposure affects melatonin production or action. However, there are deficiencies in the existing research, which leave open the possibility of an effect"* [19] (page 161).

The 2007 WHO monograph concluded that the evidence is sufficient to give confidence that ELF magnetic fields do not cause breast cancer.

3.21 As reported in the IARC monograph, experiments exposing animals (rats and mice) to ELF magnetic fields have been conducted but have proved to be inconclusive. Of the four long term bioassays discussed in the IARC report, one found an increase in incidence of thyroid C-cell tumours in male rats exposed to ELF magnetic fields at a range of flux densities tested, but failed to demonstrate a dose-response relationship. Eleven multistage carcinogenesis studies combining exposure to 7,12-dimethyl-benz(a)anthracene, a chemical which promotes tumour formation, with 50 Hz or 60 Hz magnetic fields, were performed in three laboratories. One laboratory reported significant increases in mammary tumour incidence at higher exposure levels. The second laboratory conducted three studies to replicate these findings at the highest field strengths but saw no enhancement of mammary tumorigenesis, while the third laboratory found no change in tumour incidence.

3.22 Similarly the WHO monograph concluded that results from animal studies have not shown any consistent increase in any type of cancer, including haematopoietic (tissues in which new blood cells form), breast, brain and skin tumours. A number of studies examining ELF field effects on chemically-induced mammary tumours in rats produced inconsistent results; in relation to animal studies the WHO report concludes,

"*overall there is no evidence that ELF exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate"* [11] (page 322).

Reproductive and Developmental Effects

3.23 The IARC monograph also reviews studies that examine exposure during pregnancy to power frequency electric and magnetic fields of 50 Hz or 60 Hz. However, the focus of these studies is on the use of electric blankets and electrically heated beds which have been shown to increase exposure to electric fields by 36% [12]. IARC concluded that there is little evidence to support an association of exposure to ELF electric and magnetic fields with adverse reproductive outcomes. The WHO monograph also investigated EMF exposure from electric blankets and heated beds, but in contrast to IARC, WHO suggests that some evidence exists that points to an increased risk of miscarriage associated with ELF magnetic field exposure [11].

Cardiovascular Disease

3.24 The potential for an association between cardiac effects and ELF EMF exposure has been related to heart rate variability and acute cardiovascular events. Studies relating exposure to 60 Hz magnetic fields with an increased incidence of cardiovascular disease and death have been considered by both ICNIRP and IARC, who conclude that the evidence is weak. Moreover IARC stated that,

"the possible association between exposure and altered autonomic control of the heart is speculative" [12] (page 270).

3.25 The WHO monograph summarises evidence including epidemiological studies of cardiovascular disease incidence (especially for electricity utility company employees, who have had occupational exposure to ELF EMF) and laboratory tests of heart rate variability using smaller groups of volunteers.

3.26 Although some of the heart rate variability studies reported a change in heart beat intervals during or after ELF EMF exposure, a roughly equal number of studies did not find an effect. A pooled (multi-study) analysis suggested that heart rate variation was only found where other study factors such as sleep disturbance, stress and blood sampling were present in addition to ELF EMF exposure. More recent studies using a strong magnetic field (many times greater than the maximum from an overhead power line) did not find any effect on heart rate variability. WHO's 2007 monograph concludes that,

"*Overall, the evidence does not support an association between ELF* [EMF] *exposure and cardiovascular disease.*" [11] (page 8).

Neurodegenerative Disorders

3.27 A number of studies have researched amyotrophic lateral sclerosis and Alzheimer's disease in people occupationally exposed to ELF EMF. IARC reported that when considered together the studies indicate that there appears to be an association between the occurrence of disease and estimated exposure to ELF EMF. However, as the study designs have been shown to be weak, support for the hypothesis has subsequently reduced [12]. This position is shared by ICNIRP and WHO, demonstrating that studies investigating the association between low frequency exposure and Alzheimer's disease are inadequate and inconclusive [6] [11].

3.28 The 2009 review from SCENHIR indicates a possible increase in Alzheimer's disease arising from exposure to ELF fields. However, SCENHIR concluded that further epidemiological and laboratory investigations of this observation are required [18]. This conclusion is based on laboratory studies which have provided suggestive evidence that long-term exposure of laboratory rodents to 50 Hz magnetic fields of 1.10 – 2.00 mT may impair or improve memory and increase anxiety-related behaviour in behavioural tests [18].

Immune System

3.29 A number of studies have investigated the effect of exposure to magnetic fields on markers of immune function. IARC reports [12] two studies that measured changes in the number of white blood cells that form part of the immune system, including monocytes and natural killer T-cells (a type of lymphocyte).

3.30 The first compared a control group with two groups of workers (hospital staff operating magnetic resonance imaging units and industrial workers operating induction heaters) routinely exposed to magnetic fields. The study found that the numbers of natural killer cells and monocytes were significantly increased in the exposed group.

3.31 In the second study a group of 16 men aged 20-30 years were exposed to 50 Hz, 10 μT magnetic fields either continuously or at varying intervals between the hours of 23.00 and 08.00. No significant differences were observed between the exposed group and control group for a wide range of immune function markers including monocytes and lymphocytes.

Genotoxic Effects

3.32 Genotoxic effects relate to structural changes at the gene level and include mutagenicity (mutation of specific genes), chromosomal mutation (change in the number or structure of chromosomes), micronuclei formation (small additional pieces of the nucleus, indicative of DNA damage) and adduct formation (chemicals bound to DNA causing possible mutation). A number of studies reported by IARC investigate the clastogenic effects (ability to break chromosomes) of exposure to power frequency electric and magnetic fields.

3.33 As an example, IARC reported a study in which chromosome analyses were performed on lymphocytes from 32 workers occupationally exposed for more than 20 years to 50 Hz electric and magnetic fields in 380 kV switchboards. Comparison with a control group of 22 workers who had not been exposed to EMF showed that neither the numbers of structural chromosomal changes nor the frequencies of sister chromatid exchanges were increased.

3.34 Such studies are subject to confounding by genotoxic agents such as tobacco and solvents, limiting the conclusions that can be drawn by comparing exposed and control groups. In-vitro studies conducted on mammalian cells have proved inconclusive, with little evidence that mutations could be directly caused by ELF magnetic fields [12]. The WHO monograph found that in general, studies of ELF field exposure of cells show no induction of genotoxicity at fields below 50 mT [11].

3.35 IARC concluded that results from studies into the effects on in-vitro cell proliferation, malignant transformation and cellular end points such as signal transduction are inconsistent. However, some studies suggest that ELF magnetic fields affect cell proliferation and modify cellular responses to other factors such as melatonin [12].

3.36 In summary, ELF EMF are part of the non-ionising spectrum and as such do not have enough energy to cause direct cell damage to macromolecules leading to genotoxic effects through ionisation. The above studies support that view, providing little evidence of mutation directly caused by ELF magnetic fields, although additional research has been recommended.

Conclusion

3.37 The authoritative evidence base explores a range of possible effects from ELF EMF on human health. Reviews published subsequent to the 2002 IARC review and categorisation of EMF as 'possibly carcinogenic' have reached similar conclusions: the evidence for an association between ELF EMF exposure and carcinogenic affects, particularly leukaemia, is limited, and research does not rule in or out the possibility of a causal link. The evidence for other potential health effects such as Alzheimer's, cardiovascular disease, and effects on the immune system does not support a substantive link with ELF EMF.

3.38 Extensive research has been conducted into the potential for health effects associated with ELF EMF; the 2007 WHO monograph alone draws upon around 1,000 published studies. While further research is desirable to investigate whether any causal mechanism underlies a possible correlation between ELF EMF exposure and childhood leukaemia, and whether the association is real or due to confounding factors, existing research has covered a wide breadth of topic areas, leaving limited avenues of emerging evidence. Scientific research can provide evidence that something might be unsafe but cannot prove that no health effect occurs [1], and as such while further study of cancer and other possible adverse health outcomes discussed above may be warranted, it must be accepted that a degree of uncertainty in the evidence base is likely to remain.

3.39 As a follow-up to this discussion of the existing body of evidence, a review of further studies published following the 2007 WHO report is provided in the following section.

4 Scientific Literature Post-2007

Introduction

4.1 A review of scientific literature presented by the wider scientific community following the 2007 WHO monograph has been conducted in order to determine how the current evidence base aligns with the position held by authoritative groups and to identify any discrepancies or remaining uncertainties in the health evidence base.

4.2 As highlighted by the authoritative evidence base in Chapter 3, the need for further research and independent replication of study findings is indicated, in order to establish in particular whether there is evidence of a link between ELF EMF and cancer. Therefore this area is the main focus of the following literature review.

Methodology

4.3 An initial search of literature following the 2007 WHO monograph has been conducted using the PubMed database. The main criteria for the search were that the studies considered ELF EMF in the power frequency range and had been published during 2007-2012, subsequent to the WHO monograph. The search terms used were: EMF, ELF EMF, ELF magnetic field, EMF high voltage, EMF non ionising radiation and EMF power line. In total, 111 papers were considered and the results categorised by study type: epidemiological (27); in-vitro (42) or in-vivo (11); magnetic field (17); electric field (3); and guidelines (11).

4.4 The studies were prioritised by an abstract review to determine the relevance to health effects from ELF EMF and their value to this review. Following this, 15 studies were reviewed in detail and have been summarised within this document. The full literature search can be seen in Appendix A.

4.5 A large number of studies for the subject area relate to radio frequency EMF. As this is relevant to mobile phones and associated infrastructure rather than power line frequency EMF, the terms "radio frequency" and "radiofrequency" have been excluded from the search.

4.6 In March 2014, this literature review was supplemented with a search focusing on epidemiological studies of childhood leukaemia published in 2013-14, as this had been the principal topic of interest for possible health impacts identified in the initial review, and a number of relevant peer-reviewed scientific papers had been published in the interim. The same search approach was employed, using the terms EMF/magnetic field/power line/high voltage and leukemia/leukaemia[2]. The publications that provided new epidemiological research regarding

[2] "2013/01/01"[Date - Publication] : "3000"[Date - Publication] AND (emf[Title/Abstract] OR magnetic field[Title/Abstract] OR power line[Title/Abstract] OR high voltage[Title/Abstract]) AND (leukemia[Title/Abstract] OR leukaemia[Title/Abstract])

childhood leukaemia and electricity networks or EMF are listed in Appendix A, and their findings are discussed in paragraphs 4.14 to 4.20.

Cancer

4.7 ELF magnetic fields have been classified as possibly carcinogenic to humans, with a possible correlation between long-term exposure to magnetic fields above 0.3-0.4 μT and the risk of childhood leukaemia [20]. However, a mechanism to explain this possible effect, if real, has not been identified, leading to a requirement for further research. A review by Schüz, 2011, of the epidemiological evidence base concluded that the assessment of ELF magnetic fields as a possible carcinogen that may cause childhood leukaemia remains valid [21]. To date, despite a wide body of evidence, a causal relationship has not been established and although research activities are ongoing, it is possible that this status may remain uncertain [21] (see Section 2.4.3).

Cancer promotion

4.8 The initiation of cancer by ELF fields is theoretically improbable in that ELF EMFs are non-ionising and do not have the required energy to cause direct damage at the molecular level. Mechanisms of cancer promotion including inhibited melatonin production have been considered, with some evidence of decreased blood serum level melatonin under power frequency magnetic fields [22].

4.9 Although presented in a 2007 paper, this conclusion is drawn from a 2005 review which has been superseded by the HPA paper discussed in Section 2 of this document; the HPA research failed to find consistent evidence of an association [19].

Childhood leukaemia

4.10 In case-control epidemiology studies, odds ratios are used in the reporting of results. These are the ratio of the odds of an exposure (ELF magnetic fields from power lines) in the case group (children with leukaemia) to the odds of an exposure in the control group (children without leukaemia). An odds ratio of 1 for example would indicate that childhood leukaemia is equally likely to occur in both groups from the same exposure; greater than 1 indicates that childhood leukaemia is more likely from the exposure and below 1 indicates the childhood leukaemia is less likely to occur from exposure to ELF magnetic fields from power lines.

4.11 A pooled analysis that combined 9 studies with 3,247 cases of childhood leukaemia and 10,400 control cases found a pooled odds ratio of 2.0 at exposure levels of >0.4 μT [23]. This association was also reported in the IARC monograph [12]. A more recent pooled analysis based on 7 studies (from Brazil, Germany, Japan, Tasmania, the UK and two from Italy) included 10,865 cases of leukaemia and 12,853 control cases and found an odds ratio of 1.44 for exposure of ≥0.3 μT [24]. Due to data availability, the Brazilian study only considered cases of acute lymphoblastic leukaemia in children aged eight years and under. Omitting the study from Brazil, the pooled analysis gave a combined odds ratio of 2.02 for exposure of ≥0.4 μT, similar to that provided in earlier studies [24]. Overall, this analysis relied heavily on one study that added to the overall size and number of cases but little to the statistical power, as few children with elevated exposure levels were included [21].

4.12 The consistent results of the pooled analyses for a large number of international studies reduce the possibility that an association between ELF and magnetic fields is due to chance but do not rule out potential bias or confounding variables [21].

4.13 One such confounding variable is the use in certain studies of distance from power lines as a proxy for EMF exposure. Using published data for the UK as an example, the magnetic field falls to approximately 0.2 μT at 70-80 m from typical 275-400 kV transmission lines compared with 30-50 m for 132 kV lines. In the UK 2% of residential homes with small children have background magnetic levels of 0.2 μT and 0.5% have levels of 0.4 μT [25]. As high exposure levels are rare, using power line proximity to estimate exposure can lead to misclassification compared to the alternative system of direct measurements within the home to allow exposure to be directly assigned to a household [25]. Additional confounding factors for consideration include the multiple possible sources of ELF magnetic fields, socio-economic factors, and lifestyle choices such as smoking and passive smoking [22].

Publications 2013-14

4.14 The updated literature search focusing on research papers published in 2013-14 concerning epidemiological study of childhood leukaemia identified several studies of interest that add to the evidence base. The ‘Draper study’ (discussed in paragraph 3.12) has been extended by Bunch *et al* [26] to add further evidence from Scotland and from 132 kV overhead lines to the data analysed, and to present trend in risk over time. The study continued to find an elevated childhood leukaemia risk associated with residences within 600 m of high-voltage power lines, and in particular within 200 m. However, this risk is most apparent in earlier decades of the time period considered in the study (1962-2008), which suggests that a factor that changes over time (such as population characteristics) is more likely to be the explanation than a physical effect from power lines.

4.15 A study in Denmark published in 2014 [27] that was designed to independently verify the UK study’s findings by using a comparable approach did not find an increased leukaemia risk for children living within 200 m or 600 m of high-voltage power lines. The methodology for a third independent verification study using this approach in California has been published [28], but results are not yet available.

4.16 A study in France for the period 2002-2007, published in 2013 [29], found an increased childhood leukaemia risk associated with living within 50 m of the highest-voltage (225 kV – 400 kV) overhead lines, based on a small number of cases, but did not find increased risk for greater distances or lower-voltage lines.

4.17 A pooled analysis using results from 9 previous studies published by Zhao *et al* in 2014 [30] found increased risk with exposure in the categories of greater than 0.2 μT compared to below this level, and a slightly greater risk for exposure of greater than 0.4 μT compared to less than 0.1 μT.

4.18 In a further paper, residential mobility and population mixing (which could be a demographic factor changing over time that is relevant to the Bunch *et al* findings) near power lines in the UK was investigated [31], following the hypothesis of infections following population mixing as the cause of increased childhood leukaemia risk associated with residence near nuclear sites [32]. However, this study did not find a significant association between population movement and power line proximity.

4.19 A Dutch study published in 2013 [33] followed up epidemiological evidence of an apparent childhood leukaemia cancer cluster. The study was not designed to investigate a causal relationship between high-voltage power lines and childhood leukaemia, but noted that “the children had not been subjected to prolonged exposure to strong magnetic fields emitted from the high-voltage power line.”

4.20 Overall, the epidemiological study evidence published in 2013-14 is mixed; while a pooled analysis and data from a short time period in France show an increased childhood leukaemia risk associated with magnetic field exposure and short distance to high-voltage power lines, the UK study with a very large number of cases assessed over a multi-decade time period did not find an increased risk that could plausibly be linked to physical effects from power lines, while a parallel independent Danish study following a comparable approach did not find any statistically significant increased childhood leukaemia risk.

Brain tumours

4.21 Schüz, 2011, reviewed a meta-analysis of 13 studies investigating ELF magnetic fields and childhood brain tumour risk, finding a summary odds ratio of 1.68 for exposures >0.4 μT [21]. Subsequent to this a pooled analysis of 10 studies was published which encompassed 8,372 cases of brain tumour and 11,494 control cases. Depending on the studies included the results indicate a pooled odds ratio of 1.14 or 1.16 for exposure to 0.4 μT. Schüz concludes that these odds ratios provide little evidence for an association between ELF magnetic field exposure and childhood brain tumours. Although childhood brain tumours and leukaemia are not directly comparable, due to the difference in tissue type and different potential aetiology, the substantially lower odds ratio (compared to results seen for childhood leukaemia) does not support a common source of underlying bias to explain apparent risk. This could suggest that if there is an association between ELF magnetic field exposure and childhood leukaemia, it is specific to that disease. However, the bias patterns may not be directly comparable between different studies. [21].

4.22 A 2011 study of occupational and residential exposure to ELF EMF and the risk of brain tumours in adults found an insignificant association (wide confidence interval of 0.86-10.4 indicating uncertainty) between meningioma (tumour of the brain lining) and residential exposure to EMF in subjects residing near power lines. The data suggests that occupational or residential exposure to ELF EMF may play a role in the occurrence of meningioma. However, the study is open to misclassification through the use of proximity to power lines as the methodology for establishing exposure and is based on a limited number of exposed participants, leading to statistically insignificant findings [34]. Similar conclusions were found in a pooled analysis conducted by Kheifets *et al* in 2010 [35].

Electric fields

4.23 The majority of studies focus on ELF magnetic fields rather than electric fields in part due to the method of interaction between electric fields and organisms. Electric fields are largely absorbed by skin and muscle due to the conductivity of these tissues [22]. The highest electric fields at ground level from overhead lines is approximately 10 kV m^{-1}, whereas the field strength inside a home from such an outside source is 10-1000 times lower because the building attenuates the field. Therefore within homes, wiring and appliances are the most common source of electric-field exposure.

4.24 Similarly to magnetic fields, a mechanism of action has not been established; proposed mechanisms include electric shocks, micro shocks and surface charge [36]. A systematic review of existing literature for electric fields concluded that there is limited evidence of a change in cancer risk and little basis for continued research [36].

Summary

4.25 The updated literature has been shown to be in keeping with the authoritative evidence base outlined above, in that although the evidence for classification of ELF EMF as a possible carcinogen based upon correlation between magnetic field exposure and disease incidence has not been substantially altered, no further progress has been made in establishing evidence of a causal link or a mechanism for action. A preliminary 2014 update to a European Commission health risk scientific committee opinion [37] suggests in its draft that the lack of experimental data "prevent[s] a causal interpretation" of evidence for childhood leukaemia risk from ELF EMF. Some recent national reviews have concluded that the scientific evidence does not establish that the ELF electric and magnetic fields around power lines or any device using electricity is a hazard to health [38] [39], although another indicates that the evidence base regarding a causal relationship remains unchanged [40].

Cardiovascular Disease

4.26 A recent study involving 58 volunteers exposed to two testing sessions (one real, one placebo) utilising a 60 Hz magnetic field at 1,800 μT did not result in an effect on skin blood perfusion, heart rate or heart rate variability. The magnetic field used in this study did not affect cardiovascular parameters, and therefore should magnetic field exposure have cardiovascular effects, they are smaller than observed in the study through the two hour resting period ECG [41]. A recent pilot study carried out by the same research group investigated the effect of exposure to a 200 µT 60 Hz magnetic field on human circulation. Ten volunteers were exposed to two testing sessions (one real, one placebo), and the results indicate that the magnetic field used in the study did not affect perfusion, heart rate or mean arterial pressure [42].

4.27 The above findings are in keeping with the conclusions drawn in the authoritative evidence base reported in Section 2 of this document, in particular the IARC monograph.

Neurodegenerative Disorders

4.28 There are no known biological mechanisms to explain an association between ELF EMF exposure and Alzheimer’s disease. ELF EMF has not been identified as a genotoxic agent but it has been hypothesised that it may promote or induce mutation through enhancing the effect of other agents.

4.29 A longitudinal study of the Swiss population that investigated residential exposure to power lines and mortality from neurodegenerative diseases found an odds ratio for Alzheimer’s disease in people living less than 50 m from power lines of 1.24 compared with people living 600 m or more away [43]. However, the researchers note that there is no proof of an association and although the hypothesis remains valid at present, further research is required [44]. In order to provide a possible explanation for this association a number of in vitro studies have been reviewed suggesting some evidence of induction of chromosome instability, increased production of the peptide amyloid-β and decreased production of melatonin, all of which hypothetically may contribute to the development of Alzheimer’s disease [44]. Further detailed research is required in order to establish whether there is a possible association between exposure to ELF EMF, the above mechanisms and the onset of Alzheimer’s disease. The authoritative evidence base (SCENHIR, WHO and IARC) found a possible association between the occurrence of Alzheimer’s disease and exposure to ELF EMF but that further research is required to establish this. The updated literature outlined above is in keeping with that stance, with results shown to be inconclusive, requiring additional research.

4.30 Although not strictly research into neurodegenerative disorders, in a study of cognitive performance, psychometric testing was conducted on people in a 60 Hz, 3 mT magnetic field, the results of which indicate that magnetic field exposure removed the improvements seen with practice. The study does not establish a clear magnetic field effect on human cognition but speculates that ELF magnetic field may interfere with neuropsychological processes responsible for the short term learning effect [45]. This is however in contrast to a study which placed 74 male volunteers into five groups who were either told that exposure would enhance cognitive performance, have a negative effect or remain neutral. Only one group was exposed to an ELF magnetic field of 400 µT. There was no significant difference reported between the groups for cognitive performance, psychological or physiological parameters [46].

EMF Health Protection Guidelines

International guidelines

4.31 ICNIRP has published two editions of international guidelines for recommended EMF exposure limits, in 1998 and 2010. These are expressed in the form of Basic Restriction levels for induced current in the central nervous system (1998) and internal electric field (2010). Modelling has been used to convert these basic restrictions into reference levels of external electric and magnetic field strength that could be equivalent to the Basic Restriction. Table 4.1 summarises the 1998 and updated 2010 Basic Restrictions and reference levels for long-term general public exposure.

Table 4.1: ICNIRP general public Basic Restriction and reference levels for electric and magnetic field exposure at 50 Hz [5] [6]

<table>
<tr><th></th><th>Basic Restriction</th><th>Electric field reference level</th><th>Magnetic field reference level</th></tr>
<tr><td>ICNIRP 1998 (head and trunk)</td><td>2 mA m^{-2}</td><td>5 kV m^{-1}</td><td>100 μT</td></tr>
<tr><td colspan="2">ICNIRP 2010</td><td rowspan="3">5 kV m^{-1}</td><td rowspan="3">200 μT</td></tr>
<tr><td>(CNS of head)</td><td>20 mV m^{-1}</td></tr>
<tr><td>(All tissues)</td><td>400 mV m^{-1}</td></tr>
</table>

4.32 The guideline Basic Restriction levels consider well-established effects from electric and magnetic fields such as the stimulation of peripheral and central nerves. These are based on acute (i.e. immediate or short-term) effects perceptible or detectible from EMF exposure. To those levels based on short-term exposure, ICNIRP applies precautionary reduction factors in light of the uncertainty in the scientific data for long term exposure. ICNIRP's approach takes into account the evidence presented in the WHO and IARC monographs and wider evidence base, but does not consider the evidence of any disease causation to be strong enough to form the basis of exposure guidelines. With regard to leukaemia, ICNIRP states that,

"It is the view of ICNIRP that the currently existing scientific evidence that prolonged exposure to low frequency magnetic fields is causally related with an increased risk of childhood leukemia [sic] *is too weak to form the basis for exposure guidelines. Thus, the perception of surface electric charge, the direct stimulation of nerve and muscle tissue and the induction of retinal phosphenes are the only well established adverse effects and serve as a basis for guidance."* [47] (page 2)

4.33 The 1998 ICNIRP guidelines have been recommended by the EC (1999/519/EC) and widely adopted within the EU (either by transposition of the recommendation into national legislation, or on a voluntary/guideline basis that can often form a *de-facto* standard) as well as by many other non-EU countries. Some European countries, however, apply lower magnetic field exposure limits, some examples of which are given in Table 4.2 [48].

Table 4.2: Magnetic Field Restriction Examples in Europe

Country/Region	Magnetic field restriction	Applicable to	Notes
Poland	75 μT		
Slovenia	10 μT	Public areas	Formerly 5 μT [49]
Belgium	10 μT		
Italy	3 μT	New installations near homes, schools and playgrounds	10 μT for existing installations near same; 100 μT elsewhere
Switzerland	1 μT	New installations near playgrounds, and places of long-term exposure	
Netherlands	0.4 μT	Long-term exposure of children	Not a binding limit but a recommendation to local government
Tuscany (Italy)	0.2 μT		[50]

4.34 The reduced limits set out in Table 4.2 in several cases apply for areas classed as sensitive receptors such as schools, hospitals, and new homes. In Switzerland an exemption from the lower limit is granted for new installations if all measures that are technically and financially viable have been taken [51]. In Sweden, rather than a generic limit, change from the existing background is assessed, and radical deviation from it should be reduced where reasonable [48]. In Denmark, a voluntary agreement is in place between the government and electricity industry to examine options for exposure reduction if annual exposure for a new installation would be above 0.4 μT [48]. The WHO International EMF Project provides an overview of adopted exposure limits throughout the world with the aim of providing a framework for matching EMF standards worldwide [52]. For example the limits for public exposure across a number of countries (Australia, Austria, Hungary, Italy, Poland) are comparable with those from ICNIRP but allow higher exposure levels for a few hours per day (from 100–1,000 μT) [53].

4.35 Other national interpretations of the ICNIRP guidelines exist. For example the UK's Department of Energy and Climate Change (DECC) published a voluntary code of practice for the electricity industry in 2011, updated in 2012 [54], in which the results of modelling for the HPA of EMF interaction with the body have been used to set external electric and field strength guideline limits that are equivalent to the 1998 Basic Restriction level. These are 360 μT for unperturbed magnetic field strength and 9 kV m^{-1} for unperturbed electric field strength from overhead power lines.

Precautionary principle

4.36 As noted, the prevailing international guidelines commonly accepted in EU states do not recommend EMF exposure restrictions on the basis of possible but unconfirmed health impacts discussed in this review, although as a precautionary approach they do apply significant reduction factors from the thresholds of known physical effects from EMF in order to account for scientific uncertainty regarding issues such as the potential for long-term health impacts.

4.37 A viewpoint therefore exists which suggests that, given the (limited) evidence particularly regarding a possible correlation of long-term magnetic field exposure and childhood leukaemia at field strengths significantly lower than the ICNIRP guideline limits, it may be appropriate to apply the precautionary principle and consider further intervention where practicable to reduce the potential exposure to EMF.

4.38 Gee, 2009, states that,

"the precautionary principle was designed to justify actions to protect the public and the environment in the absence of some significant knowledge, and could be used to justify exposure reductions to EMF, despite current gaps in knowledge." [55] (page 220).

This is relevant given that a mechanism of action has not been established to explain any potential association between exposure to ELF magnetic field strengths below the international guideline level and adverse health outcomes. Nevertheless, as noted by Kheifets *et al*, 2010, there has been a shift in the tone of debate surrounding risk management to,

"how can we do something measured and reasonable that is a correct response to the scientific evidence and associated uncertainty, as well as to public concern." [56] (page 1487).

4.39 A full discussion of this issue, which is likely to be a national policy matter, is outside the scope of this literature review. However, it is worth noting that an open paper in 2010 by Maslanyj *et al* offers a useful summary of the application of the precautionary principle to this issue. The authors conclude that although there is,

"no clear indication of harm at field levels implicated … the aetiology of childhood leukaemia is poorly understood. Taking a precautionary approach suggests that low-cost intervention to reduce exposure is appropriate. This assumes that if the risk is real, its impact is likely to be small. It also recognises the consequential cost of any major intervention. The recommendation is controversial in that other interpretations of the data are possible, and low-cost intervention may not fully alleviate the risk." [57] (page 8)

4.40 The paper notes in particular that due to uncertainties in the evidence and the fact that they may not be resolved in the near future,

"despite the need for evidence-based policy making, many of the decisions remain value driven and therefore subjective." [57] (page 8)

4.41 The recommendation of a precautionary stance echoes WHO's 2007 view, which suggested that the use of 'suitable precautionary measures to reduce exposure is reasonable and warranted' in view of uncertainties about the effects of chronic magnetic field exposure, but that due to the weakness of the evidence of a link between exposure to ELF magnetic fields and childhood leukaemia, the benefits of exposure reduction on health are unclear. WHO emphasised that any precautionary measures should not compromise the benefits of electric power, and that the costs of any precautionary measures to further reduce exposure would only be justified where they are very low or have no cost.

4.42 Discussing the precautionary principle in a recent publication, however, Repacholi, 2012 [58] notes that when assessing the evidence offered by scientific studies, there are four key criteria, namely: (i) *Do the studies overall show a statistically significant and strong relationship between the exposure and the health effect?*; (ii) *Are the results of different types of studies consistent?*; (iii) *Is there a statistically significant dose-response relationship*?; and (iv) *Is it biologically plausible that exposure is capable of causing the health effect*? He concludes that the view of WHO Task Force on EMF in reviewing scientific studies undertaken has been that the evidence, while mixed, may partially satisfy the first criterion but fails to satisfy the remaining three criteria and does not support a health risk from EMF overall. Given this, Repacholi references the Task Force in stating that ICNIRP exposure guidelines and their scientific validity would be undermined were they to be reduced by national authorities "*to some arbitrary level in the name of precaution*" [11], cited in [58], and suggests that doing so may inflame rather than help address public perceptions of risk.

Conclusion

4.43 Following the 2007 WHO monograph, additional scientific research has been carried out to try and determine whether there is a causal link between ELF EMF and disease, in particular childhood leukaemia. To this end, the evidence base remains inconclusive; the IARC categorisation of ELF EMF as a possible carcinogen remains supported by evidence of possible correlation between exposure and disease, but evidence of a causal relationship or a plausible mechanism to explain causation has not been established following extensive research. Some recent national reviews have concluded that the scientific evidence does not establish that the ELF electric and magnetic fields around power lines or any device using electricity is a hazard to health [38] [39]. Epidemiological studies of childhood leukaemia published in 2013-14 continue to provide mixed evidence, with some studies finding increased risk associated with residential proximity to power lines but others not, while trends over time data in childhood leukaemia risk for those living close to power lines in the largest UK study implicates a non-EMF factor.

4.44 Study limitations such as estimating long term exposure, the source of exposure and relation to a health outcome through a given mechanism of action cast doubt as to whether a firm conclusion will be reached in the near future. Similarly, the results of research into neurodegenerative disorders remain inconclusive, with the need for further research indicated in order to establish whether a real health impact exists. The results for ELF EMF and cardiovascular disease in both the authoritative and updated literature have failed to establish an association between the two with future research perhaps better targeted toward neurodegenerative disease and cancer. Similar conclusions have been drawn for the health outcomes associated with electric fields.

4.45 In the light of these findings, existing public exposure guidelines from ICNIRP have been set based on robust, well established acute effects from EMF. They do not account for postulated possible long term health effects from extremely low frequency fields due to the uncertainty surrounding the evidence base, but do incorporate a significant reduction factor from the lowest threshold for established effects, to allow for uncertainty and for long-term exposure. In the absence of an established causal mechanism it is considered appropriate to remain within guidelines set to manage known effects and where possible to further reduce unnecessary exposure.

Evidence Base

5 EMF Evidence Based Study Scope and Key Aims

5.1 The key aim of this element of the study is to compile a robust EMF evidence base from high-voltage transmission infrastructure in Ireland, and relate this to the present state of scientific knowledge regarding potential health impacts as discussed in the literature review. The primary scope of work undertaken has been a series of measurements at varying distances from a range of existing infrastructure items representative of the typical designs in use throughout Ireland, at locations around Dublin and Co. Kildare.

5.2 As discussed in the preceding sections, it is felt that real-world measurements of EMF from operational power lines, allied to a review of the health impact research literature, provides the best evidence from which to address perceived as well as actual risk from EMF.

5.3 Magnetic field strength depends directly on the load (amount of power) carried by the transmission infrastructure items, and so it is necessary not only for such an evidence base to contain measurements taken under typical operating conditions, but also for measurements and analysis to consider (real-world) high-load conditions – i.e. during periods when the load on the transmission grid is greater than average.

5.4 Analysis of measured magnetic field strength together with records of the load on power lines over a year allows magnetic field strength at average and highest loads to be estimated, using the measured data. Measurements have also been made to record the magnetic field experienced where several power lines cross or run together in close proximity.

6 Approach

Site selection

6.1 The strength of EMF generated and profile of how the field strength changes with distance is primarily dependent upon power line geometry, the current carried, and the load balance between phases. High-voltage transmission infrastructure in Ireland comprises a range of tower and cable designs, transmitting power over single or multiple circuits at a number of different voltages (and, hence, currents for a given power load).

6.2 In order to capture a robust dataset regarding EMF from power lines, it is necessary to survey a representative range of overhead and underground transmission line designs carrying varying power loads. This would allow a generalised set of typical EMF data for classes of power lines under these load conditions to be established, that can be applied to future developments.

6.3 Conversely, field strength as experienced by a receptor at a given location would be influenced by a range of highly site-specific local factors such as topography, structures, and transient/changeable factors such as other sources of EMF or weather conditions. Duration of receptor exposure and location within the field would also strongly influence the potential degree of exposure.

6.4 Investigation of such local factors is not a goal of this study, as their combination would likely be unique to any given location or receptor. The goal of site selection, instead, has been to choose power lines representative of the range of designs used, in settings that allow unobstructed space for measurement. This has been designed to allow focus on the power line EMF rather than influences of particular settings. Secondary considerations included the practicalities of land access and choice of general study areas that contain multiple power lines of different designs.

6.5 For these reasons, areas near the transmission substations at Dunstown, Maynooth, Kilteel and Finglas were chosen, all to the west of Dublin, within County Dublin and County Kildare. Two additional sites were used: at the Curragh (Co. Kildare), open land was used for measurements of a 400 kV single circuit overhead line with horizontal tower design, and at Firhouse in Dublin, additional measurements of a double-circuit 110 kV line were made due to access limitations at Maynooth. A plan of sampling point locations is given in Appendix B.

6.6 EMF strength drops rapidly with distance from the source. In addition, electric and magnetic fields are vectors, which means that the combined field strength from multiple sources would not typically be as great as the scalar sum of their maximum strength. These two points ensure that field strength measurements tend to be dominated by single proximate sources. The distance between EMF sources even where several are present in the area of a substation is sufficient to allow measurements of individual power lines.

6.7 These sites also enabled EMF measurements to be taken of the substations themselves, as the substations at Dunstown, Maynooth and Kilteel comprise 400 kV, 220 kV and 110 kV transformer and switching equipment.

6.8 Table 6.1 shows the high-voltage transmission range of infrastructure types used in Ireland and the sites chosen for EMF measurements of examples for each type.

Table 6.1: Infrastructure elements and EMF measurement sites

Infrastructure	Measurement site (location plan shown in Appendix B)
Overhead power lines (AC)	
400 kV single circuit on double circuit tower	Dunstown (Co. Kildare)
400 kV single circuit	The Curragh (Co. Kildare)
220 kV double circuit	Maynooth (Co. Kildare)
220 kV single circuit	Dunstown (x2) (Co. Kildare)
110 kV double circuit	Maynooth and Firhouse (Co. Kildare and Co. Dublin)
110 kV single circuit	Kilteel (Co. Kildare)
Underground power cables (AC)	
220 kV single circuit	Finglas (Co. Dublin)
110 kV single circuit	Finglas (Co. Dublin)
Substations (AC)	
400 kV / 220 kV transformer substation	Dunstown (Co. Kildare)
220 kV / 110 kV transformer substation	Maynooth (Co. Kildare)
110 kV transmission substation	Kilteel (Co. Kildare)

Survey times

6.9 The EMF survey aimed to record field strengths under typical conditions, representative of normal power loads on the grid infrastructure elements, as well as higher load conditions when a greater amount of power was being transmitted.

6.10 Power demand, and hence grid load, varies over two distinct temporal scales: daily over a 24-hour cycle, and seasonally over an annual cycle. Factors influencing daily demand profiles include social and working routines, while annual patterns are influenced by factors such as colder weather and shorter daylight hours in the winter. A third scale of variation over a week, with differences in demand over working days and the weekend, may also be perceived.

6.11 In light of these variations in power load carried, measurements that targeted typical conditions were undertaken during September 2012 and March 2013 at three intervals per day, over a period of three days per week (two weekdays and one weekend day) for each type of overhead line and underground cable, in order to capture a representative picture of EMF strength under typical operating conditions.

6.12 One further set of measurements targeted higher load conditions. Analysis of historic total grid load data indicated that the highest annual loads tend to occur in the winter, particularly in December and January. A single set of measurements for each item of infrastructure was conducted in January 2013.

6.13 Although total grid load in Ireland has the relatively clear trends discussed, load on individual power lines in the grid can be much more variable, due to factors such as load balancing within the grid and the generation and storage stations that are active at a given time.

6.14 Real-time load data and hourly records of loads were used to establish the load on each infrastructure item at the time at which measurements were taken.

Measurement methods

Measurement distances

6.15 Existing published calculations [59] and measurements [9] of EMF from power lines indicate that the strength of both the magnetic and electric field would be expected to reduce proportionate to approximately the inverse square or inverse cube (depending on design, phasing) of distance from the source.

6.16 For this reason, a measurement profile was chosen that allocates a greater proportion of measurements to the area close to the line, in order to offer finer resolution in the area where the field strength changes most rapidly.

6.17 Measurements at up to 100 m from the power line centrelines were proposed, as the field strength would (due to the decrease of field strength with distance noted above) be negligible compared to its maximum directly under/above the source.

6.18 Due to the closer spacing of cores in underground cables, the field strength was expected to drop more rapidly with distance than for the overhead lines. This was borne out in pilot measurements taken, and measurements were therefore grouped more closely over a shorter distance for the underground cables.

6.19 Substations were measured from the closest publically-accessible point, which in all three cases was the outer perimeter security fence, in order to be representative of potential general public exposure. The distance between EMF sources (HV equipment on the substation site) and fence meant that a shorter measurement distance beyond the fence was warranted; space constraints at the sites limited this to 15 m, 30 m and 50 m at the substations measured.

6.20 Substation measurements were taken at the farthest accessible point on the fence from overhead power lines crossing it, in order to reduce as far as possible the influence of field strength from the overhead lines on the results.

6.21 Measurement distances are summarised in Table 6.2.

Table 6.2: EMF measurement distances

Infrastructure	Measurement distances (m)
400 kV overhead line 220 kV overhead line 110 kV overhead line	0, 5, 10, 15, 20, 25, 50, 75, 100*
220 kV underground cable	0, 2, 5, 10, 15, 20, 25, 30, 35, 40, 50
110 kV underground cable	0, 2, 4, 6, 8, 10, 12
Substations	0, 5, 10, 15, 20, 25, 30, 50**

* Limited to 75 m in some cases due to space/access constraints

** Maximum; limited to 15 m and 30 m in other cases due to space constraints

6.22 A distance of 0 m corresponds to the central point under the power line, above the underground cable, or at the substation fence. For horizontal design overhead lines, the central point lay directly under the middle (of three) phase wires. For double circuit vertical design overhead lines, the central point lay directly under the central earth wire, equidistant from the wires of each circuit either side. For the single circuit overhead line on double circuit pylons, the central point lay directly under the lower phase wire. Positioning was established visually, using parallax between the phase wires.

6.23 The centreline of both underground cables was located using the EMF meter, on the predication that this would be the point at which the maximum magnetic field strength would be experienced. It would not be possible to confirm that this alignment with the cable’s physical location is borne out without excavating the cable; however, it is the location of maximum field strength that is of interest, rather than cable centreline *per se*.

Measurement equipment

6.24 Magnetic field measurements were conducted using a Narda EHP-50D meter with electric and magnetic field probes. The meter offers three-axis field measurement, with an RMS (root mean square) total of field strength measured presented in the results. A calibration certificate for the meter used is reproduced at Appendix C.

Measurement height

6.25 All measurements were taken with the EMF meter at 1 m above ground level. Potential EMF interaction with the body is through induced currents, primarily in the central nervous system, and such currents are generated by the field over the entire surface of the body. Field strength will not be uniform over the body as the distance from source is greater at head or feet, for example. A measurement height of 1 m above ground is, however, considered to provide a good approximation of field strength as it would be experienced body-wide, being approximately at the height of a standing adult's torso.

6.26 The height of the power line above the point of measurement also influences the field strength measured. Measurements were conducted from a point measured to be in the centre of the span between pylons, at which point the line sags to its lowest level. Where the topography of the measurement site was not flat (especially on the Curragh), the measurement centre point was selected on high ground in order to avoid capturing artificially low field strengths due to greater line clearance over a valley or dip in the land (i.e. greater than usual vertical distance between power line and measurement point).

6.27 Underground cable burial depth would also affect the magnetic field measured at 1 m above ground level; however it was not possible to ascertain cable depth. In general, however, direct-buried underground cables (as opposed to those located in conduits or utilities pipes) are typically at a depth of 1 m – 2 m.

Measurement variation

6.28 A number of factors influence real-world measurements of electric and magnetic fields, that would cause variation in the measurement results over several series of measurements at the same infrastructure item, even when the recorded loads at the time of measurement are similar or the same. Factors likely to cause variability in the measurement results include:

- Exact load at the time of measurement. Loads were generally recorded from real-time data at the start of measurement series, and may have varied while measurements were undertaken.
- Topography of the measurement sites. Although relatively flat sites were selected where possible, topography will have affected the straight-line distance from the EMF sources to a small degree.
- Meteorological conditions at the time of measurement. Ambient temperature can affect the heating, and hence degree of sag (affecting measurement distance), in overhead line conductors. Wind causes some movement in the conductors of overhead lines, again affecting distance from them. Electric field measurements are particularly sensitive to conductivity, affected by humidity and rainfall.
- Transmission system voltage variability, which would directly affect the electric field strength measured. Within the Grid Code [60], under normal operation, variation from 370 kV to 410 kV, 210 kV to 240 kV and 105 kV to 120 kV is possible around the nominal operating voltages of 400 kV, 220 kV and 110 kV respectively. During transmission system disturbances, variation from 350 kV to 420 kV, 200 kV to 245 kV and 99 kV to 123 kV is possible around the nominal operating voltages of 400 kV, 220 kV and 110 kV respectively.

- EMF meter accuracy. Meter calibration results are given in Appendix C. This indicates that meter accuracy would be a minor component of results variation.

6.29 Variability within results would be expected in measurements conducted under real-world conditions (as opposed to theoretical calculations). The consistency of results, and degree of variability, is discussed in the results consistency section of chapter 7.

7 Magnetic Field Results

7.1 Table 7.1 to Table 7.15 show the magnetic field strength measured for each of the high-voltage transmission infrastructure items surveyed, with the load at the time of each measurement. Variation in the results measured at similar loads is due to factors outlined in the measurement variation discussion in Section 6. The consistency of results is discussed further in the results consistency section, below.

Results tables

Table 7.1: Measured magnetic field for 400 kV single circuit overhead line (double circuit tower) [see Figure 7.1]

Name	Moneypoint → Dunstown									
Location	Dunstown									
Type	400 kV single circuit									
Design	Double circuit tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	10:35	14:02	16:41	09:30	12:13	15:18	10:30	12:47	16:02	14:40
Load (MVA)	181	201	256	199	238	247	223	152	121	286
Dist. (m)	**Magnetic field (μT)**									
0	2.30	2.40	3.20	2.52	3.08	3.02	2.70	2.10	1.70	3.74
5	2.04	2.10	2.96	2.30	2.92	2.86	2.60	1.94	1.58	3.57
10	1.72	2.02	2.50	1.90	2.40	2.36	2.18	1.62	1.32	3.24
15	1.34	1.40	1.96	1.52	1.90	1.86	1.74	1.26	1.04	2.89
20	0.98	1.20	1.60	1.20	1.48	1.48	1.36	0.98	0.83	2.07
25	0.79	0.98	1.20	0.94	1.18	1.16	1.08	0.77	0.67	1.28
50	0.31	0.70	0.50	0.32	0.45	0.44	0.41	0.29	0.25	0.57
75	0.17	0.50	0.45	0.19	0.23	0.28	0.20	0.14	0.12	0.46
100	0.10	0.11	0.17	0.11	0.14	0.16	0.12	0.09	0.07	0.21

Table 7.2: Measured magnetic field for 400 kV single circuit overhead line (horizontal tower configuration) [see Figure 7.2]

Name	Moneypoint → Dunstown									
Location	The Curragh									
Type	400 kV single circuit									
Design	Single circuit tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	12:58	15:31	18:20	11:23	14:30	16:44	09:30	12:01	15:16	13:30
Load (MVA)	196	255	236	212	243	237	166	177	221	280
Dist. (m)	**Magnetic field (µT)**									
0	3.20	4.30	3.80	3.56	3.92	3.78	2.54	2.64	3.30	4.86
5	3.00	4.30	3.77	3.50	3.90	3.68	2.52	2.56	3.28	4.83
10	2.80	3.90	3.40	3.24	3.58	3.28	2.40	2.40	2.98	4.61
15	2.10	3.20	2.70	2.68	2.88	2.62	1.96	1.96	2.46	4.34
20	1.60	2.40	2.09	2.04	2.16	2.02	1.50	1.48	1.82	3.61
25	1.20	1.60	1.60	1.50	1.58	1.48	1.10	1.10	1.34	2.78
50	0.50	0.50	0.50	0.45	0.48	0.44	0.34	0.33	0.39	0.78
75	0.40	0.40	0.38	0.19	0.19	0.19	0.15	0.15	0.18	0.52
100	0.05	0.05	0.05	0.12	0.12	0.11	0.04	0.11	0.07	0.20

Table 7.3: Measured magnetic field for 220 kV single circuit overhead line 1 [see Figure 7.3]

Name	Dunstown → Turlough Hill									
Location	Dunstown									
Type	220 kV single circuit									
Design	Horizontal tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	11:10	14:30	17:10	10:23	12:50	15:58	11:00	13:10	16:25	15:00
Load (MVA)	35	49	20	42	81	73	55	59	18	42
Dist. (m)	**Magnetic field (µT)**									
0	1.30	2.10	0.90	1.82	3.52	3.18	2.32	2.44	0.68	1.97
5	1.20	2.20	0.60	1.62	3.30	3.04	2.12	2.30	0.58	1.93
10	1.02	1.80	0.60	1.25	2.64	2.42	1.53	1.84	0.50	1.84
15	0.93	1.30	0.45	0.84	1.82	1.66	1.19	1.22	0.32	1.42
20	0.66	0.90	0.05	0.56	1.20	1.05	0.80	0.74	0.24	1.01
25	0.44	0.60	0.05	0.38	0.83	0.75	0.56	0.50	0.17	0.73
50	0.16	0.05	0.08	0.10	0.21	0.19	0.16	0.10	0.06	0.30
75	0.07	0.05	0.01	0.04	0.09	0.08	0.08	0.03	0.03	0.09
100	0.02	0.02	0.01	0.02	0.03	0.03	0.02	0.02	0.01	n/a

Table 7.4: Measured magnetic field for 220 kV single circuit overhead line 2 [see Figure 7.4]

Name	Dunstown → Maynooth									
Location	Dunstown									
Type	220 kV single circuit									
Design	Horizontal tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	12:00	15:00	17:30	10:45	13:12	16:08	11:15	13:30	16:43	15:15
Load (MVA)	82	38	58	93	72	67	60	74	26	20
Dist. (m)	**Magnetic field (μT)**									
0	2.96	1.20	2.10	3.10	2.44	2.32	1.88	2.44	0.81	1.05
5	2.88	1.20	1.70	2.94	2.38	2.18	1.72	2.28	0.82	0.95
10	2.30	0.80	1.55	2.42	1.96	1.64	1.42	1.92	0.65	0.95
15	1.78	0.60	1.30	1.78	1.44	1.30	1.05	1.50	0.48	0.92
20	1.20	0.40	0.80	1.24	0.97	0.86	0.72	1.02	0.32	0.73
25	0.71	0.40	0.50	0.86	0.70	0.62	0.52	0.72	0.23	0.46
50	0.22	0.05	0.05	0.25	0.20	0.17	0.14	0.20	0.09	0.13
75	0.10	0.05	0.05	0.10	0.09	0.09	0.07	0.09	0.03	0.06

Table 7.5: Measured magnetic field for 110 kV single circuit overhead line [see Figure 7.5]

Name	Kilteel → Maynooth									
Location	Kilteel									
Type	110 kV single circuit									
Design	Horizontal wooden pole									
Date	04/09/12	04/09/12	04/09/12	06/09/12	06/09/12	06/09/12	08/09/12	08/09/12	08/09/12	21/01/13
Time	09:36	12:36	15:15	10:00	12:20	16:47	11:00	13:35	16:47	13:00
Load (MVA)	13	14	14	13	14	12	14	14	12	14
Dist. (m)	**Magnetic field (μT)**									
0	0.93	0.98	1.01	0.97	1.01	0.93	1.06	1.06	0.93	1.22
5	0.90	0.90	0.85	0.84	0.87	0.82	0.97	0.93	0.82	1.00
10	0.60	0.52	0.55	0.54	0.58	0.57	0.66	0.58	0.57	0.87
15	0.40	0.30	0.31	0.32	0.33	0.30	0.39	0.36	0.30	0.52
20	0.27	0.20	0.20	0.19	0.21	0.19	0.24	0.22	0.19	0.34
25	0.17	0.13	0.14	0.13	0.13	0.12	0.16	0.15	0.12	0.23
50	0.03	0.04	0.04	0.03	0.04	0.06	0.04	0.04	0.06	0.09
75	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.04
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	n/a

Table 7.6: Measured magnetic field for 220 kV double circuit overhead line circuit 1 [see Figure 7.6]

Name	Maynooth → Woodlands									
Location	Maynooth									
Type	220 kV double circuit									
Design	Vertical tower									
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13	21/01/13
Time	11:17	14:01	15:00	11:00	12:58	13:46	10:23	11:16	12:06	10:40
Load (MVA)	237	206	204	173	171	168	77	64	66	148
Dist. (m)	**Magnetic field (µT)**									
0	4.97	4.23	3.75	3.19	3.07	3.14	2.09	1.56	1.65	2.46
5	4.42	3.91	3.63	3.18	3.13	3.21	1.69	1.70	1.81	3.15
10	3.49	3.09	2.97	2.54	2.54	2.59	1.31	1.36	1.42	2.58
15	2.62	2.24	2.12	1.83	1.87	1.89	0.96	0.93	0.98	1.98
20	1.92	1.65	1.50	1.34	1.35	1.40	0.65	0.66	0.68	1.49
25	1.42	1.22	1.13	1.02	0.99	1.08	0.48	0.49	0.53	1.17
50	0.51	0.42	0.40	0.36	0.37	0.36	0.16	0.16	0.21	0.38
75	0.32	0.30	0.28	0.28	0.29	0.28	0.11	0.28	0.12	0.24
100	0.15	0.14	0.13	0.11	0.11	0.11	0.05	0.06	0.06	0.12

Table 7.7: Measured magnetic field for 220 kV double circuit overhead line circuit 2 [see Figure 7.7]

Name	Maynooth → Shannonbridge									
Location	Maynooth									
Type	220 kV double circuit									
Design	Vertical tower									
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13	21/03/13
Time	11:34	14:13	15:07	11:13	13:06	13:52	10:31	11:24	12:25	10:50
Load (MVA)	10	17	16	40	39	47	108	109	108	32
Dist. (m)	**Magnetic field (µT)**									
0	2.25	2.50	2.39	2.33	2.26	2.22	2.48	2.61	2.43	3.58
5	1.69	1.91	1.80	1.87	1.76	1.76	1.97	2.01	1.96	2.92
10	1.09	1.43	1.28	1.39	1.19	1.32	1.33	1.52	1.29	1.29
15	0.88	1.02	0.94	1.00	0.97	0.98	1.05	1.09	1.03	0.96
20	0.63	0.76	0.69	0.76	0.71	0.73	0.81	0.88	0.79	0.80
25	0.41	0.58	0.53	0.59	0.58	0.56	0.63	0.69	0.61	0.64
50	0.17	0.25	0.23	0.23	0.26	0.23	0.23	0.27	0.22	0.28
75	0.22	0.19	0.20	0.20	0.19	0.20	0.19	0.20	0.19	0.15
100	0.12	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.09	0.08

Table 7.8: Measured magnetic field for 110 kV double circuit overhead line circuit 1 [see Figure 7.8]

Name	Maynooth → Rinawade								
Location	Maynooth								
Type	110 kV double circuit								
Design	Vertical tower								
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13
Time	12:27	14:42	15:51	11:41	13:33	14:13	10:58	11:46	12:52
Load (MVA)	32	30	30	33	31	32	25	27	30
Dist. (m)*	**Magnetic field (μT)**								
0	1.71	1.69	1.59	1.72	1.51	1.44	1.22	1.60	1.72
5	1.32	1.22	1.11	1.21	1.24	1.19	0.91	1.01	1.19
10	0.93	0.88	0.78	0.91	0.94	0.94	0.74	0.75	0.86
15	0.64	0.57	0.55	0.63	0.66	0.65	0.55	0.56	0.61
20	0.47	0.41	0.38	0.46	0.49	0.49	0.42	0.42	0.39
25	0.34	0.31	0.28	0.34	0.37	0.36	0.31	0.32	0.31
50	0.11	0.10	0.09	0.12	0.12	0.13	0.12	0.11	0.09
75	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

* Space constraints permitted measurement only to 75 m

Table 7.9: Measured magnetic field for 110 kV double circuit overhead line circuit 2 [see Figure 7.9]

Name	Maynooth → Ryebrook								
Location	Maynooth								
Type	110 kV double circuit								
Design	Vertical tower								
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13
Time	12:18	14:30	15:22	11:32	13:23	14:06	10:49	11:40	14:50
Load (MVA)	10	17	18	17	19	19	35	29	21
Dist. (m)	**Magnetic field (μT)**								
0	1.76	1.64	1.67	1.68	1.71	1.59	1.99	1.69	1.78
5	1.29	1.26	1.34	1.39	1.36	1.29	1.56	1.38	1.42
10	0.84	0.78	0.82	0.89	0.88	0.92	1.14	0.90	0.92
15	0.54	0.49	0.51	0.57	0.56	0.62	0.60	0.58	0.61
20	0.37	0.33	0.36	0.42	0.38	0.40	0.42	0.39	0.43
25	0.26	0.24	0.24	0.28	0.27	0.30	0.31	0.27	0.32
50	0.10	0.08	0.09	0.13	0.09	0.11	0.11	0.10	0.10
75	0.06	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.07
100	0.03	0.04	0.04	0.03	0.03	0.03	0.05	0.04	0.04

Table 7.10: Measured magnetic field for 110 kV double circuit overhead line 3* [see Figure 7.9]

Name	Cookstown → Inchicore
Location	Firhouse
Type	110 kV double circuit
Design	Vertical tower
Date	25/01/13
Time	16:00
Load (MVA)	59
Dist. (m)	**Magnetic field (μT)**
0	2.44
5	2.37
10	1.86
15	1.41
20	0.95
25	0.78
50	0.22
75	0.13
100	0.06

* This single set of measurements was taken targeting high load conditions due to access constraints at the Maynooth site

Table 7.11: Measured magnetic field for 220 kV single circuit underground cable [see Figure 7.10]

Name	Huntstown → Corduff									
Location	Rosemount Business Park									
Type	220 kV single circuit									
Design	Underground cable									
Date	04/09/12	04/09/12	04/09/12	06/09/12	06/09/12	06/09/12	08/09/12	08/09/12	08/09/12	21/01/13
Time	11:07	13:51	18:28	08:55	11:52	15:41	08:11	11:46	14:40	14:40
Load (MVA)	316	224	366	229	241	237	360	347	351	369
Dist. (m)	**Magnetic field (μT)**									
0	17.58	15.08	24.32	14.40	15.78	14.44	23.04	23.68	24.32	26.01
5	4.77	3.15	6.94	1.98	2.28	2.36	6.22	6.67	5.68	3.67
10	1.44	1.00	2.70	0.54	0.56	0.61	1.35	2.07	1.62	1.10
15	0.74	0.53	0.51	0.25	0.24	0.26	0.31	0.29	0.33	0.73
20	0.60	0.39	0.41	0.13	0.15	0.15	0.17	0.15	0.19	0.37
25	0.42	0.37	0.33	0.08	0.09	0.09	0.15	0.10	0.11	0.77
30	0.36	0.33	0.31	0.05	0.06	0.06	0.10	0.04	0.07	0.46
35	0.34	0.25	0.21	0.03	0.03	0.03	0.07	0.05	0.05	0.28

Table 7.12: Measured magnetic field for 110 kV single circuit underground cable [see Figure 7.11]

Name	Finglas → Dardistown								
Location	Finglas								
Type	110 kV single circuit								
Design	Underground cable								
Date	04/09/12	04/09/12	04/09/12	06/09/12	06/09/12	06/09/12	08/09/12	08/09/12	08/09/12
Time	10:45	13:37	18:47	08:30	12:05	16:01	11:35	14:20	18:01
Load (MVA)	22	22	22	21	22	22	22	21	21
Dist. (m)	Magnetic field (μT)								
0	1.98	2.12	2.28	2.12	2.16	2.32	2.22	2.12	2.08
2	1.04	1.52	1.32	1.26	1.26	1.24	1.48	1.30	1.26
4	0.54	0.66	0.56	0.51	0.56	0.58	0.67	0.52	0.55
6	0.20	0.32	0.30	0.29	0.31	0.31	0.35	0.32	0.32
8	0.16	0.19	0.18	0.17	0.22	0.18	0.23	0.22	0.22
10	0.12	0.13	0.14	0.12	0.12	0.13	0.15	0.14	0.15
12	0.09	0.09	0.10	0.08	0.09	0.09	0.10	0.11	0.10

Table 7.13: Measured magnetic field for 400/220 kV substation [see Figure 7.12]

Name	Dunstown 400/220 kV substation									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	10:45	14:17	16:52	09:42	12:27	15:26	10:45	13:01	16:17	15:30
Load (MVA)	176	197	248	181	234	235	233	162	115	281
Dist. (m)	Magnetic field (μT)									
0	0.12	0.11	0.10	0.13	0.11	0.12	0.11	0.11	0.10	0.07
5	0.09	0.09	0.08	0.09	0.10	0.09	0.09	0.09	0.09	0.11
10	0.06	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.11
15	0.05	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.10

Table 7.14: Measured magnetic field for 220/110 kV substation [see Figure 7.13]

Name	Maynooth 220/110 kV substation									
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13	21/01/13
Time	11:45	14:25	15:21	11:21	13:16	14:02	10:44	11:38	12:32	11:00
Load (MVA)	135	135	134	141	143	138	122	123	122	154
Dist. (m)	**Magnetic field (µT)**									
0	0.10	0.11	0.09	0.10	0.10	0.09	0.10	0.12	0.10	0.00
5	0.69	0.70	0.69	0.69	0.70	0.64	0.72	0.69	0.69	0.51
10	0.57	0.57	0.54	0.57	0.57	0.57	0.57	0.56	0.57	0.44
15	0.50	0.49	0.49	0.51	0.49	0.49	0.49	0.49	0.49	0.36
20	0.44	0.44	0.44	0.44	0.44	0.44	0.42	0.44	0.44	0.29
25	0.38	0.41	0.38	0.38	0.38	0.38	0.38	0.38	0.38	n/a
30	0.34	0.34	0.36	0.34	0.29	0.34	0.34	0.34	0.34	n/a

Table 7.15: Measured magnetic field for 110 kV substation [see Figure 7.14]

Name	Kilteel 110 kV substation									
Date	04/09/12	04/09/12	04/09/12	06/09/12	06/09/12	06/09/12	08/09/12	08/09/12	08/09/12	21/01/13
Time	09:00	12:26	16:41	10:20	12:40	17:10	11:15	13:50	17:25	13:10
Load (MVA)	13	14	14	15	14	14	11	10	10	15
Dist. (m)	**Magnetic field (µT)**									
0	0.05	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.07
5	0.03	0.05	0.04	0.03	0.03	0.05	0.05	0.05	0.05	0.07
10	0.03	0.04	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.07
15	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.07
20	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.07
25	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.06
50	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.06

Results graphs

7.2 Figure 7.1 to Figure 7.14 show the measured magnetic field strength plotted against distance for each of the high-voltage transmission infrastructure items surveyed. For double-circuit overhead lines, the load at the time of measurement is given for both circuits on the graphs of measurements to each side of the overhead line. The measured magnetic field strength is influenced by the load on both circuits.

7.3 Variation in the results measured at similar loads is due to factors outlined in the measurement variation discussion in Section 6.

Figure 7.1: Measured magnetic field plotted against distance for 400 kV single circuit overhead line (double circuit tower) [see Table 7.1]

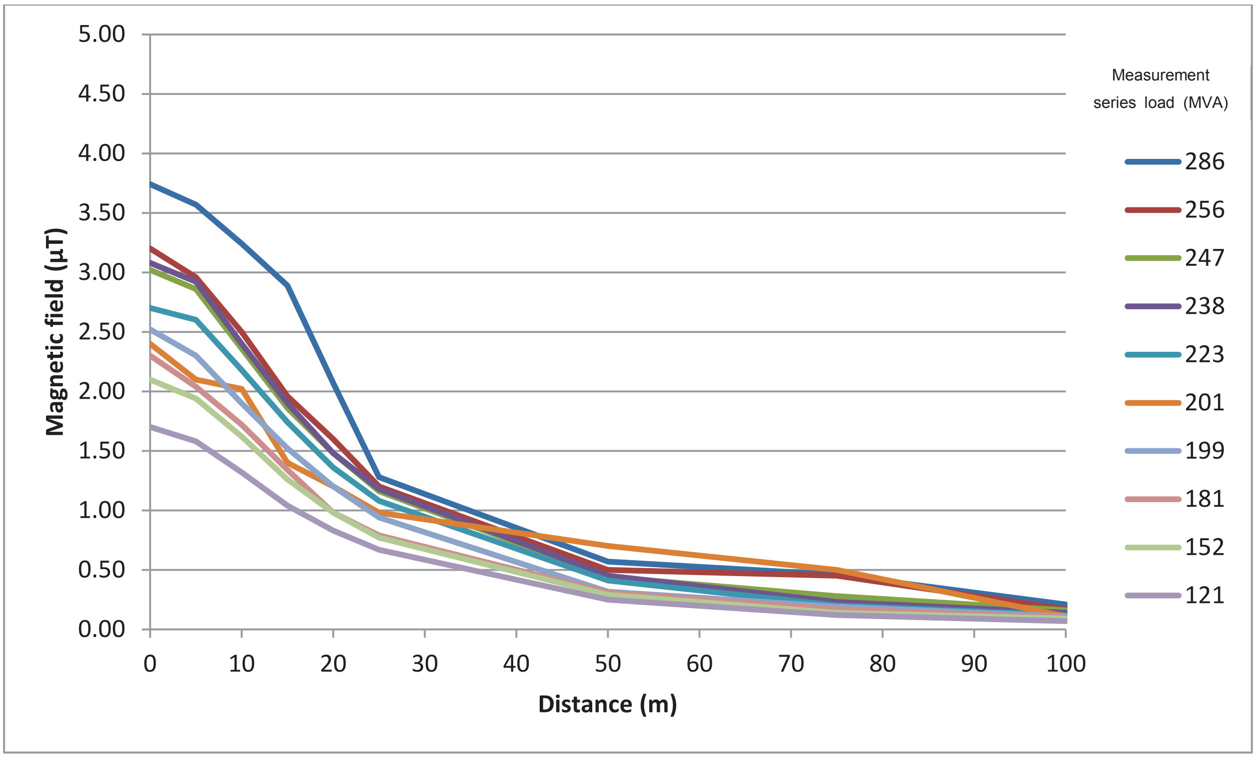


Figure 7.2: Measured magnetic field plotted against distance for 400 kV single circuit overhead line (horizontal tower configuration) [see Table 7.2]

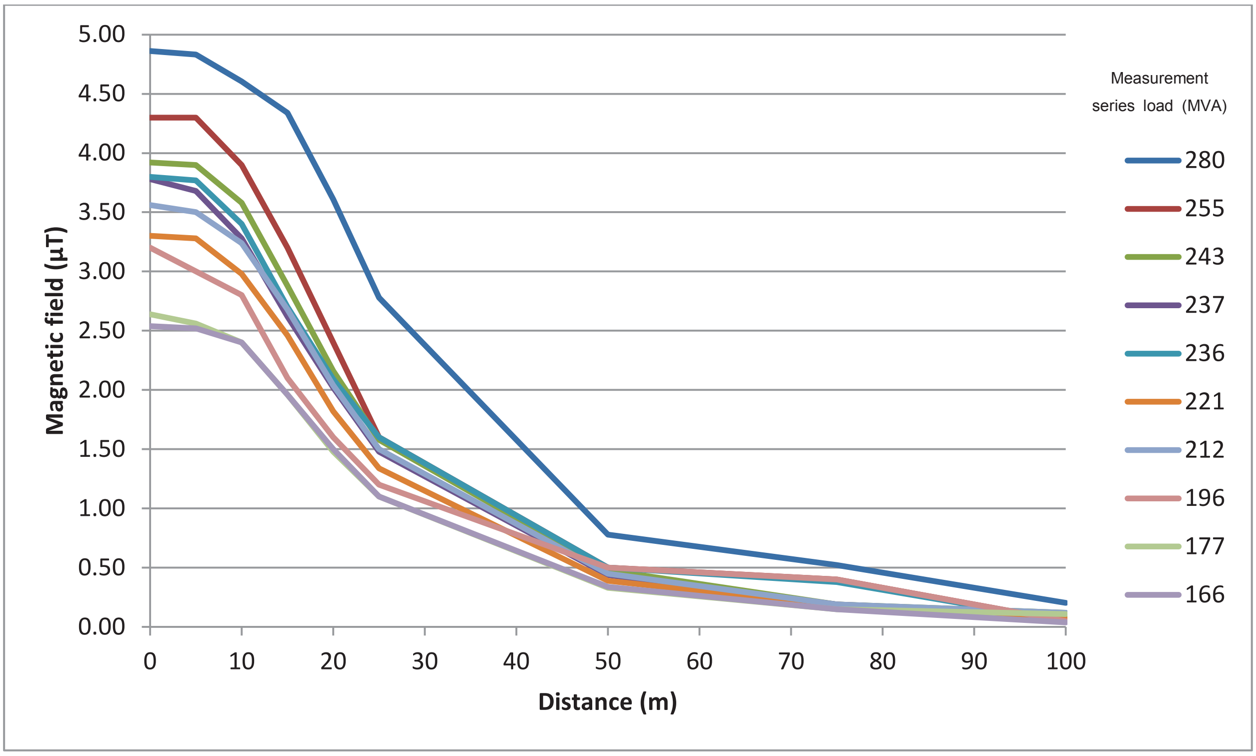


Figure 7.3: Measured magnetic field plotted against distance for 220 kV single circuit overhead line 1 [see Table 7.3]

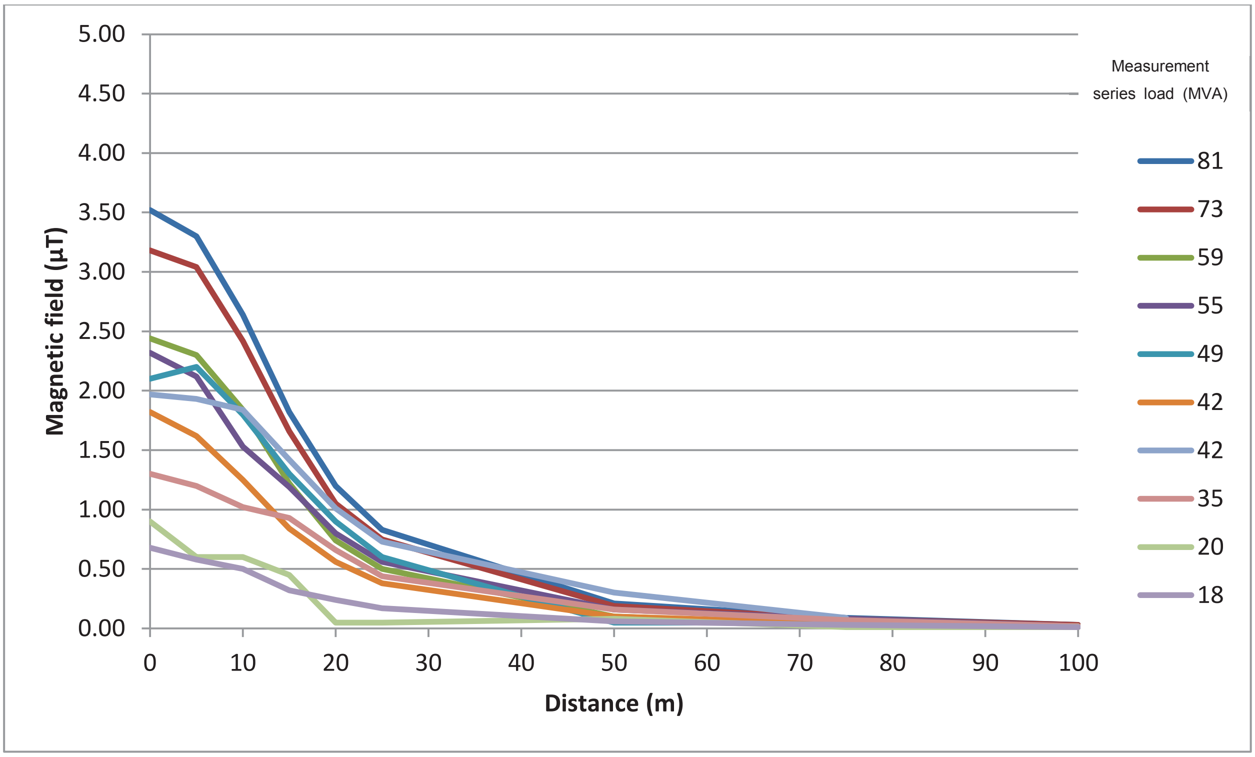


Figure 7.4: Measured magnetic field plotted against distance for 220 kV single circuit overhead line 2 [see Table 7.4]

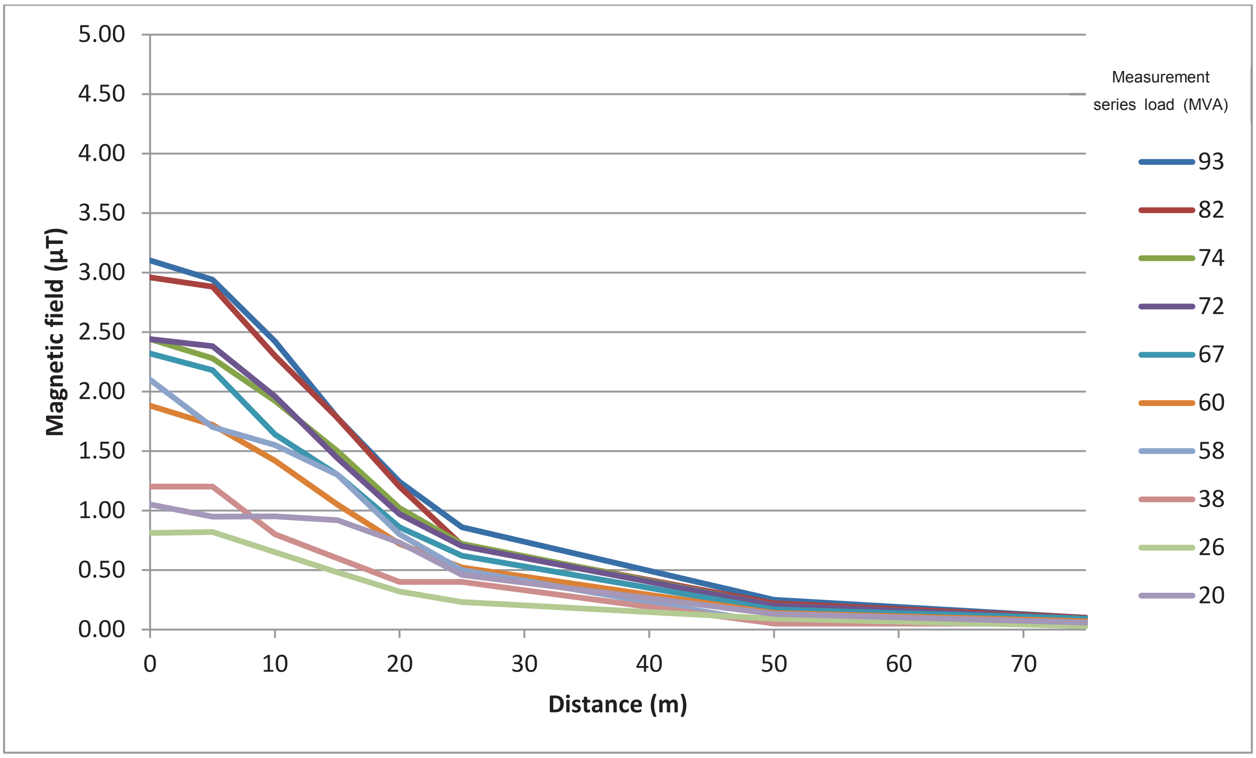


Figure 7.5: Measured magnetic field plotted against distance for 110 kV single circuit overhead line [see Table 7.5]

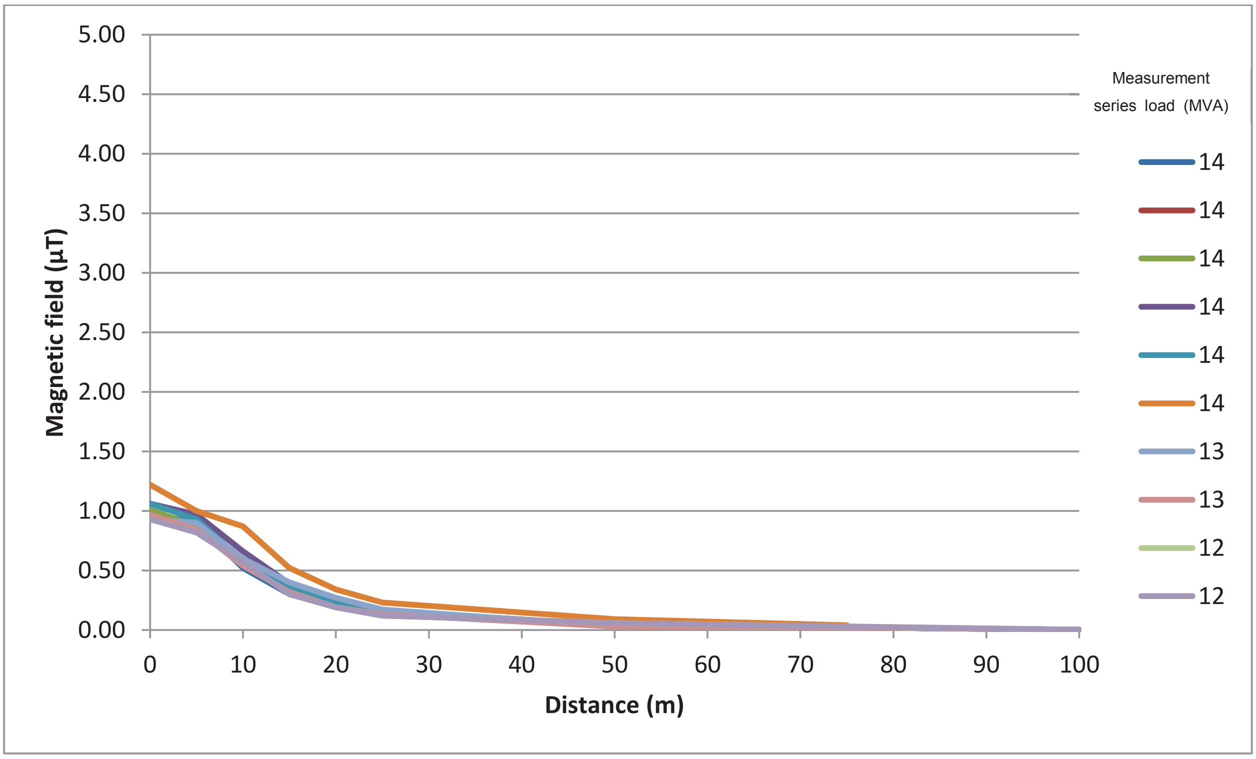
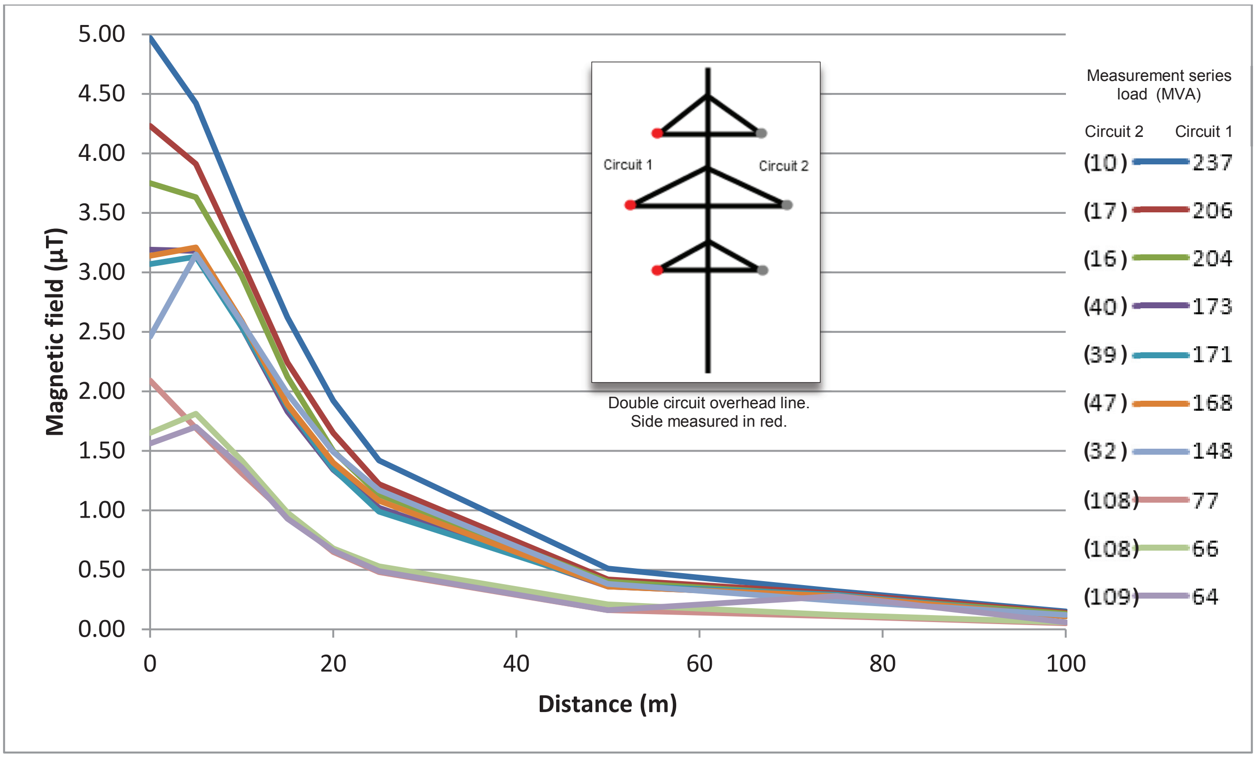
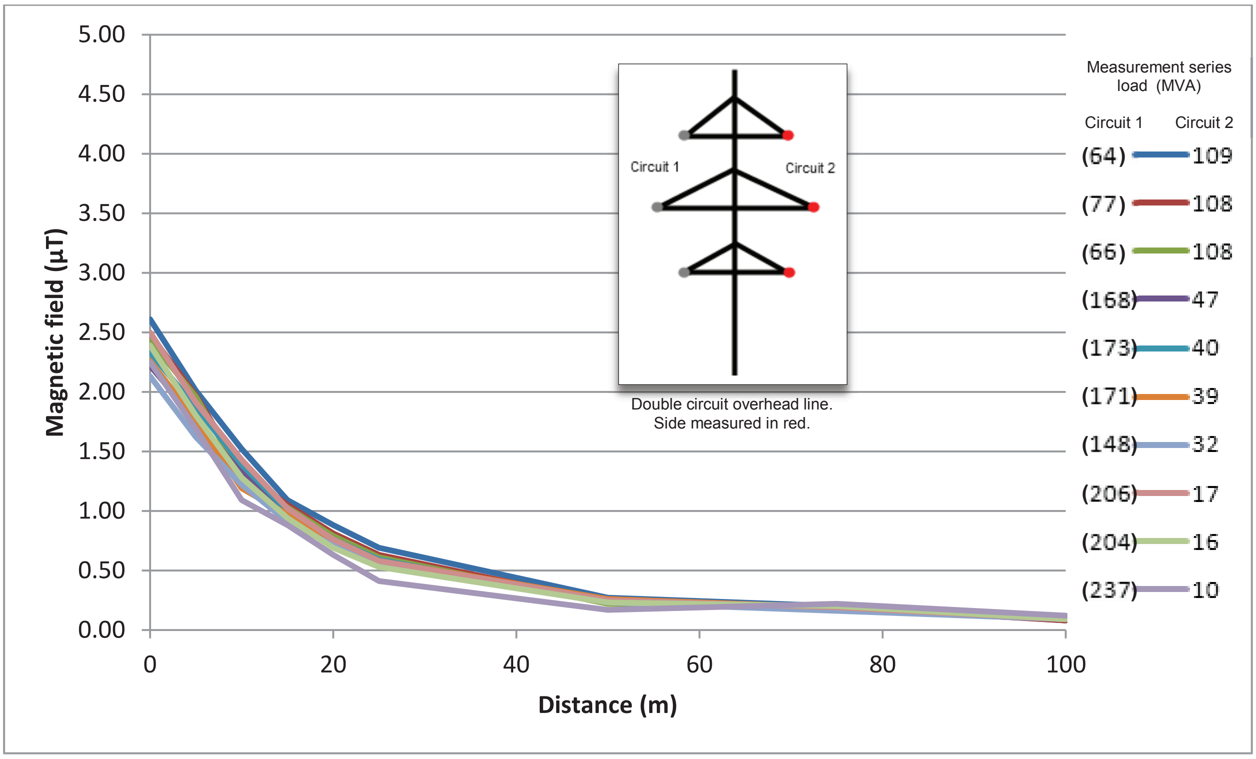


Figure 7.6: Measured magnetic field plotted against distance for 220 kV double circuit overhead line circuit 1 [see Table 7.6]



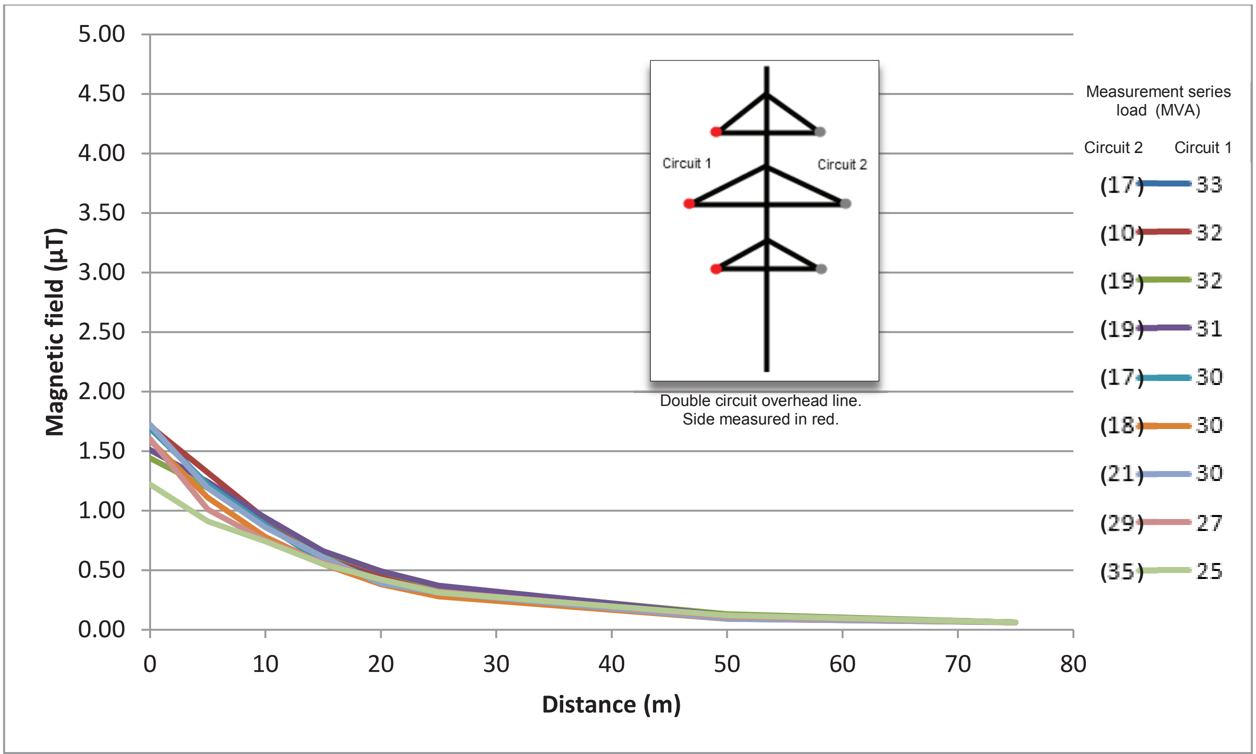
Note: the magnetic field measured to each side of this overhead line was also influenced by the load on the circuit on the other side of the line. The measured magnetic field on each side of the overhead line is shown in this figure and Figure 7.7. In each case, the loads on the circuit on the opposite site to the measurements are shown in brackets.

Figure 7.7: Measured magnetic field plotted against distance for 220 kV double circuit overhead line circuit 2 [see Table 7.7]



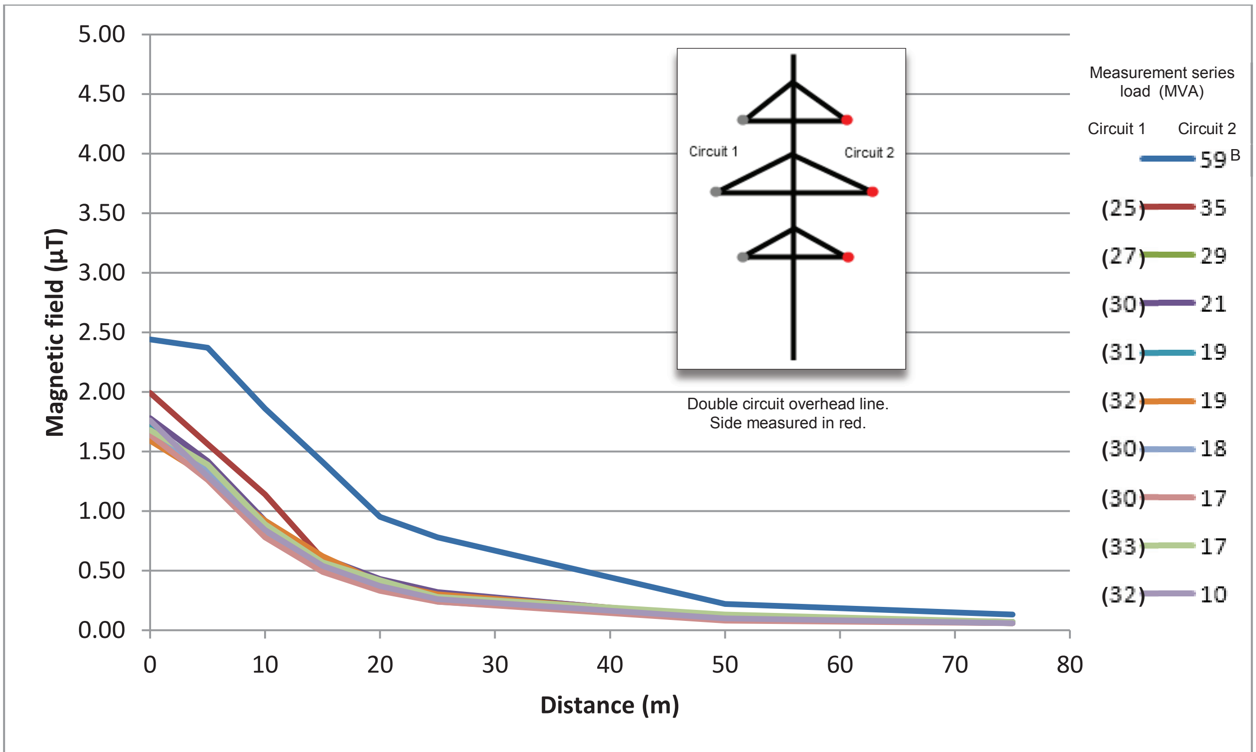
Note: the magnetic field measured to each side of this overhead line was also influenced by the load on the circuit on the other side of the line. The measured magnetic field on each side of the overhead line is shown in this figure and Figure 7.6. In each case, the loads on the circuit on the opposite site to the measurements are shown in brackets.

Figure 7.8: Measured magnetic field plotted against distance for 110 kV double circuit overhead line circuit 1 [see Table 7.8]



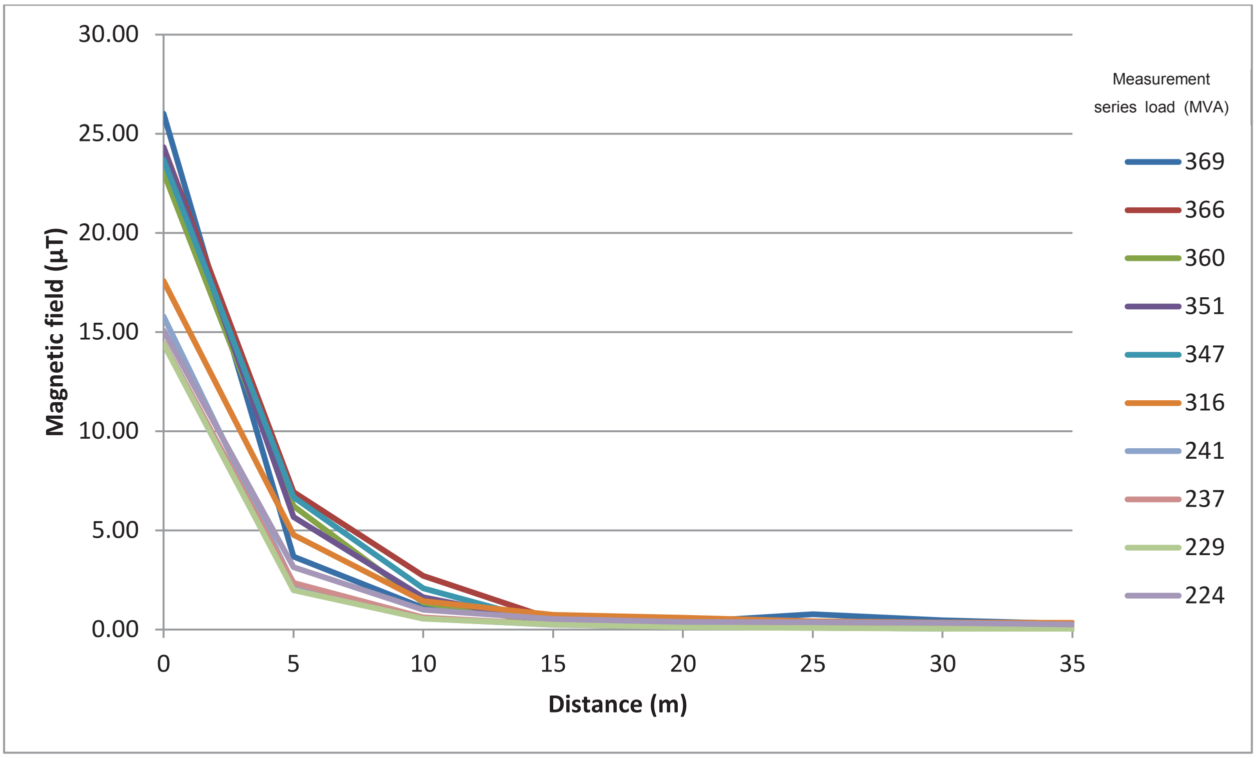
Note: the magnetic field measured to each side of this overhead line was also influenced by the load on the circuit on the other side of the line. The measured magnetic field on each side of the overhead line is shown in this figure and Figure 7.9. In each case, the loads on the circuit on the opposite site to the measurements are shown in brackets.

Figure 7.9: Measured magnetic field plotted against distance for 110 kV double circuit overhead line circuit 2 [see Table 7.9 and Table 7.10]



Note A: the magnetic field measured to each side of this overhead line was also influenced by the load on the circuit on the other side of the line. The measured magnetic field on each side of the overhead line is shown in this figure and Figure 7.8. In each case, the loads on the circuit on the opposite site to the measurements are shown in brackets.
Note B: measurements at 59 MVA load taken for Cookstown→Inchicore overhead line.

Figure 7.10: Measured magnetic field plotted against distance for 220 kV single circuit underground cable [see Table 7.11]



Note: the graph scale is greater in this plot than all others in this section (due to results magnitude)

Figure 7.11: Measured magnetic field plotted against distance for 110 kV single circuit underground cable [see Table 7.12]

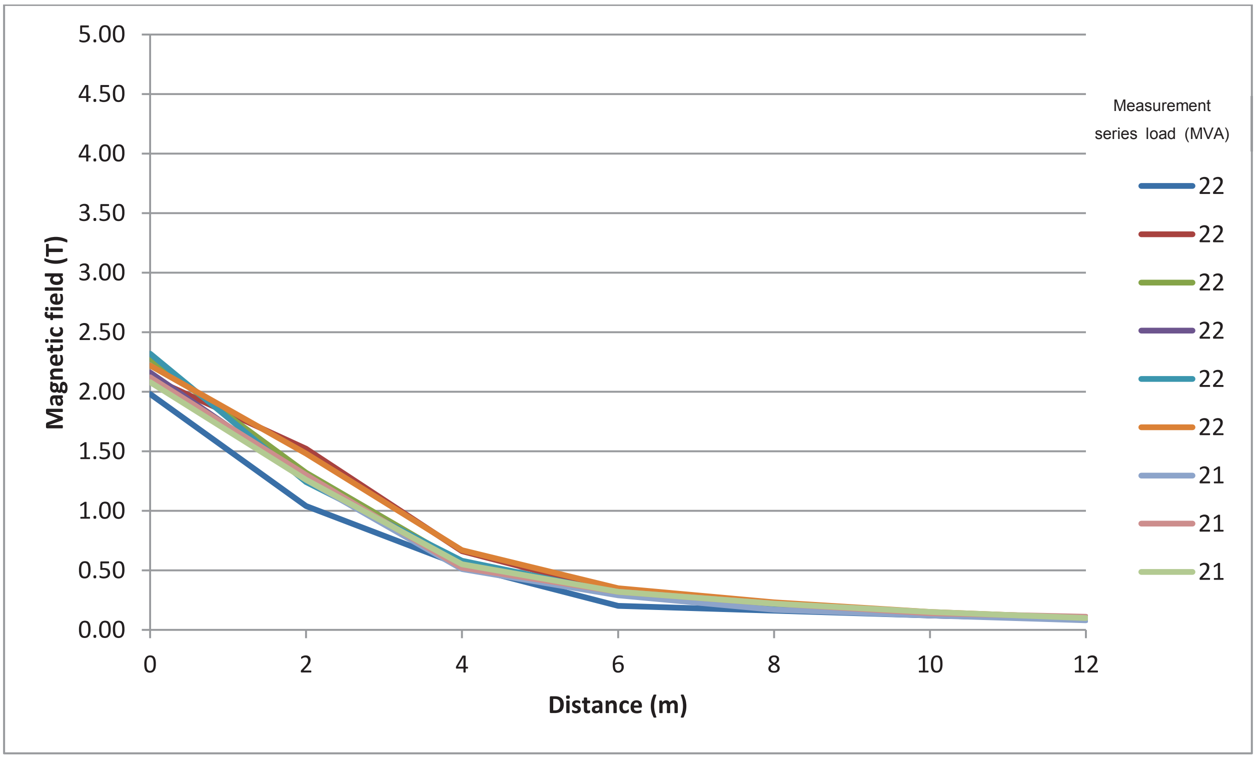


Figure 7.12: Measured magnetic field plotted against distance for 400/220 kV substation [see Table 7.13]

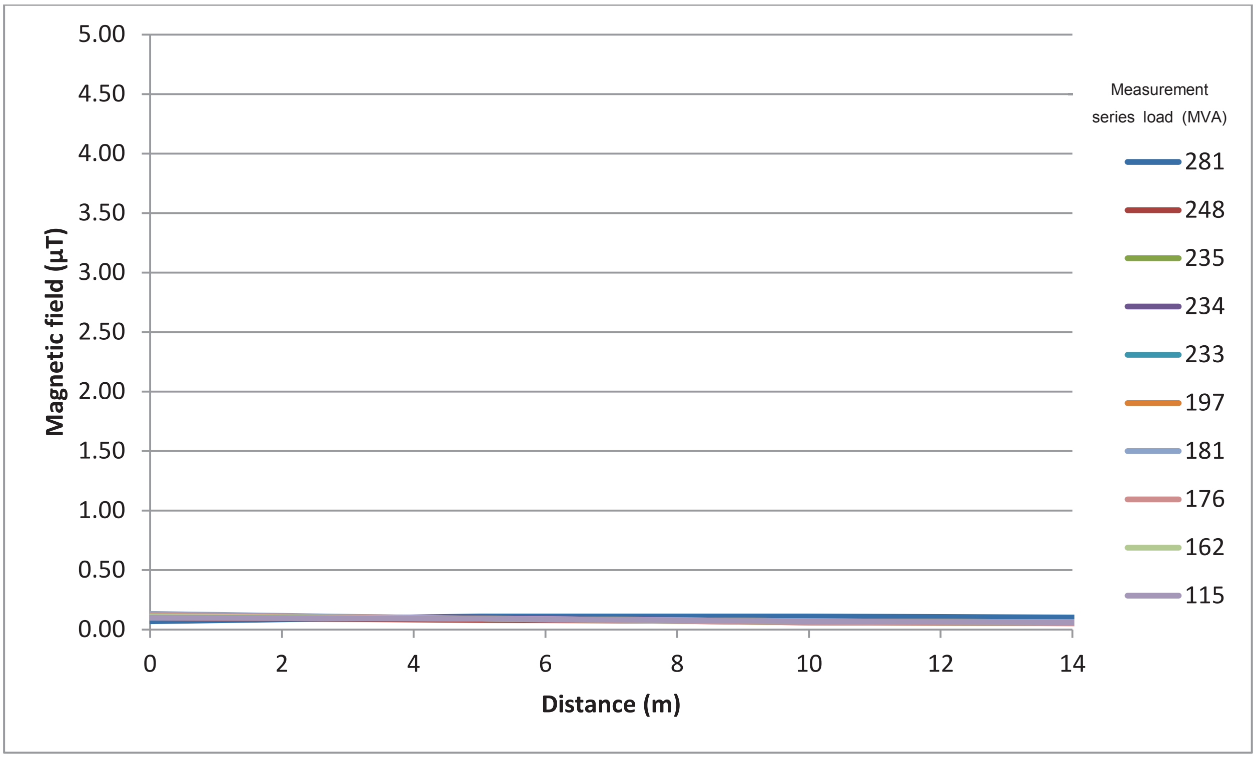


Figure 7.13: Measured magnetic field plotted against distance for 220/110 kV substation [seeTable 7.14]

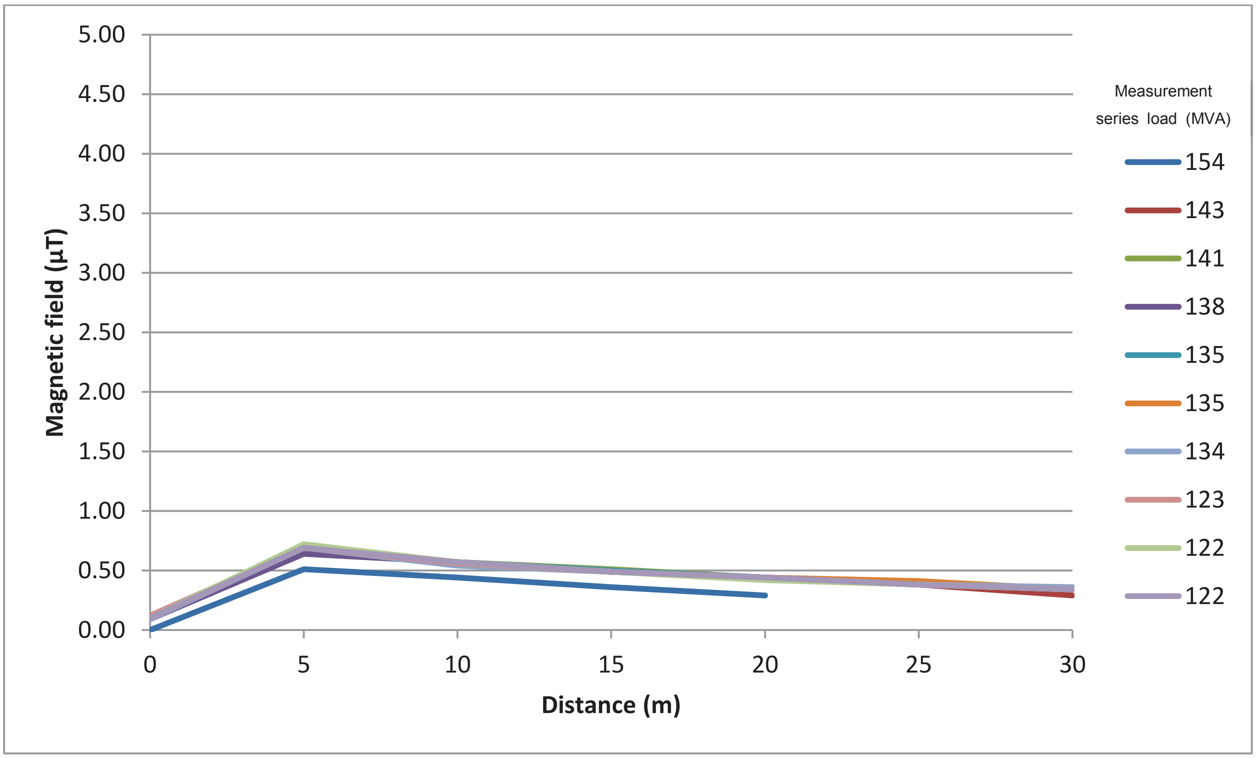
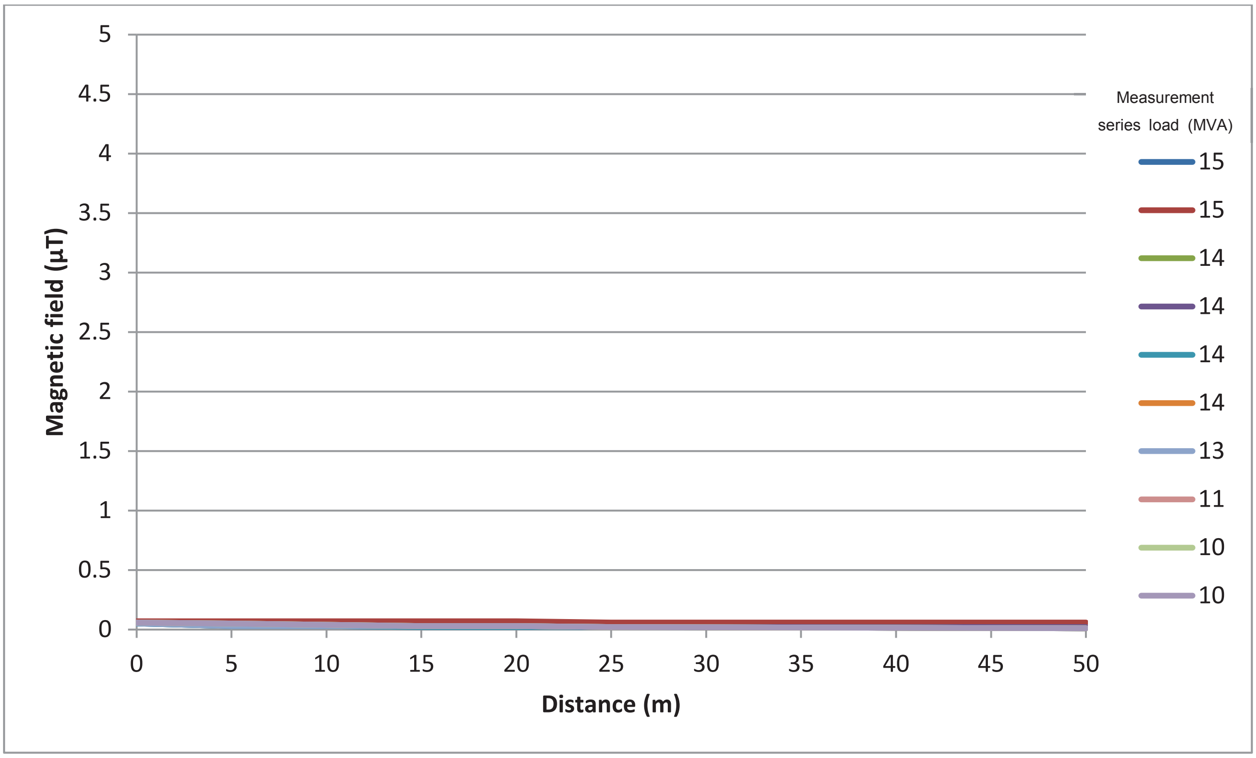


Figure 7.14: Measured magnetic field plotted against distance for 110 kV substation [see Table 7.15]



Discussion

7.4 The maximum magnetic field strength recorded among the overhead power lines was 4.97 μT for the 220 kV double-circuit overhead line, with a maximum of 26.01 μT recorded for the 220 kV underground cable and 0.72 μT for the 220/110 kV substation. All measured results fall well below the 2010 ICNIRP guideline reference level for general public exposure of 200 μT. As expected, the magnetic field strength recorded for all types of overhead power lines and underground power cables under all load conditions falls rapidly with distance from their centrelines.

7.5 Magnetic field strengths measured directly under overhead lines vary across those surveyed, dependent on load, from 0.68 μT to the maximum of 4.97 μT noted. Although the peak magnetic field strength from the 220 kV underground cable is considerably greater than any overhead lines, it also decreases more rapidly with distance from the cable, reaching a similar level to overhead lines at 5 m – 10 m distance. Peak magnetic field strength from the underground cables is greater than overhead lines at similar load due to the smaller distance to the measurement point, as the burial depth of cables is less than the overhead clearance of overhead lines. However, the magnetic field strength decreases more rapidly with lateral distance from the underground cables than overhead lines for the same reason: a small change in distance laterally affects the straight-line distance from the underground cable proportionally more than the straight-line distance from the overhead line conductor, as the initial distance is smaller.

7.6 The magnetic field at the 400 kV and 110 kV substation perimeters is very weak (<0.2 μT) and has a limited trend for decrease with distance, suggesting a contribution to the measured field from overhead lines around the substations. The magnetic field measured at the 220/110 kV substation shows a peak of up to 0.72 μT consistently at the 5 m distance interval (suggesting influence from a nearby overhead line), decreasing with distance thereafter, although the field strength at the perimeter is around 0.1 μT, similar to the other substations.

7.7 As described in the approach/methodology section, the vector nature of EMF and the rapid decrease in field strength with distance means that in general, magnetic field exposure at a given point is likely to be dominated by a single proximate source. Non-standard conditions, i.e. where several powerlines or other items of high-voltage transmission infrastructure are in close proximity, are therefore considered unlikely to lead to significantly different cumulative effects to the measurements of individual items. Nevertheless, the possibility of greater field strength was investigated with a series of transects under overhead lines that are in close proximity (<100m), and a further measurement was taken where the downleads (conductors from the final transmission tower into the substation) of the Moneypoint-Dunstown 400 kV line cross the closest publically-accessible point at the Dunstown substation into the substation busbar. Transects were conducted in October 2011 using a Spectran NF-5035 meter with display hold function, to capture the highest magnetic field strength recorded while traversing under and between the lines.

7.8 The maximum magnetic field strength recorded where three 220 kV overhead lines stand in close proximity exiting the Dunstown substation was 2.47 µT, directly under the outer phase of one line, with lower readings recorded between them. A transect under two 220 kV overhead lines exiting the Maynooth substation similarly recorded maximum magnetic field strengths of 1.60 µT and 3.18 µT directly under each line, with lower magnetic field strengths throughout the zone of overlapping influence between them. Finally, the maximum magnetic field strength recorded where the 400 kV overhead line downleads cross into the substation was 1.91 µT, comparable to the reading under other parts of the line.

7.9 These results indicate that, as anticipated, the greatest magnetic field strength experienced at ground level would be from the proximate overhead line. Greater cumulative field strengths in between lines in close proximity was not found.

Annual load scaling

7.10 The series of measurements at different loads for each infrastructure item allows a mean magnetic field strength per MVA (unit load) to be calculated for each distance interval. Combined with hourly records of load for each infrastructure item from one year encompassing the survey periods (April 2012 – March 2013 inclusive), this allows the typical magnetic field (based on mean or median load) and magnetic field at high load (top 95th percentile) to be calculated.

7.11 The term '95th percentile' means that of all of the loads recorded (at hourly or 15 minute intervals) during the one year period for a particular overhead line or underground cable, 95% were lower than or equal to the 95th percentile load value, and 5% were greater than it. It has been calculated by first sorting the loads into rank order, and determining the rank of the 95th percentile using *rank = 0.95 x the number of load records* and then applying linear interpolation to determine the exact load where the rank is not an integer.

7.12 The results are presented for several distance intervals in Table 7.16 to Table 7.22. Variation around the mean magnetic field per MVA is indicated with the calculated standard deviation, discussed further in the following section.

Table 7.16: Annual load-scaled magnetic field for 400 kV single circuit overhead line (double circuit tower)

Name	Moneypoint -> Dunstown			
Location	Dunstown			
Type	400 kV single circuit			
Design	Double circuit tower			
Distance (m)	**0**	**25**	**50**	**100**
Magnetic field strength per MVA (µT)	0.0128	0.0048	0.0020	0.0006
Standard deviation +/-	0.0007	0.0003	0.0005	0.0001
Median annual load (MVA)	178.29	178.29	178.29	178.29
Magnetic field strength (µT)	2.283	0.860	0.360	0.107
Standard deviation +/-	0.124	0.058	0.095	0.011
Mean annual load (MVA)	164.69	164.69	164.69	164.69
Magnetic field strength (µT)	2.109	0.794	0.333	0.099
Standard deviation +/-	0.115	0.054	0.088	0.010
95^{th} percentile annual load (MVA)	281.71	281.71	281.71	281.71
Magnetic field strength (µT)	3.607	1.359	0.570	0.169
Standard deviation +/-	0.196	0.092	0.150	0.018

Table 7.17: Annual load-scaled magnetic field for 400 kV single circuit overhead line (single circuit tower)

Name	Moneypoint -> Dunstown			
Location	Dunstown			
Type	400 kV single circuit			
Design	Single circuit tower			
Distance (m)	**0**	**25**	**50**	**100**
Magnetic field strength per MVA (µT)	0.0161	0.0068	0.0021	0.0004
Standard deviation +/-	0.0008	0.0012	0.0003	0.0002
Median annual load (MVA)	178.29	178.29	178.29	178.29
Magnetic field strength (µT)	2.865	1.209	0.375	0.073
Standard deviation +/-	0.147	0.205	0.058	0.034
Mean annual load (MVA)	164.69	164.69	164.69	164.69
Magnetic field strength (µT)	2.646	1.117	0.347	0.067
Standard deviation +/-	0.136	0.189	0.053	0.031
95^{th} percentile annual load (MVA)	281.71	281.71	281.71	281.71
Magnetic field strength (µT)	4.051	1.292	0.451	0.141
Standard deviation +/-	1.047	0.373	0.126	0.038

Table 7.18: Annual load-scaled magnetic field for 220 kV single circuit overhead line 1

Name	Dunstown -> Turlough Hill			
Location	Dunstown			
Type	220 kV single circuit			
Design	Horizontal tower			
Distance (m)	**0**	**25**	**50**	**100**
Magnetic field strength per MVA (μT)	0.0424	0.0102	0.0032	0.0004
Standard deviation +/-	0.0030	0.0037	0.0017	0.0002
Median annual load (MVA)	33.54	33.54	33.54	33.54
Magnetic field strength (μT)	1.421	0.343	0.108	0.013
Standard deviation +/-	0.100	0.125	0.058	0.005
Mean annual load (MVA)	52.54	52.54	52.54	52.54
Magnetic field strength (μT)	2.225	0.538	0.170	0.021
Standard deviation +/-	0.157	0.196	0.091	0.008
95^{th} percentile annual load (MVA)	166.22	166.22	166.22	166.22
Magnetic field strength (μT)	7.041	1.702	0.537	0.066
Standard deviation +/-	0.498	0.621	0.289	0.027

Table 7.19: Annual load-scaled magnetic field for 220 kV single circuit overhead line 2

Name	Dunstown -> Maynooth			
Location	Dunstown			
Type	220 kV single circuit			
Design	Horizontal tower			
Distance (m)	**0**	**25**	**50**	**75**
Magnetic field strength per MVA (μT)	0.0354	0.0106	0.0028	0.0014
Standard deviation +/-	0.0063	0.0044	0.0015	0.0006
Median annual load (MVA)	36.75	36.75	36.75	36.75
Magnetic field strength (μT)	1.300	0.391	0.102	0.050
Standard deviation +/-	0.231	0.161	0.055	0.022
Mean annual load (MVA)	42.95	42.95	42.95	42.95
Magnetic field strength (μT)	1.519	0.456	0.120	0.058
Standard deviation +/-	0.270	0.189	0.065	0.025
95^{th} percentile annual load (MVA)	99.02	99.02	99.02	99.02
Magnetic field strength (μT)	3.502	1.052	0.276	0.135
Standard deviation +/-	0.623	0.435	0.149	0.059

Table 7.20: Annual load-scaled magnetic field for 110 kV single circuit overhead line

Name	Kilteel -> Maynooth			
Location	Kilteel			
Type	110 kV single circuit			
Design	Horizontal wooden pole			
Distance (m)	**0**	**25**	**50**	**100**
Magnetic field strength per MVA (µT)	0.0754	0.0110	0.0035	0.0001
Standard deviation +/-	0.0048	0.0022	0.0014	0.0000
Median annual load (MVA)	14.09	14.09	14.09	14.09
Magnetic field strength (µT)	1.063	0.155	0.050	0.001
Standard deviation +/-	0.068	0.031	0.020	0.000
Mean annual load (MVA)	15.89	15.89	15.89	15.89
Magnetic field strength (µT)	1.198	0.175	0.056	0.001
Standard deviation +/-	0.077	0.035	0.022	0.000
95th percentile annual load (MVA)	33.30	33.30	33.30	33.30
Magnetic field strength (µT)	2.512	0.367	0.118	0.002
Standard deviation +/-	0.161	0.074	0.047	0.001

Table 7.21: Annual load-scaled magnetic field for 220 kV underground cable

Name	Corduff -> Huntstown			
Location	Rosemount Business Park			
Type	220 kV single circuit			
Design	Underground cable			
Distance (m)	**0**	**10**	**20**	**30**
Magnetic field strength per MVA (µT)	0.0651	0.0041	0.0009	0.0006
Standard deviation +/-	0.0044	0.0017	0.0005	0.0005
Median annual load (MVA)	227.18	227.18	227.18	227.18
Magnetic field strength (µT)	14.783	0.930	0.205	0.137
Standard deviation +/-	1.006	0.377	0.121	0.118
Mean annual load (MVA)	240.49	240.49	240.49	240.49
Magnetic field strength (µT)	15.649	0.985	0.217	0.145
Standard deviation +/-	1.065	0.399	0.128	0.125
95th percentile annual load (MVA)	388.40	388.40	388.40	388.40
Magnetic field strength (µT)	25.274	1.591	0.351	0.234
Standard deviation +/-	1.720	0.644	0.207	0.201

Table 7.22: Annual load-scaled magnetic field for 110 kV underground cable

Name	Finglas -> Dardistown			
Location	Finglas			
Type	110 kV single circuit			
Design	Underground cable			
Distance (m)	**0**	**4**	**8**	**12**
Magnetic field strength per MVA (μT)	0.0995	0.0264	0.0091	0.0044
Standard deviation +/-	0.0045	0.0023	0.0013	0.0004
Median annual load (MVA)	20.42	20.42	20.42	20.42
Magnetic field strength (μT)	2.032	0.539	0.186	0.089
Standard deviation +/-	0.092	0.047	0.026	0.009
Mean annual load (MVA)	19.65	19.65	19.65	19.65
Magnetic field strength (μT)	1.955	0.519	0.179	0.086
Standard deviation +/-	0.088	0.045	0.025	0.009
95th percentile annual load (MVA)	25.76	25.76	25.76	25.76
Magnetic field strength (μT)	2.563	0.680	0.234	0.112
Standard deviation +/-	0.115	0.059	0.032	0.011

Results consistency

7.13 Standardising the magnetic field measurements against load, as in the above tables, also allows the level of consistency in the measurement results to be investigated. Magnetic field strength is directly dependent upon current and should therefore vary linearly at a given distance with changes in power load (as the voltage on each infrastructure item is approximately fixed).

7.14 The standard deviation in the results is typically <20% for measurements closer to the centrelines, but up to around 40-50% for the measurements at the greatest distances. However, it is small (1×10^{-5} to 9×10^{-3} μT) in absolute terms per MVA at these distances.

7.15 This indicates good consistency for many measurement results recorded at the higher loads, close to the line/cable, but less so where the magnetic field was weaker at greater distances. However, the variation in measurements of the weaker fields at the greatest distances (where the standard deviation in percentage terms is typically greatest) would translate into absolute apparent errors in magnetic field strength of one standard deviation under typical loads in the order of <0.04 μT for overhead lines and <0.2 μT for underground cables.

7.16 The magnetic field measured on each side of the 220 kV and 110 kV double circuit overhead lines is influenced by the load on both the circuits (both sides of the line). Standardising measurements per-MVA and scaling on that basis would not account for the relative influence of the load on each individual circuit (with the load on the circuit on the same side as the measurements having a greater influence, particularly at closer distances) or for potential field cancellation between the circuits (e.g. due to transposed phasing). Results scaling to annual loads has therefore not been undertaken for the double circuit overhead lines.

7.17 In general it should be noted that the use of variation on a per-MVA basis as a measure of possible non-systematic error in the results depends upon the load data being accurate for the exact time the measurements were taken. In reality, load data given in real time were recorded at the start of the measurement series (potentially varying while it was undertaken) and were rounded to 1 MVA. Load data from annual records were available mainly at hourly intervals. Unrecorded variance in actual load may be a cause of some apparent inconsistency in the data when standardised against load, which does not reflect genuine error in the measurements at a particular time.

8 Electric field results

8.1 Table 8.1 to Table 8.13 show the electric field strength measured for each of the high-voltage transmission infrastructure items surveyed, with the power load at the time of each measurement. Variation in the results measured at similar loads is due to factors outlined in the measurement variation discussion in Section 6.

Results tables

Table 8.1: Measured electric field for 400 kV single circuit overhead line (double circuit tower) [see Figure 8.1]

Name	Moneypoint → Dunstown									
Location	Dunstown									
Type	400 kV single circuit									
Design	Double circuit tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	10:35	14:02	16:41	09:30	12:13	15:18	10:30	12:47	16:02	14:40
Load (MVA)	181	201	256	199	238	247	223	152	121	286
Dist. (m)	**Electric field (kV m^{-1})**									
0	3.90	3.60	3.42	3.48	3.15	3.74	4.08	3.96	3.10	4.72
5	3.12	3.43	2.99	2.74	2.96	3.00	3.55	3.43	2.86	4.44
10	1.93	1.51	1.81	1.73	1.78	1.78	2.20	2.16	2.02	3.84
15	1.10	0.82	0.92	0.95	1.00	0.96	1.21	1.12	0.99	1.83
20	0.51	0.70	0.58	0.68	0.48	0.47	0.91	0.77	0.53	0.98
25	0.31	0.40	0.32	0.42	0.28	0.30	0.65	0.49	0.33	0.71
50	0.21	0.22	0.16	0.22	0.16	0.15	0.28	0.20	0.15	0.29
75	0.11	0.11	0.11	0.14	0.09	0.11	0.15	0.10	0.09	0.16
100	0.07	0.07	0.07	0.10	0.06	0.07	0.15	0.06	0.06	0.15

Table 8.2: Measured electric field for 400 kV single circuit overhead line (horizontal tower configuration) [see Figure 8.2]

Name	Moneypoint → Dunstown									
Location	The Curragh									
Type	400 kV single circuit									
Design	Single circuit tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	12:58	15:31	18:20	11:23	14:30	16:44	09:30	12:01	15:16	13:30
Load (MVA)	196	255	236	212	243	237	166	177	221	280
Dist. (m)	**Electric field (kV m^{-1})**									
0	1.43	1.46	2.16	1.25	1.26	1.32	2.76	2.51	1.32	2.85
5	1.91	1.77	2.45	1.57	1.62	1.74	3.20	2.93	1.60	3.18
10	2.89	2.74	3.59	2.51	2.53	2.72	4.15	3.89	2.42	3.6
15	2.92	2.95	3.81	2.76	2.76	2.70	4.31	4.19	2.74	3.74
20	2.29	2.29	2.92	2.28	2.23	2.15	3.40	3.20	2.24	3.63
25	1.56	1.62	2.11	1.58	1.53	1.54	2.63	2.40	1.54	3.63
50	0.28	0.30	0.43	0.30	0.29	0.28	0.98	0.84	0.28	0.73
75	0.10	0.10	0.13	0.12	0.13	0.13	0.61	0.44	0.10	0.43
100	0.01	0.04	0.05	0.04	0.04	0.04	0.24	0.16	0.06	0.15

Table 8.3: Measured electric field for 220 kV single circuit overhead line 1 [see Figure 8.3]

Name	Dunstown → Turlough Hill									
Location	Dunstown									
Type	220 kV single circuit									
Design	Horizontal tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	11:10	14:30	17:10	10:23	12:50	15:58	11:00	13:10	16:25	15:00
Load (MVA)	35	49	20	42	81	73	55	59	18	42
Dist. (m)	**Electric field (kV m^{-1})**									
0	1.19	1.11	1.14	0.87	0.93	1.02	1.09	0.74	0.69	2.85
5	1.75	1.49	1.83	1.38	1.36	1.52	1.96	1.84	1.59	2.67
10	2.14	1.88	2.04	1.64	1.64	1.65	2.22	2.01	1.47	2.49
15	1.73	1.73	1.32	1.35	1.35	1.15	1.80	1.29	0.98	2.20
20	1.14	1.09	0.84	0.68	0.67	0.72	1.23	0.75	0.60	1.67
25	0.60	0.56	0.53	0.46	0.83	0.41	0.79	0.52	0.36	1.12
50	0.11	0.37	0.09	0.09	0.09	0.08	0.16	0.10	0.06	0.34
75	0.04	0.11	0.03	0.03	0.03	0.03	0.05	0.04	0.03	0.09
100	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	n/a

Table 8.4: Measured electric field for 220 kV single circuit overhead line 2 [see Figure 8.4]

Name	Dunstown → Maynooth									
Location	Dunstown									
Type	220 kV single circuit									
Design	Horizontal tower									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	12:00	15:00	17:30	10:45	13:12	16:08	11:15	13:30	16:43	15:15
Load (MVA)	82	38	58	93	72	67	60	74	26	20
Dist. (m)*	Electric field (kV m^{-1})									
0	0.76	0.71	0.72	0.65	0.70	0.72	1.11	1.09	1.06	1.37
5	1.25	1.16	1.23	1.14	1.08	1.11	1.26	1.18	1.40	1.89
10	1.58	1.64	1.80	1.42	1.35	1.44	1.75	1.67	1.54	2.30
15	1.55	1.39	1.64	1.35	1.29	1.22	1.44	1.73	1.34	2.46
20	0.87	0.94	1.02	0.80	0.82	0.78	0.93	1.17	0.86	2.30
25	0.53	0.58	0.59	0.41	0.43	0.42	0.54	0.58	0.51	1.80
50	0.09	0.11	0.14	0.09	0.11	0.09	0.12	0.14	0.17	0.28
75	0.02	0.03	0.03	0.02	0.03	0.02	0.03	0.02	0.05	0.07

* Space constraints permitted measurement only to 75 m

Table 8.5: Measured electric field for 110 kV single circuit overhead line [see Figure 8.5]

Name	Kilteel → Maynooth									
Location	Kilteel									
Type	110 kV single circuit									
Design	Horizontal wooden pole									
Date	04/09/12	04/09/12	04/09/12	06/09/12	06/09/12	06/09/12	08/09/12	08/09/12	08/09/12	21/01/13
Time	09:36	12:36	15:15	10:00	12:20	16:47	11:00	13:35	16:47	13:00
Load (MVA)	13	14	14	13	14	12	14	14	12	14
Dist. (m)	Electric field (kV m^{-1})									
0	0.32	0.20	0.22	0.30	0.20	0.20	0.57	0.20	0.20	0.51
5	0.91	0.76	0.78	0.97	0.78	0.83	1.09	0.75	0.83	1.51
10	0.90	0.77	0.68	0.80	0.70	0.75	0.93	0.52	0.75	2.39
15	0.62	0.45	0.38	0.52	0.40	0.42	0.78	0.30	0.42	1.55
20	0.32	0.25	0.21	0.25	0.23	0.23	0.41	0.14	0.23	0.87
25	0.21	0.15	0.03	0.16	0.13	0.13	0.26	0.02	0.13	0.48
50	0.06	0.03	0.02	0.03	0.02	0.06	0.06	0.01	0.02	0.09
75	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.03
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	n/a

Table 8.6: Measured electric field for 220 kV double circuit overhead line circuit 1 [see Figure 8.6]

Name	Maynooth → Woodlands									
Location	Maynooth									
Type	220 kV double circuit									
Design	Vertical tower									
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13	21/01/13
Time	11:17	14:01	15:00	11:00	12:58	13:46	10:23	11:16	12:06	10:40
Load (MVA)	237	206	204	173	171	168	77	64	66	148
Dist. (m)	**Electric field (kV m^{-1})**									
0	4.17	3.89	3.69	3.62	3.41	3.69	4.55	4.37	4.11	3.49
5	3.22	2.98	2.94	3.11	3.04	2.89	3.57	3.40	3.21	2.82
10	1.81	1.76	1.66	1.68	1.64	1.66	2.22	2.00	1.98	2.00
15	1.04	0.96	0.91	0.94	0.93	1.01	1.76	1.49	1.42	1.19
20	0.58	0.56	0.51	0.52	0.48	0.49	1.01	0.75	0.54	0.67
25	0.38	0.34	0.30	0.32	0.24	0.35	0.56	0.46	0.46	0.41
50	0.07	0.07	0.07	0.08	0.08	0.08	0.16	0.12	0.10	0.09
75	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.09	0.06	0.06
100	0.03	0.03	0.03	0.03	0.03	0.03	0.06	0.05	0.04	0.03

Table 8.7: Measured electric field for 220 kV double circuit overhead line circuit 2 [see Figure 8.7]

Name	Maynooth → Shannonbridge									
Location	Maynooth									
Type	220 kV double circuit									
Design	Vertical tower									
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13	21/03/13
Time	11:34	14:13	15:07	11:13	13:06	13:52	10:31	11:24	12:25	10:50
Load (MVA)	10	17	16	40	39	47	108	109	108	32
Dist. (m)	**Electric field (kV m^{-1})**									
0	3.38	3.06	2.89	3.13	2.95	2.79	3.74	3.66	3.22	3.58
5	2.15	2.67	2.02	2.29	1.62	2.17	2.92	2.80	2.31	2.92
10	1.33	1.30	1.01	1.22	1.09	1.17	1.55	1.49	1.25	1.29
15	0.77	0.78	0.66	0.65	0.52	0.67	1.01	0.96	0.66	0.96
20	0.59	0.56	0.49	0.58	0.54	0.51	0.90	0.86	0.59	0.80
25	0.46	0.43	0.37	0.45	0.44	0.25	0.75	0.67	0.42	0.64
50	0.21	0.19	0.17	0.19	0.20	0.20	0.41	0.28	0.20	0.28
75	0.15	0.13	0.13	0.14	0.13	0.13	0.20	0.15	0.13	0.15
100	0.06	0.06	0.06	0.06	0.07	0.06	0.12	0.07	0.06	0.08

Table 8.8: Measured electric field for 110 kV double circuit overhead line circuit 1 [see Figure 8.8]

Name	Maynooth → Rinawade							
Location	Maynooth								
Type	110 kV double circuit								
Design	Vertical tower								
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13
Time	12:27	14:42	15:51	11:41	13:33	14:13	10:58	11:46	12:52
Load (MVA)	32	30	30	33	31	32	25	27	30
Dist. (m)*	**Electric field (kV m^{-1})**								
0	2.28	2.41	2.20	2.31	1.94	2.21	3.16	3.03	2.86
5	1.19	1.37	1.32	1.34	1.06	1.24	2.24	1.98	1.67
10	0.53	0.48	0.36	0.45	0.52	0.45	0.84	0.66	0.59
15	0.24	0.22	0.24	0.24	0.23	0.24	0.45	0.35	0.26
20	0.23	0.24	0.24	0.22	0.21	0.22	0.37	0.36	0.25
25	0.22	0.21	0.22	0.20	0.19	0.18	0.34	0.34	0.23
50	0.12	0.10	0.08	0.11	0.10	0.09	0.19	0.16	0.11
75	0.06	0.06	0.06	0.05	0.05	0.05	0.09	0.08	0.06

* Space constraints permitted measurement only to 75 m

Table 8.9: Measured electric field for 110 kV double circuit overhead line circuit 2 [see Figure 8.9]

Name	Maynooth → Ryebrook								
Location	Maynooth								
Type	110 kV double circuit								
Design	Vertical tower								
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13
Time	12:18	14:30	15:22	11:32	13:23	14:06	10:49	11:40	14:50
Load (MVA)	10	17	18	17	19	19	35	29	21
Dist. (m)	**Electric field (kV m^{-1})**								
0	2.33	2.18	2.24	2.14	2.25	2.01	3.13	2.95	2.52
5	1.32	1.19	1.31	1.35	1.31	1.13	2.07	1.85	1.52
10	0.48	0.39	0.38	0.46	0.46	0.35	0.77	0.63	0.58
15	0.23	0.21	0.22	0.19	0.23	0.18	0.39	0.34	0.29
20	0.22	0.20	0.23	0.18	0.21	0.17	0.41	0.32	0.26
25	0.19	0.19	0.19	0.16	0.19	0.16	0.35	0.28	0.21
50	0.11	0.10	0.10	0.10	0.08	0.07	0.18	0.15	0.11
75	0.07	0.06	0.06	0.06	0.07	0.06	0.09	0.06	0.06
100	0.04	0.03	0.04	0.03	0.04	0.03	0.06	0.05	0.04

Table 8.10: Measured electric field for 110 kV double circuit overhead line 3* [see Figure 8.9]

Name	Cookstown → Inchicore
Location	Firhouse
Type	110 kV double circuit
Design	Vertical tower
Date	25/01/13
Time	16:00
Load (MVA)	59
Dist. (m)	**Electric field (kV m^{-1})**
0	2.33
5	1.65
10	0.81
15	0.5
20	0.286
25	0.25
50	0.17
75	0.11
100	0.05

* This single set of measurements was taken targeting high load conditions due to access constraints at the Maynooth site

Table 8.11: Measured electric field for 400/220 kV substation [see Figure 8.10]

Name	Dunstown 400/220 kV substation									
Date	03/09/12	03/09/12	03/09/12	05/09/12	05/09/12	05/09/12	09/09/12	09/09/12	09/09/12	21/01/13
Time	10:45	14:17	16:52	09:42	12:27	15:26	10:45	13:01	16:17	11:00
Load (MVA)	176	197	248	181	234	235	233	162	115	281
Dist. (m)	**Electric field (kV m^{-1})**									
0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07
5	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.03	0.12
10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12

Table 8.12: Measured electric field for 220/110 kV substation [see Figure 8.11]

Name	Maynooth 220/110 kV substation									
Date	01/03/13	01/03/13	01/03/13	04/03/13	04/03/13	04/03/13	09/03/13	09/03/13	09/03/13	21/01/13
Time	11:45	14:25	15:21	11:21	13:16	14:02	10:44	11:38	12:32	11:00
Load (MVA)	135	135	134	141	143	138	122	123	122	154
Dist. (m)	Electric field (kV m^{-1})									
0	0.03	0.04	0.03	0.04	0.04	0.03	0.02	0.03	0.04	0.00
5	0.11	0.10	0.09	0.10	0.09	0.10	0.12	0.11	0.10	0.12
10	0.08	0.09	0.08	0.07	0.07	0.08	0.07	0.06	0.07	0.07
15	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.03	0.03	0.04
20	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
25	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	n/a
50	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	n/a

Table 8.13: Measured electric field for 110 kV substation [see Figure 8.12]

Name	Kilteel 110 kV substation									
Date	04/09/12	04/09/12	04/09/12	06/09/12	06/09/12	06/09/12	08/09/12	08/09/12	08/09/12	21/01/13
Time	09:00	12:26	16:41	10:20	12:40	17:10	11:15	13:50	17:25	13:10
Load (MVA)	13	14	14	15	14	14	11	10	10	15
Dist. (m)	Electric field (kV m^{-1})									
0	0.00	0.00	0.00	0.00	0.00	0.00	n/a	n/a	0.00	0.03
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04
10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
20	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
25	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01

Results graphs

8.2 Figure 8.1 to Figure 8.12 show the measured electric field strength plotted against distance for each of the high-voltage transmission infrastructure items surveyed. Variation in the results measured at similar loads is due to factors outlined in the measurement variation discussion in Section 6.

Figure 8.1: Measured electric field plotted against distance for 400 kV single circuit overhead line (double circuit tower) [see Table 8.1]

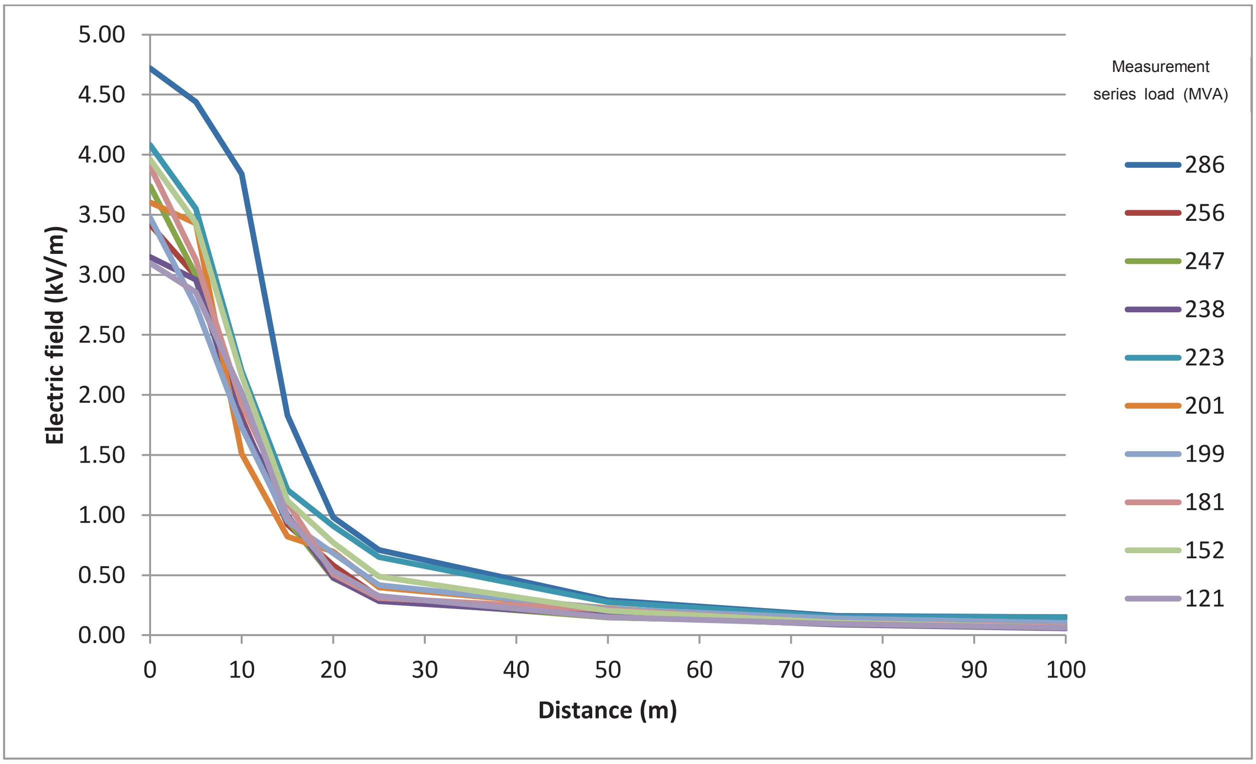


Figure 8.2: Measured electric field plotted against distance for 400 kV single circuit overhead line (horizontal tower configuration) [see Table 8.2]

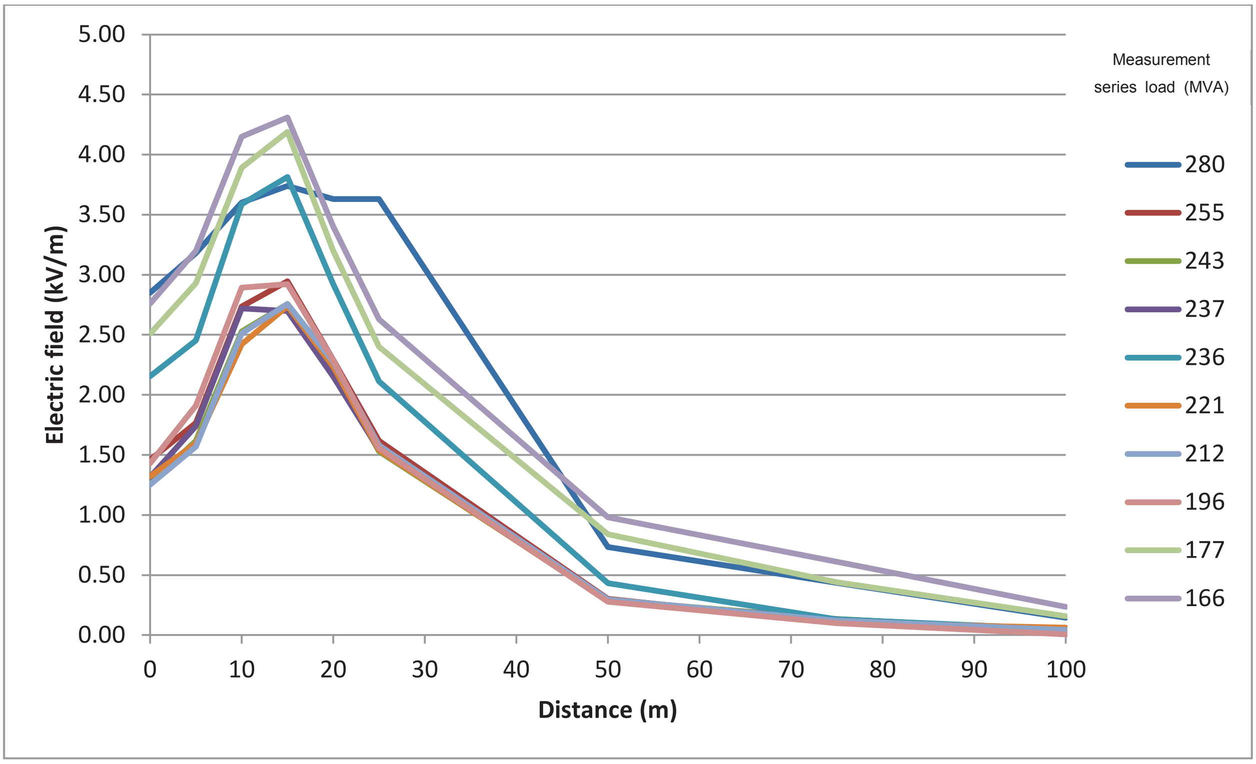


Figure 8.3: Measured electric field plotted against distance for 220 kV single circuit overhead line 1 [see Table 8.3]

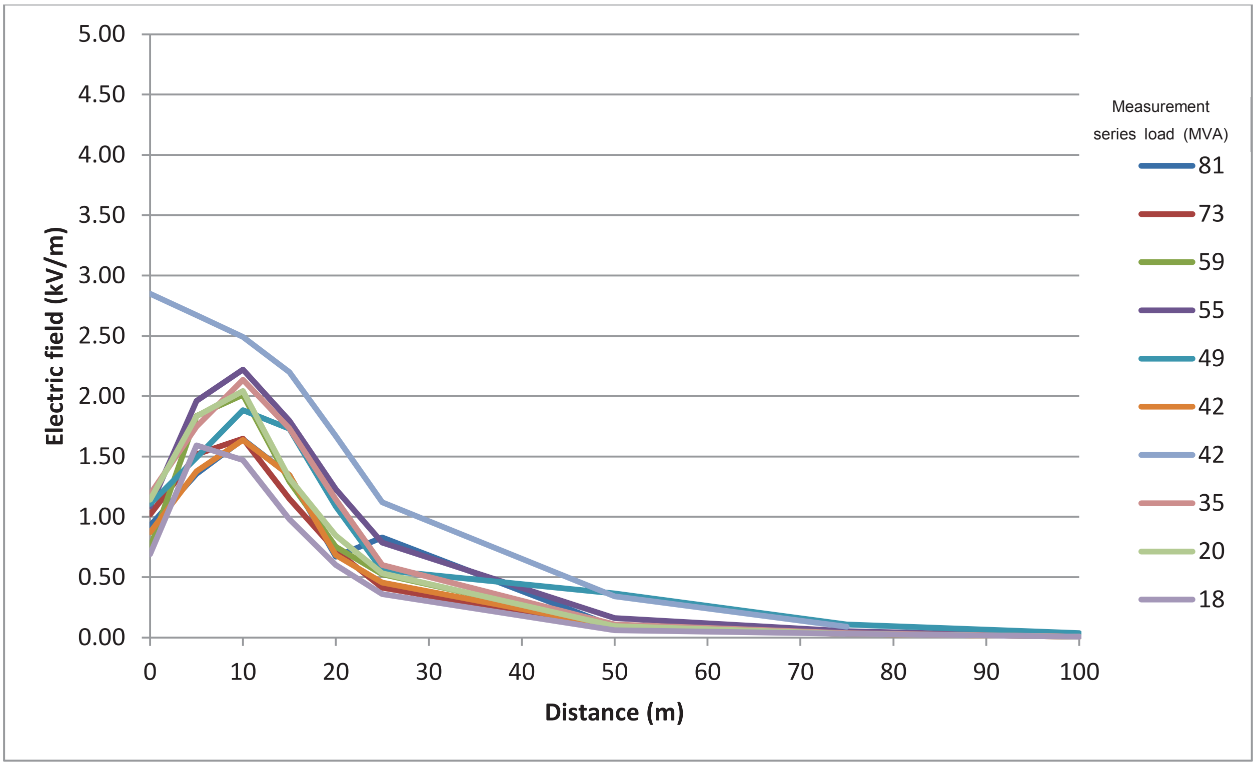


Figure 8.4: Measured electric field plotted against distance for 220 kV single circuit overhead line 2 [see Table 8.4]

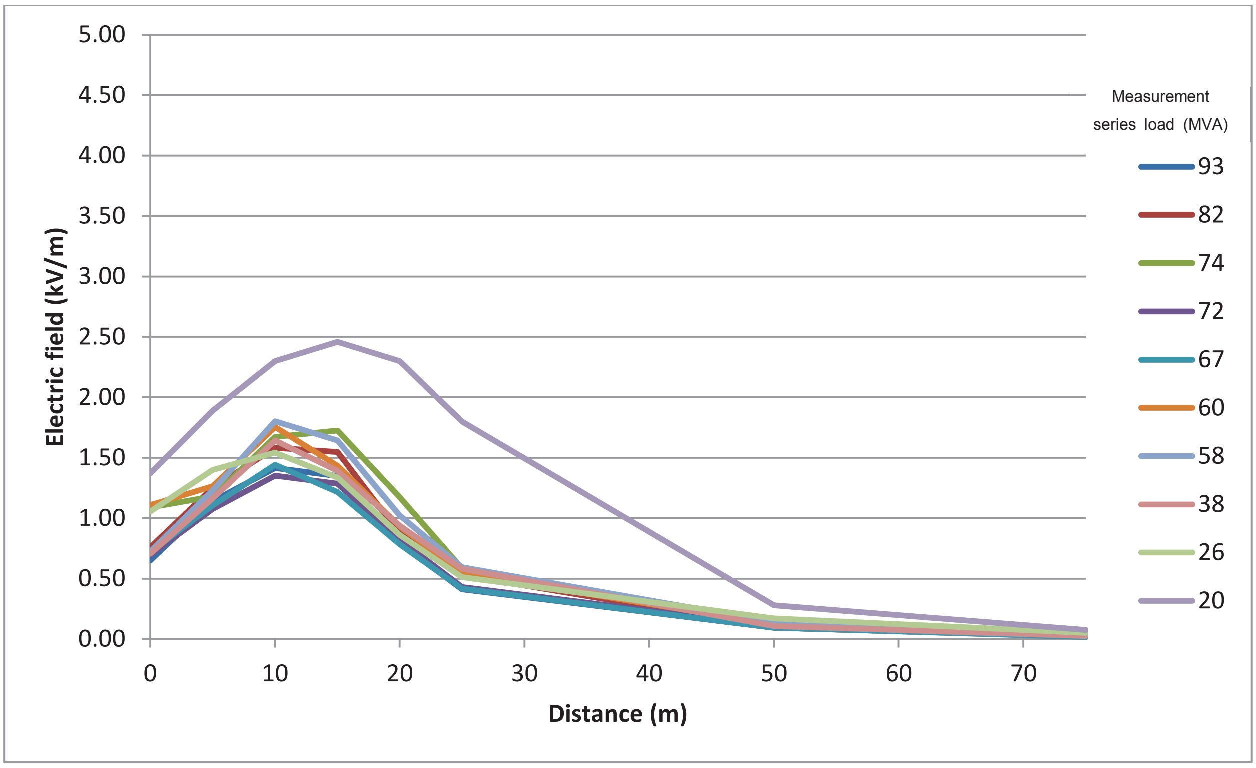


Figure 8.5: Measured electric field plotted against distance for 110 kV single circuit overhead line [see Table 8.5]

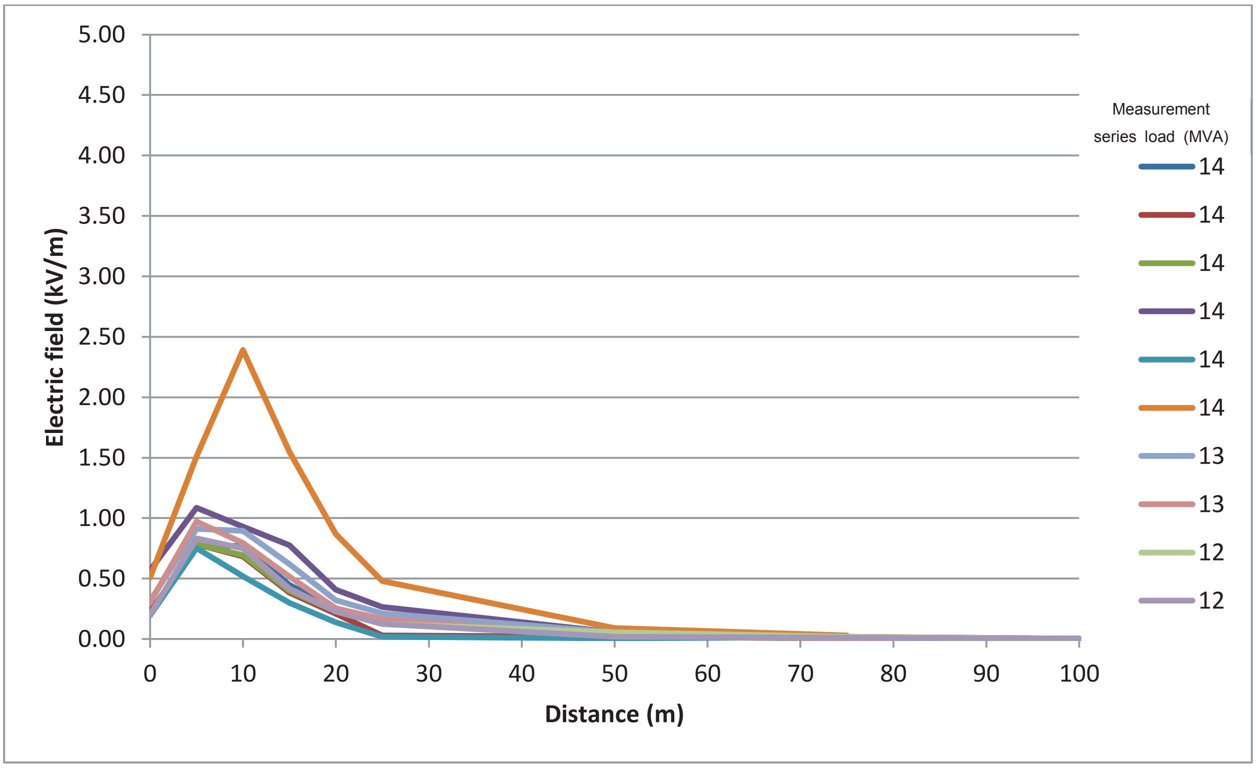


Figure 8.6: Measured electric field plotted against distance for 220 kV double circuit overhead line circuit 1 [see Table 8.6]

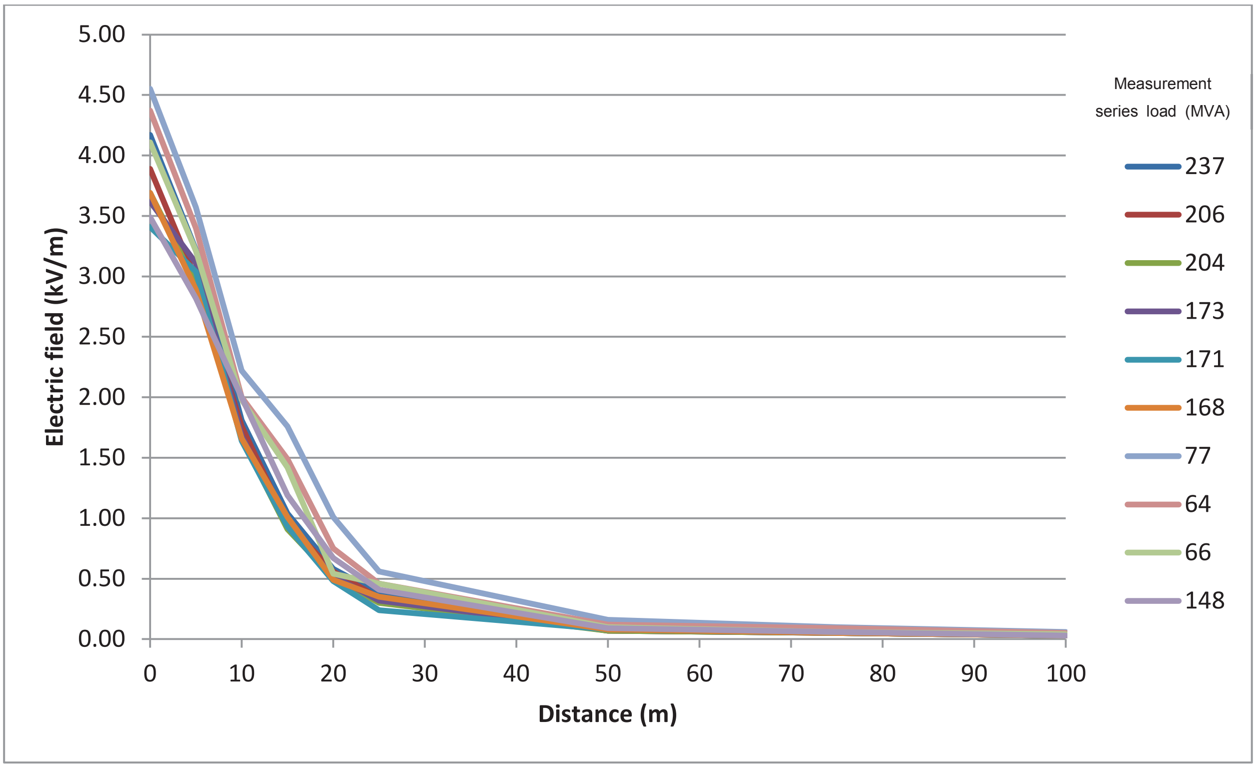


Figure 8.7: Measured electric field plotted against distance for 220 kV double circuit overhead line circuit 2 [see Table 8.7]

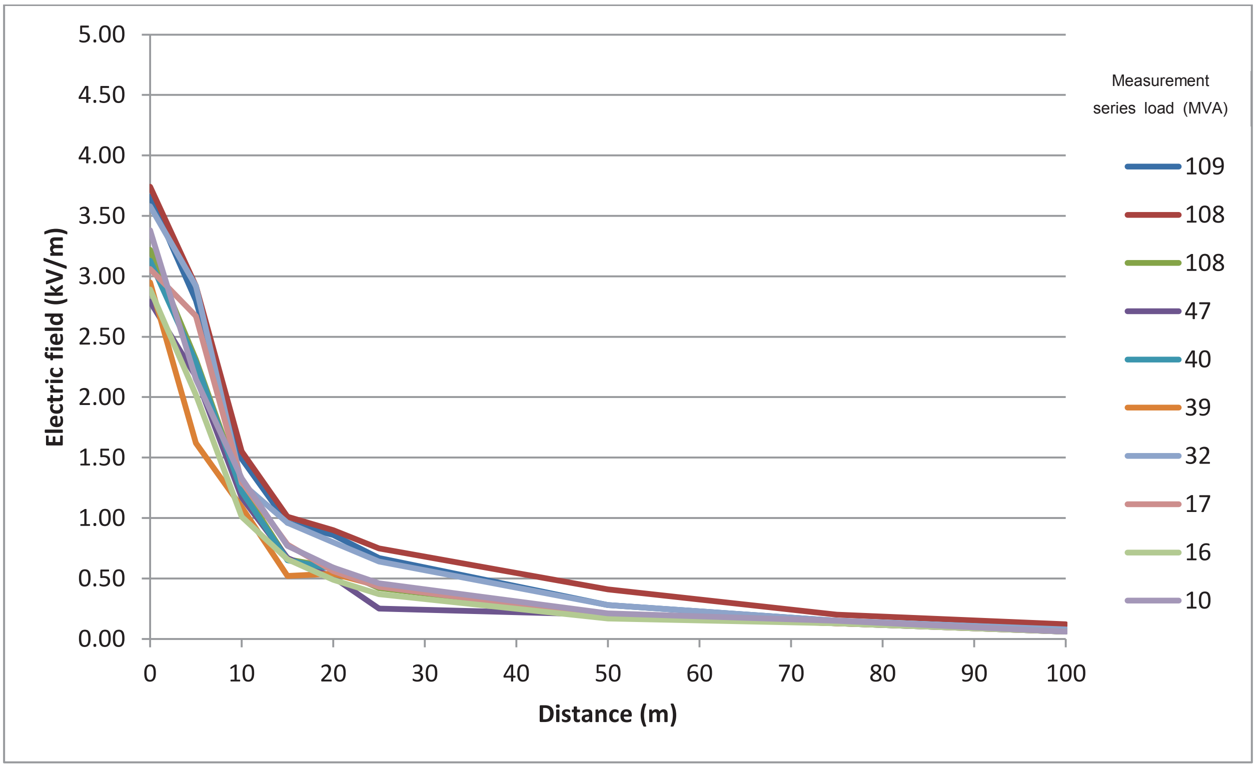


Figure 8.8: Measured electric field plotted against distance for 110 kV double circuit overhead line circuit 1 [see Table 8.8]

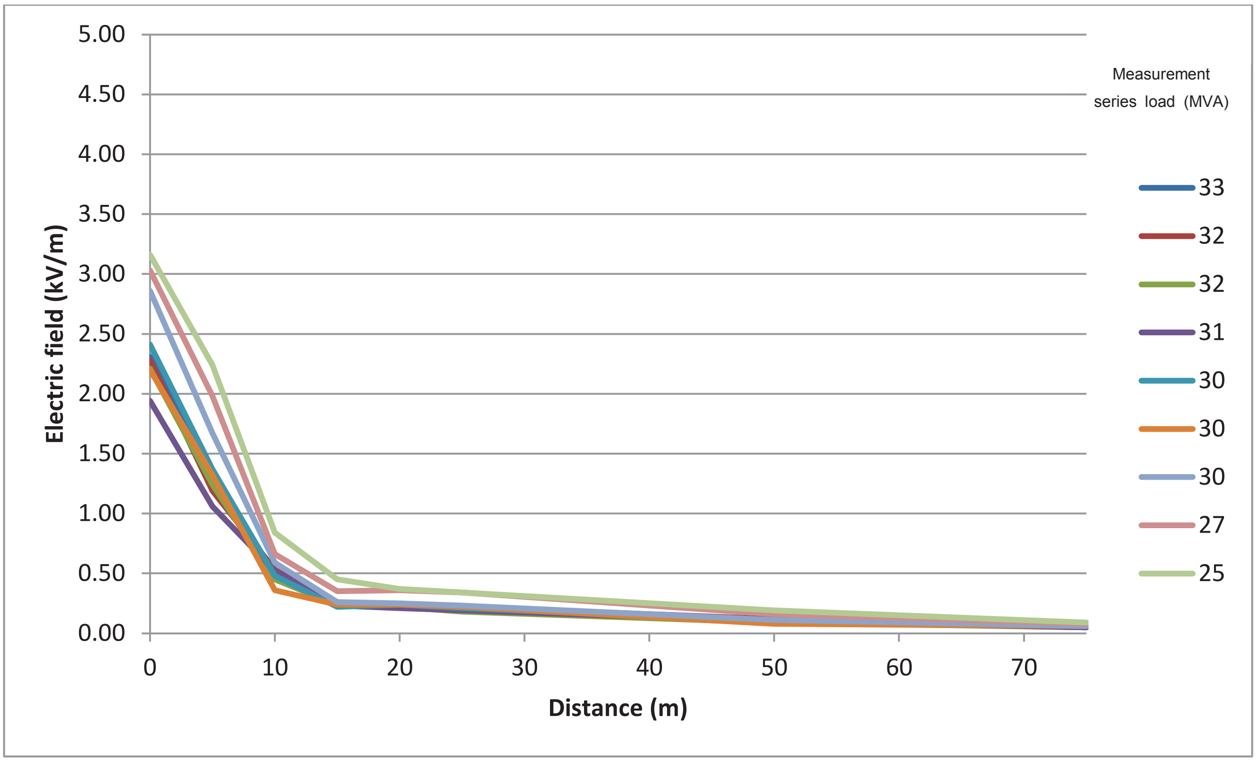
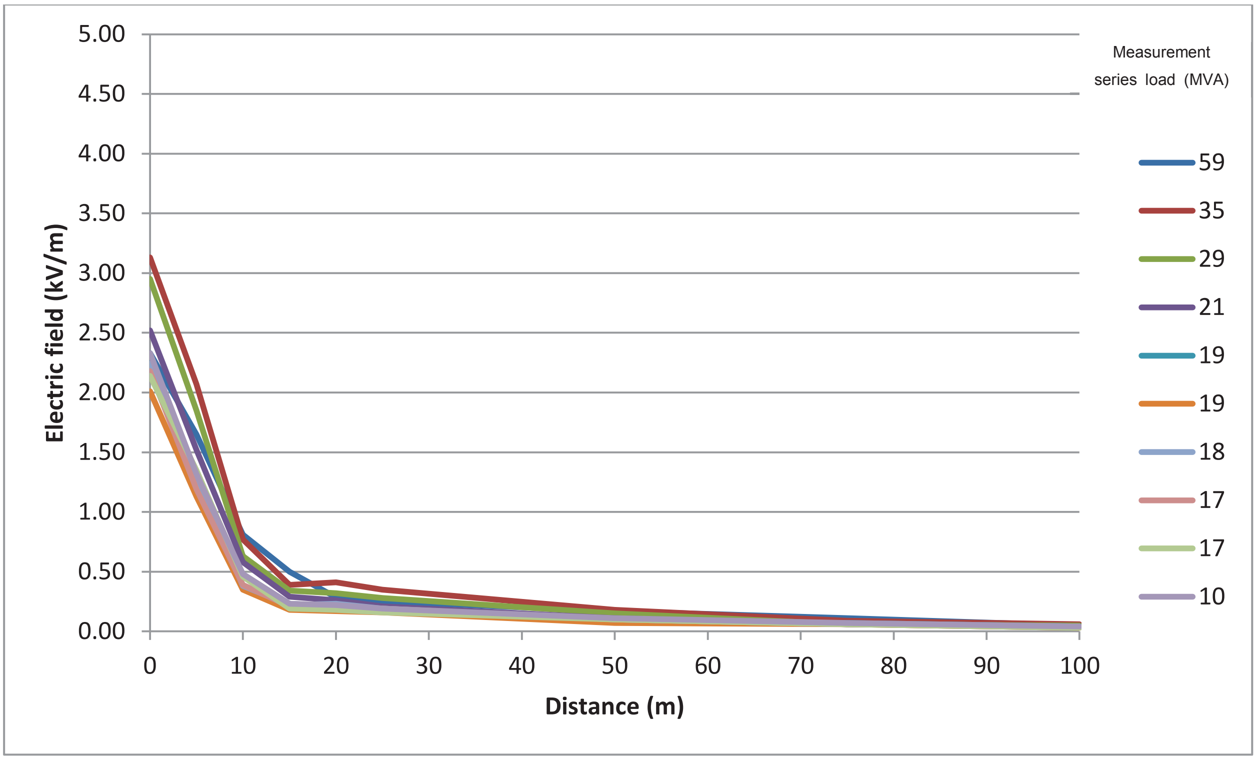


Figure 8.9: Measured electric field plotted against distance for 110 kV double circuit overhead line circuit 2 [see Table 8.9 and Table 8.10]



Measurements at 59 MVA load taken for Cookstown→Inchicore overhead line

Figure 8.10: Measured electric field plotted against distance for 400/220 kV substation [see Table 8.11]

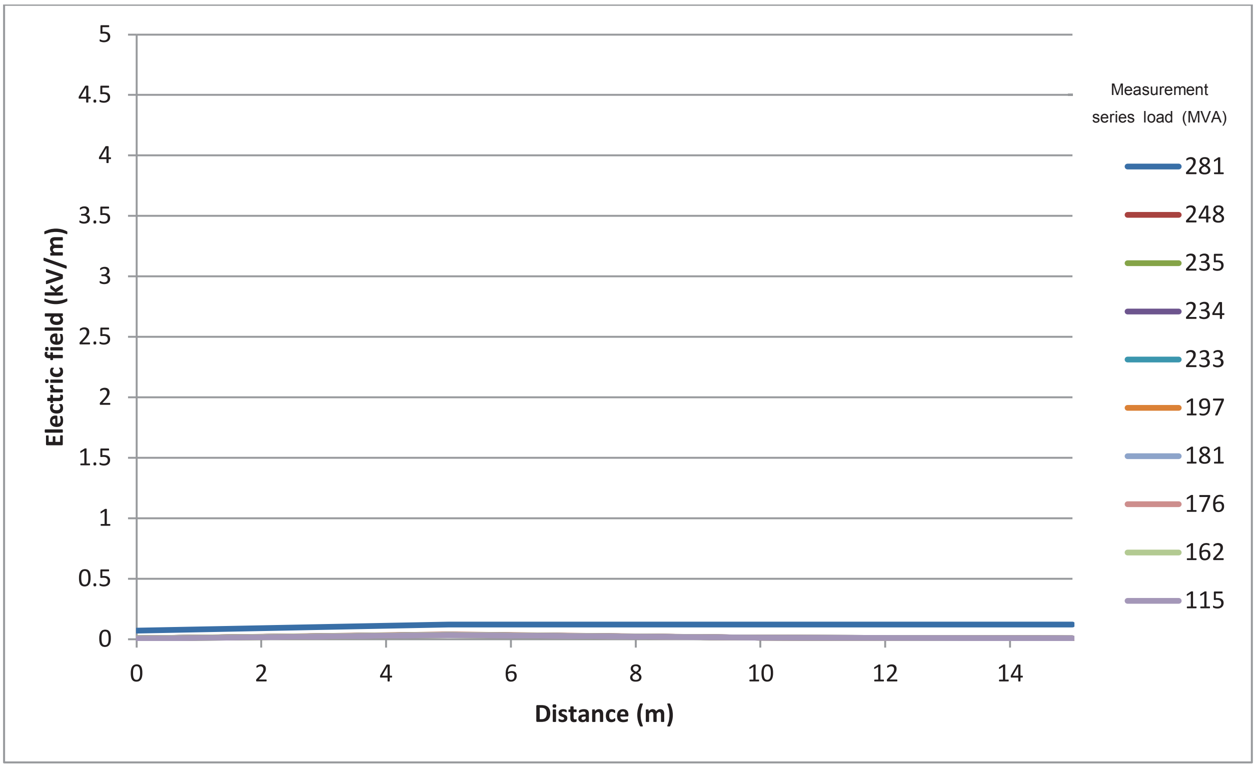


Figure 8.11: Measured electric field plotted against distance for 220/110 kV substation [see Table 8.12]

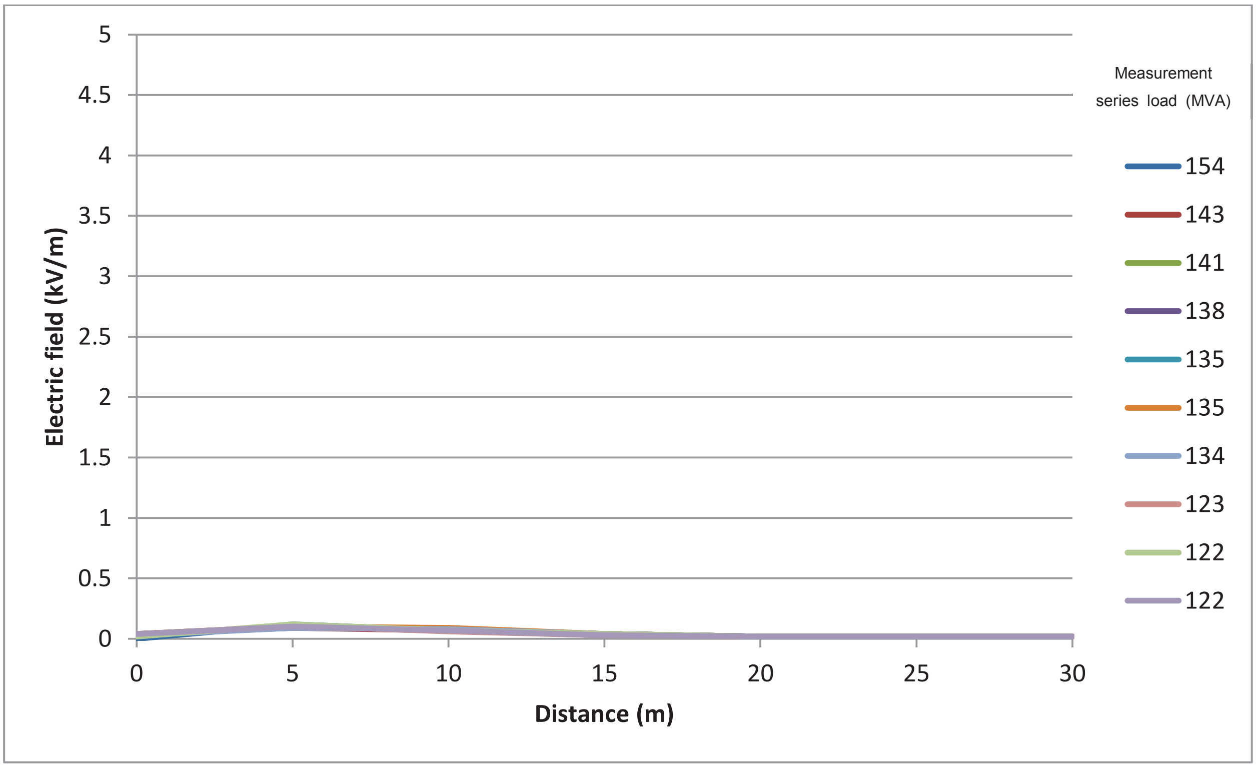
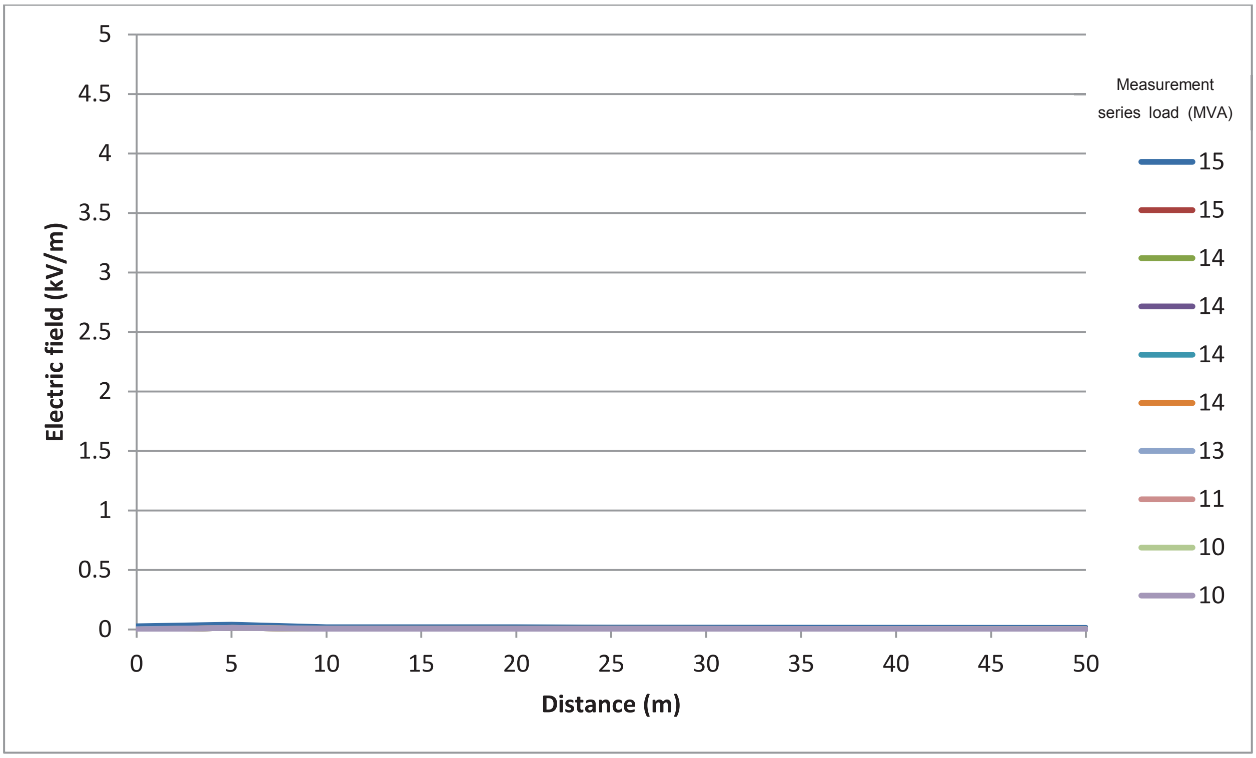


Figure 8.12: Measured electric field plotted against distance for 110 kV substation [see Table 8.13]



Discussion

8.3 The maximum electric field strength recorded among the overhead power lines was 4.72 kV m^{-1} for the 400 kV overhead line, and the maximum recorded among the substations was 0.12 kV m^{-1} for both the 400 kV and 220/110 kV substations. There is no electric field above ground level for underground cables, as the field is fully screened by the cable sheath. All measured results fall below the 2010 ICNIRP guideline reference level for general public exposure of 5 kV m^{-1}.

8.4 For single-circuit overhead lines, the peak electric field strength measured was at around 5 m – 15 m distance from the centreline; these towers carry the conductors spaced horizontally, and the peak field strength has been recorded under the outer conductor. In all cases, the measured electric field strength decreases rapidly with distance from the peak.

8.5 Electric field strengths measured directly under the conductors of overhead lines vary across those surveyed, from 0.75 kV m^{-1} to the maximum of 4.72 kV m^{-1} noted.

8.6 The electric field measured at substations is very weak (peaking at 0.12 kV m^{-1}), and is lower immediately at the perimeter in all cases. This is likely to be due to the metal fence of the perimeter providing a path to earth for the electric field at that location, effectively screening the electric field measured adjacent to it.

8.7 Electric field strength depends on voltage rather than current, and would not be expected to vary significantly under differing load conditions (although some change due to thermal expansion of overhead lines, causing sag that reduces ground clearance and hence measurement distance, would be expected). However, significant variability and some outlier measurements are evident in the plots of the multiple series of electric field measurements. This is likely to reflect variation in the transmission system voltage (either within Grid Code normal expected ranges, or potentially a transmission system disturbance), and also the fact that electric field measurements can be affected by environmental confounding factors such as weather conditions and grounding by nearby objects or natural features.

9 Conclusions

9.1 Widely adopted international guidelines for continuous public exposure to ELF electric and magnetic fields, published by ICNIRP, exist to protect public health. These guideline values are based upon well-established acute effects on the body or the thresholds at which physical impacts from fields can be perceived, with a 'safety factor' to allow for scientific uncertainty and the potential cumulative impacts of long-term exposure. The guidelines are expressed both as a basic restriction (for induced current in the central nervous system or internal electric field) and a reference level (external field strength at which the basic restriction could not be exceeded).

9.2 The most recent published reference levels (2010) are 200 µT and 5 kV m^{-1} for magnetic and electric field strength respectively, although at the present time, the standing EC recommendation for their adoption (1999/519/EC) is based upon a more stringent former reference level (1998) of 100 µT for the magnetic field and the same reference level of 5 kV m^{-1} for the electric field.

Magnetic field

9.3 The maximum magnetic field strengths measured at all overhead lines, underground cables and substation perimeters surveyed are well below the ICNIRP reference level to protect public health (Table 9.1).

Table 9.1: Maximum measured magnetic field strength

2010 ICNIRP reference level	200 µT	
	Maximum field strength	**Percentage of reference level**
Underground cable	26.01 µT	13.01 %
Overhead line	4.97 µT	2.49 %
Substation perimeter	0.72 µT	0.36 %

9.4 Based on the measured data, magnetic field strengths estimated for overhead power lines and underground cables using records of annual load are also well below the ICNIRP reference level to protect public health under typical (mean or median load) and high power load (95^{th} percentile) conditions (Table 9.2).

Table 9.2: Maximum magnetic field strength under annual typical and high loads

2010 ICNIRP reference level		200 µT	
Overhead line*	Mean load	1.20 – 2.37 µT	0.60 – 1.18 %
	Median load	1.06 – 2.56 µT	0.53 – 1.28 %
	95^{th} percentile load	2.51 – 7.04 µT	1.26 – 3.52 %
Underground cable	Mean load	1.96 –15.65 µT	0.98 – 7.83 %
	Median load	2.03 – 14.78 µT	1.02 – 7.39 %
	95^{th} percentile load	2.56 – 25.27 µT	1.28 – 12.64 %

* Excluding double circuit lines

Electric field

9.5 The maximum electric field strengths measured at all overhead lines and substation perimeters surveyed are below the ICNIRP reference level to protect public health (Table 9.3). Underground cables produce no electric field above ground.

Table 9.3: Maximum measured electric field strength

2010 ICNIRP reference level	5 kV m^{-1}	
Overhead line	4.72	94 %
Substation perimeter	0.12	2.4 %

Public exposure

9.6 The maximum magnetic field strength from all high-voltage transmission infrastructure items measured falls well below the ICNIRP guideline reference level for the protection of public health. This is the case for power loads at the times of measurement, and also the case when measurement results are scaled to higher loadings (those not exceeded 95% of the time in a typical year for the infrastructure included in the study). Under the EC recommendation, these public exposure guidelines are applicable primarily to long-term, residential exposure.

9.7 Although remaining within the guideline reference level is considered appropriate to protect health, health protection bodies suggest that, based on the health impacts research literature, public perception of risk can be addressed through application of a precautionary approach in which unnecessary magnetic field exposure is further reduced. EirGrid typically aims, on the grounds of residential amenity and visual impact, to site new high-voltage transmission infrastructure away from populated areas and to maintain at least a 50 m distance from individual dwellings where feasible. This existing approach inherently offers a further reduction in magnetic field exposure, as the field strength decreases rapidly with distance away from the power line.

9.8 The maximum electric field strength measured from the highest-voltage overhead line (400 kV) is relatively close to the ICNIRP reference level. However, this reference level is set on a highly conservative basis that ensures that the ICNIRP basic restriction for electric field exposure cannot be exceeded by external field strengths below the reference level.

Appendices

Appendix 1: Literature Search

This table summarises the review that has been undertaken of scientific literature presented by the wider scientific community following the 2007 WHO monograph. An initial search was conducted using the PubMed database. The main criteria for the search were that the studies considered ELF EMF in the power frequency range and had been published during 2007-2012, subsequent to the WHO monograph. The search terms used were: EMF, ELF EMF, ELF magnetic field, EMF high voltage, EMF non ionising radiation and EMF power line. The 111 papers found were prioritised by an abstract review, from which a smaller number studies have been drawn upon in detail and cited in the literature review document.

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
electric field	Occupational exposure matrix for exposure to all EMF factors (electric field, magnetic field, nuisance shocks). Concludes that four job categories have highest exposure namely cable splicers, electricians, line workers, and substation operators	Bracken, TD	2009	An integrated job exposure matrix for electrical exposures of utility workers	Journal of Occupational and Environmental Hygiene	6 (8)	499-509
electric field		Goodman, R	2009	Extremely low frequency electric fields and cancer: assessing the evidence	Bioelectromagnetics	31(2)	89-101
electric field	Literature review on health effects from weak electromagnetic fields with power frequency of 50/60 Hz. Concludes that we are far from understanding the biophysics background of potential EMF effects on human subjects. Therefore further intensive studies are needed to eliminate existing drawbacks	Zmyslony, M	2008	Biological effects and health risk of power frequency electromagnetic fields (neoplasms excluded)	Medycyna Pracy (Poland)	59 (5)	421-428
epidemiological	The study examines the association between residential contact currents, magnetic field and childhood leukaemia in California. No evidence found of an association	Does, M	2011	Exposure to electrical contact currents and the risk of childhood leukaemia	Radiation Research	175 (3)	390-396
epidemiological	Investigates whether contact current is responsible for the association between childhood leukaemia and magnetic fields. Concludes that associations appear large enough to support the possibility that contact current could be responsible for the associated of childhood leukaemia with magnetic fields	Kavet, R	2011	The relationship between residential magnetic fields and contact voltage: a pooled analysis	Radiation Research	Ahead of print	Ahead of print
epidemiological		Maes, A	2011	Can cytogenetics explain the possible association between exposure to extreme low-frequency magnetic fields and Alzheimer's disease	Journal of Applied Toxicology	Ahead of print	

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
epidemiological	Acute lymphoblastic leukaemia among children whose mothers have been exposed to occupational ELF EMF. The study did not find an increased risk of ALL in offspring of parents with occupational exposure to ELF	Reid, A	2011	Risk of childhood acute lymphoblastic leukaemia following parental occupational exposure to extremely low frequency electromagnetic fields	British Journal of Cancer	Ahead of print	
epidemiological	Review document	Lagroye, I	2011	ELF magnetic fields: Animal studies, mechanisms of action	Progress in Biophysics and Molecular Biology	Ahead of print	
epidemiological	Impact of 60Hz 3mT MF on human cognitive performance. Power line workers and welders. Speculates a link between ELF MF and interference with neuropsychological processes responsible for short term learning	Corbacio, M	2011	Human cognitive performance in a 3 mT power-line frequency magnetic field	Bioelectromagnetics	Ahead of print	
epidemiological		de Kleijn, S	2011	Extremely low frequency electromagnetic field exposure does not modulate toll-like receptor signalling in human peripheral blood mononuclear cells	Cytokine	54 (1)	43-50
epidemiological		Legros A, Corbacio M, Beuter A, Modolo J, Goulet D, Prato FS, Thomas AW.	2011	Neurophysiological and behavioural effects of a 60Â Hz, 1,800Â Î¼T magnetic field in humans.	Eur J Appl Physiol.	ahead of print	
epidemiological		Kheifets, L	2010	A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors	American Journal of Epidemiology	172 (7)	752-761
epidemiological	Results do not suggest a MF effect	McNamee, DA	2010	The response of the human circulatory system to an acute 200-uT 60-Hz magnetic field exposure	International archives of occupational and environmental health	84 (3)	267-77
epidemiological		Carpenter, DO	2010	Electromagnetic fields and cancer: the cost of doing nothing	Reviews on Environmental Health	25 (1)	75-80
epidemiological		Chen, C	2010	Extremely low-frequency electromagnetic fields exposure and female breast cancer risk: a meta-analysis based on 24,338 cases and 60,628 controls	Breast cancer res treatment	123 (2)	569-576
epidemiological		Hug, K	2010	Parental occupational exposure to extremely low frequency magnetic fields and childhood cancer: a German case-control study	American Journal of Epidemiology	171 (1)	27-35

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
epidemiological		McNamee, DA	2010	The cardiovascular response to an acute 1800-microT 60-Hz magnetic field exposure in humans	International archives of occupational and environmental health	83(4)	441-454
epidemiological		Mehic B.	2010	Retraction: Evaluation of carcinogenic effects of electromagnetic fields (EMF).	Bosn J Basic Med Sci	10(4)	331
epidemiological		Bayazit V, Bayram B, Pala Z, Atan O.	2010	Evaluation of carcinogenic effects of electromagnetic fields (EMF).	Bosn J Basic Med Sci	10(4)	332
epidemiological		Kheifets L, Swanson J, Kandel S, Malloy TF.	2010	Risk governance for mobile phones, power lines, and other EMF technologies.	Risk Annals	30(10)	1481-94
epidemiological		Gobba, F	2009	Natural killer cell activity decreases in workers occupationally exposed to extremely low frequency magnetic fields exceeding 1 microT	International journal immunopathology pharmacology	22 (4)	1059-1066
epidemiological		Schüz, J	2009	Electromagnetic fields and epidemiology: an overview inspired by the fourth course at the International School of Bioelectromagnetics	Bioelectromagnetics	30(7)	511-24
epidemiological	Concludes that high levels of exposure misclassification render the findings from studies that rely on distance alone un-interpretable	Maslanyj M	2009	Power frequency magnetic fields and risk of childhood leukaemia: misclassification of exposure from the use of the 'distance from power line' exposure surrogate.	Bioelectromagnetics	30(3)	183-8
epidemiological		Binhi V.	2008	Do naturally occurring magnetic nanoparticles in the human body mediate increased risk of childhood leukaemia with EMF exposure?	Int J Radiat Biol	84(7)	569-79
epidemiological		Ahlbom A, Bridges J, de Seze R, Hillert L, Juutilainen J, Mattsson MO, Neubauer G, Schoz J, Simko M, Bromen K.	2008	Possible effects of electromagnetic fields (EMF) on human health--opinion of the scientific committee on emerging and newly identified health risks (SCENIHR).	Toxicology	246(2-3)	248-50
epidemiological		Mezei G, Gadallah M, Kheifets L.	2008	Residential magnetic field exposure and childhood brain cancer: a meta-analysis.	Epidemiology	19(3)	424-30

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
epidemiological		Otto M, von Maehendahl KE.	2007	Electromagnetic fields (EMF): do they play a role in children's environmental health (CEH)?	Int J Hyg Environ Health	210(5)	635-44
epidemiological		Kheifets, L. *et al*	2010	A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors	American Jnl of Epidemiology	Online version	10.1093/aje/kwq181
epidemiological	Review of literature dealing with health effects of exposure to EMF emitted by installations including power lines and transformer stations. Concludes that further intensive investigations are required	Zmyslony M	2007	Biological mechanisms and health effects of EMF in view of requirements of reports on the impact of various installations on the environment	Medycyna Pracy (Poland)	58(1)	27-36
guidelines		Safigianni AS, Spyridopoulos AI, Kanas VL.	2011	Electric and Magnetic Field Measurements in a High Voltage Centre.	Ann Occup Hyg.	ahead of print	
guidelines		Bakker, JF	2011	Children and adults exposed to electromagnetic fields at the ICNIRP reference levels: theoretical assessment of the induced peak temperature increase	Physics in Medicine and Biology	56(15)	4967-89
guidelines		Damvik, M	2010	Health risk assessment of electromagnetic fields: a conflict between the precautionary principle and environmental medicine methodology	Reviews on Environmental Health	25(4)	325-33
guidelines		Fragopoulou, A	2010	Scientific panel on electromagnetic field health risks: consensus points, recommendations, and rationales	Reviews on Environmental Health	25(4)	307-17
guidelines		Swanson J.	2009	Consultation on revisions to the European Directive on occupational EMF exposure.	Journal of Radiological Protection	29(2)	291-292
guidelines	The paper considers the definitions of precaution, prevention, risk, uncertainty, and ignorance; the use of different strengths of evidence for different purposes; the nature and main direction of the methodological and cultural biases within the environmental health sciences; the need for transparency in evaluating risks; and public participation in risk analysis. These issues are relevant to the risk assessment of electro-magnetic fields (EMF).	Gee D.	2009	Late Lessons from Early Warnings: Towards realism and precaution with EMF?	Pathophysiology	16(2-3)	217-31

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
guidelines		Szuba M.	2009	Consequences of changed regulations on the protection of the environment against the influence of the 50 Hz magnetic field.	Med Pr.	60(1)	51-7
guidelines	Considers recent developments that are relevant to formulating the next generation of guidelines. Particularly a simplified approach to magnetic field assessment in non-uniform magnetic fields and assessment of exposure to high electric fields in realistic situations (i.e. line workers)	Kavet, R	2008	Recent advances in research relevant to electric and magnetic field exposure guidelines	Bioelectromagnetics	29 (7)	499-526
guidelines		Wood AW.	2008	Extremely low frequency (ELF) electric and magnetic field exposure limits: rationale for basic restrictions used in the development of an Australian standard.	Bioelectromagnetics.	29(6)	414-28
guidelines	Expressing EMF recommendations for children, how to communicate risk regarding EMF and children	Polzl, C	2011	EMF recommendations specific for children?	Progress in Biophysics and Molecular Biology	Ahead of print	Ahead of print
guidelines		Nielsen JB, Elstein A, Gyrd-Hansen D, Kildemoes HW, Kristiansen IS, Stavring H.	2010	Effects of alternative styles of risk information on EMF risk perception.	Bioelectromagnetics	31(7)	504-12
in vitro	EMF interactions with DNA at different frequency ranges. Concludes that the resulting DNA damage could account for increases in cancer epidemiology	Blank, M	2011	DNA is a fractal antenna in electromagnetic fields	International journal of radiation biology	87 (4)	409-415
in vitro		Lee, HJ	2011	Combined effects of 60Hz electromagnetic field exposure with various stress factors on cellular transformation in NIH3T3 cells	Bioelectromagnetics	Ahead of print	
in vitro		Bayat, PD	2011	Effect of exposure to extremely low electro-magnetic field during prenatal period on mice spleen	Indian Journal of Experimental Biology	49 (8)	634-638
in vitro		Ravera, S	2011	Extremely low-frequency electromagnetic fields affect lipid-linked carbonic anhydrase	Electromagnetic biology and medicine	30 (2)	67-73
in vitro	ELF MF genotoxic effect on e-coli. Under specific conditions of exposure ELF MF was shown to act as a non-toxic but cell growth stimulating agent	Belyaev, I	2011	Toxicity and SOS-response to ELF magnetic fields and nalidixic acid in E. coli cells	Mutation research	18;722 (1)	56-61

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
in vitro		Verschaeve, L	2011	Gentoxicity investigation of ELF-magnetic fields in Salmonella typhimurium with the sensitive SOS-based VITOTOX test	Bioelectromagnetics	32 (7)	580-584
in vitro		Luukkonen, J	2011	Pre-exposure to 50 Hz magnetic fields modifies menadione-induced genotoxic effects in human SH-SY5Y neuroblastoma cells	Published online		
in vitro		Inham-Garip, A	2011	Effect of extremely low frequency electromagnetic fields on growth rate and morphology of bacteria	International journal of radiation biology	ahead of print	
in vitro		Prato, FS	2011	The detection threshold for extremely low frequency magnetic fields may be below 1000 nT-Hz in mice	Bioelectromagnetics	32 (7)	561-569
in vitro		Collard, JF	2011	In vitro study of the effects of ELF electric fields on gene expression in human epidermal cells	Bioelectromagnetics	32 (1)	28-36
in vitro		Zhang J, Dewilde AH, Chinn P, Foreman A, Barry S, Kanne D, Braunhut SJ.	2011	Herceptin-directed nanoparticles activated by an alternating magnetic field selectively kill HER-2 positive human breast cells in vitro via hyperthermia.	Int J Hyperthermia.	27(7	682-97.
in vitro		Bayat PD, Ghanbari A, Saeid B, Khazaei M, Ghorbani R, Ayubian M.	2011	Effect of exposure to extremely low electro-magnetic field during prenatal period on mice spleen.	Indian J Exp Biol	49(8)	634-638
in vitro		Hong ME, Yoon KH, Jung YY, Lee TJ, Park ES, Sohn UD, Jeong JH.	2011	Influence of exposure to extremely low frequency magnetic field on neuroendocrine cells and hormones in stomach of rats.	Korean J Physiol Pharmacol	15(3)	137-42
in vitro		Polidori E, Zeppa S, Potenza L, Martinelli C, Colombo E, Casadei L, Agostini D, Sestili P, Stocchi V.	2011	Gene expression profile in cultured human umbilical vein endothelial cells exposed to a 300mT static magnetic field.	Bioelectromagnetics	ahead of print	
in vitro		Laszlo JF, Porszasz R.	2011	Exposure to static magnetic field delays induced preterm birth occurrence in mice.	Am J Obstet Gynecol.	ahead of print	

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
in vitro	The results of this study show that intracellular Ca(2+) accumulation in cardiac ventricles can increase in rats exposed to ELF magnetic field	Sert C, Soker S, Deniz M, Nergiz Y.	2011	Intracellular Ca (2+) levels in rat ventricle cells exposed to extremely low frequency magnetic field.	Electromagn Biol Med	30(1)	14-20
in vitro	Stem cells exposed to ELF MF to evaluate whether exposure affects growth, metabolism and differentiation of stem cells. The results suggest that ELF magnetic field may influence the early development of hMSCs related adult cells	Yan, J	2010	Effects of extremely low-frequency magnetic field on growth and differentiation of human mesenchymal stem cells	Electromagnetic biology and medicine	29 (4)	165-76
in vitro		Song HS, Kim HR, Ko MS, Jeong JM, Kim YH, Kim MC, Hwang YH, Sohn UD, Gimm YM, Myung SH, Sim SS.	2010	Effect of Extremely Low Frequency Electromagnetic Fields (EMF) on Phospholipase Activity in the Cultured Cells.	Korean J Physiol Pharmacol	14(6)	427-433
in vitro		Friedl AA, Rühm W.	2010	Editorial expression of concern regarding: Pilger A et al. (2004) No effects of intermittent 50 Hz EMF on cytoplasmic free calcium and on the mitochondrial membrane potential in human diploid fibroblasts, Radiat Environ Biophys 43:203-207.	Radiat Environ Biophys	49(3)	293-4
in vitro		Yang Y, Tao C, Zhao D, Li F, Zhao W, Wu H.	2010	EMF acts on rat bone marrow mesenchymal stem cells to promote differentiation to osteoblasts and to inhibit differentiation to adipocytes.	Bioelectromagnetics	31(4)	277-85
in vitro		Sun W, Tan Q, Pan Y, Fu Y, Zhang D, Lu D, Chiang H.	2010	Superimposition of an incoherent magnetic field eliminated the inhibition of hormone secretion induced by a 50-Hz magnetic field in human villous trophoblasts in vitro.	Cell Physiol Biochem	26(4-5)	793-8
in vitro		Masuda H, de Gannes FP, Haro E, Billaudel B, Ruffle G, Lagroye I, Veyret B.	2010	Lack of effect of 50-Hz magnetic field exposure on the binding affinity of serotonin for the 5-HT 1B receptor subtype.	Brain Res.	1368	44-51
in vitro		Kim J, Ha CS, Lee HJ, Song K.	2010	Repetitive exposure to a 60-Hz time-varying magnetic field induces DNA double-strand breaks and apoptosis in human cells.	**Biochem Biophys Res Commun.**	400(4)	739-44

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
in vitro		Sun W, Tan Q, Pan Y, Fu Y, Sun H, Chiang H.	2010	Effects of 50-Hz magnetic field exposure on hormone secretion and apoptosis-related gene expression in human first trimester villous trophoblasts in vitro.	Bioelectromagnetics.	31(7)	566-72
in vitro		Mannerling AC, SimkÃ³ M, Mild KH, Mattsson MO.	2010	Effects of 50-Hz magnetic field exposure on superoxide radical anion formation and HSP70 induction in human K562 cells.	Radiat Environ Biophys.	49(4)	731-41
in vitro		Okudan N, Celik I, Salbacak A, Cicekcibasi AE, Buyukmumcu M, Gokbel H.	2010	Effects of long-term 50 Hz magnetic field exposure on the micro nucleated polychromatic erythrocyte and blood lymphocyte frequency and argyrophilic nucleolar organizer regions in lymphocytes of mice.	Neuro Endocrinol Lett.	31(2)	208-14
in vitro		Gulturk S, Demirkazik A, Kosar I, Cetin A, Dokmetas HS, Demir T.	2010	Effect of exposure to 50 Hz magnetic field with or without insulin on blood-brain barrier permeability in streptozotocin-induced diabetic rats.	Bioelectromagnetics	31(4)	262-9
in vitro		Sun H, Che Y, Liu X, Zhou D, Miao Y, Ma Y.	2010	Effects of prenatal exposure to a 50-Hz magnetic field on one-trial passive avoidance learning in 1-day-old chicks.	Bioelectromagnetics	31(2)	150-5
in vitro	These results convincingly prove the negative effect of EMF on the antiestrogenic effect of melatonin in breast cancer cells.	Girgert, R	2010	Signal transduction of the melatonin receptor MT1 is disrupted in breast cancer cells by electromagnetic fields	Bioelectromagnetics	31(3)	237-45
in vitro		Ruiz-Gomez, MJ	2009	Electromagnetic fields and the induction of DNA strand breaks	Electromagnetic biology and medicine	28(2)	201-214
in vitro		Strasck L, BÃ¡rtovÃ¡ E, Krejci J, Fojt L, Vetterl V.	2009	Effects of ELF-EMF on brain proteins in mice.	Electromagnetic biology and medicine	28(1)	96-104
in vitro		Pourlis AF.	2009	Reproductive and developmental effects of EMF in vertebrate animal models.	Pathophysiology	16(2-3)	179-89
in vitro		Gobba F, Bargellini A, Scaringi M, Bravo G, Borella P.	2009	Extremely low frequency-magnetic fields (ELF-EMF) occupational exposure and natural killer activity in peripheral blood lymphocytes.	Sci Total Environ	407(3)	1218-1223

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
in vitro	The findings indicate that the oxidative stress resulting from exposure to 50 Hz magnetic field of 10 mT induction may produce a number of adverse effects within the cell and thus may lead to systemic disturbances in the human body	Henrykowska G, Jankowski W, Pacholski K, Lewicka M, Smigielski J, Dziedziczak-Buczynska M, Buczynski A.	2009	The effect of 50 hz magnetic field of different shape on oxygen metabolism in blood platelets: in vitro studies.	Int J Occup Med Environ Health	22(3)	269-76
in vitro		Janac B, Tovilovic G, Tomic M, Prolic Z, Radenovic L.	2009	Effect of continuous exposure to alternating magnetic field (50 Hz, 0.5 mT) on serotonin and dopamine receptors activity in rat brain.	Gen Physiol Biophys.	28 Spec No:41-6.	
in vitro	Concluded that exposure to the ELF-EMFs for different time periods produced significant decreases in plasma catalase activities in the 3-month exposure groups but no effects on progesterone level, on 17-beta estradiol level, or on the morphology and weight of uterus and ovaries	Aydin, M	2009	Evaluation of hormonal change, biochemical parameters, and histopathological status of uterus in rats exposed to 50-Hz electromagnetic field	Toxicological and Industrial Health	25(3)	153-8
in vitro		Al-Akhras MA.	2008	Influence of 50 Hz magnetic field on sex hormones and body, uterine, and ovarian weights of adult female rats.	Electromagn Biol Med.	27(2)	155-63
in vitro		Keklikci U, Akpolat V, Ozekinci S, Unlu K, Celik MS.	2008	The effect of extremely low frequency magnetic field on the conjunctiva and goblet cells.	Curr Eye Res.	33(5)	441-6
in vitro		Erdal N, Gurgul S, Tamer L, Ayaz L.	2008	Effects of long-term exposure of extremely low frequency magnetic field on oxidative/nitrosative stress in rat liver.	J Radiat Res (Tokyo)	49(2)	181-7
in vitro	Study found no changes in transcript protein level on the autonomic nervous system and catecholaminergic system	Benfante, R	2008	The expression of PHOX2A, PHOX2B and of their target gene dopamine-beta-hydroxylase (DbetaH) is not modified by exposure to extremely-low-frequency electromagnetic field (ELF-EMF) in a human neuronal model.	Toxicology in vitro	22(6)	1489-95
in vitro		Torres-Duran PV, Ferreira-Hermosillo A, Juarez-Oropeza MA, Elias-ViÃ±as D, Verdugo-Diaz L.	2007	Effects of whole body exposure to extremely low frequency electromagnetic fields (ELF-EMF) on serum and liver lipid levels, in the rat.	Lipids Health Dis	16;6	31

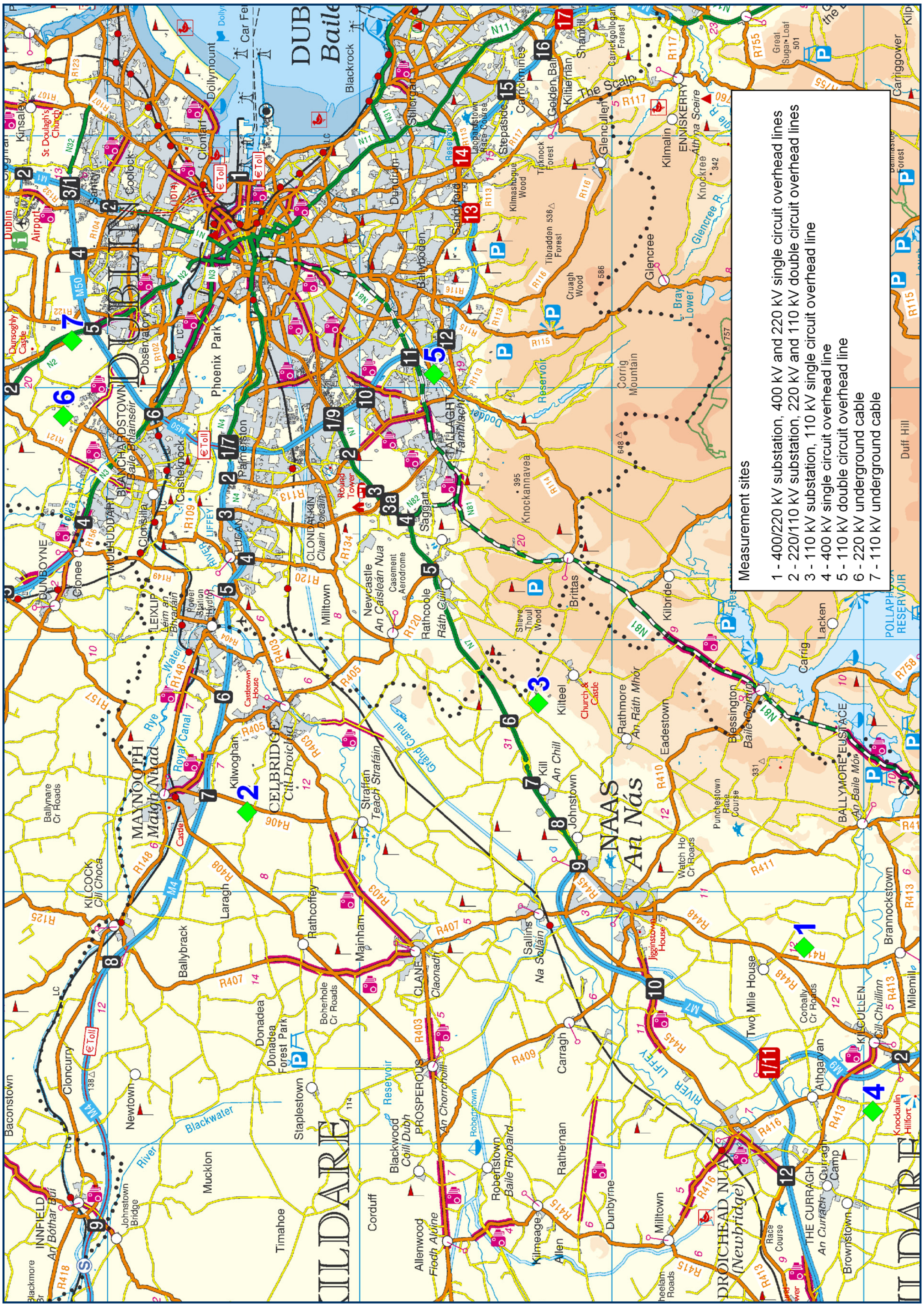
Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
in vitro		Roychoudhury, S	2009	Influence of a 50 Hz extra low frequency electromagnetic field on spermatozoa motility and fertilisation rates in rabbits	Journal of environmental science and health	44(10)	1041-1047
in vivo		Cam, ST	2011	Occupational exposure to magnetic fields from transformer stations and electric enclosures in Turkey	Electromagnetic biology and medicine	30 (2)	74-79
in vivo		Gobba, F	2011	Occupational and environmental exposure to extremely low frequency magnetic fields: a personal monitoring study in a large group of workers in Italy	Journal of Exposure Science and Environmental Epidemiology	Ahead of print	
in vivo	Spot measurement of ELF EMF and RF over 8 years covering 35 municipalities in Serbia. Paper presents a summary of values measured in households underneath overhead power lines. Measured levels below ICNIRP guideline safe values	Vulevic, B	2011	Survey of ELF magnetic field levels in households near overhead power lines in Serbia	Radiation Protection Dosimetry	145 (4)	385-388
in vivo	Residential proximity to transmission lines is unlikely to be associated with stillbirth, but more research is needed to rule out a possible link	Auger, N	2011	Stillbirth and residential proximity to extremely low frequency power transmission lines: a retrospective cohort study	Occupational and Environmental Medicine	Ahead of print	
in vivo	Review which considers the limitation of the methodology for measuring exposure (point in time measurements in homes) and evidence of whether EMF is carcinogenic	Miller, AB	2010	Electric and magnetic fields at power frequencies	Chronic Diseases in Canada	29 Suppl 1	69-83
in vivo		Baldi, I	2010	Occupational and residential exposure to electromagnetic fields and risk of brain tumors in adults: A case-control study in Gironde, France	International journal of cancer	Ahead of print	
in vivo		Tomitsch, J	2010	Survey of electromagnetic field exposure in bedrooms of residences in lower Austria	Bioelectromagnetics	31 (3)	200-208
in vivo		Kroll, ME	2010	Childhood cancer and magnetic fields from high-voltage power lines in England and Wales: a case-control study	British Journal of Cancer	103(7)	1122-7
in vivo		Cakir, DU	2009	Alterations of haematological variations in rats exposed to extremely low frequency magnetic fields (50Hz)	Archives of medical research	40(5)	352-356

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
in vivo		Duyan G, Xu G, Yu H, Yang S, Yang Q, Yan W.	2008	Modelling of electromagnetic environment of transmission lines for studying effect of ELF-EMF.	Conf Proc IEEE Eng Med Biol Soc		1331-4
in vivo		Jeffers, D	2007	Transmission lines, EMF and population mixing.	Radiation Protection Dosimetry	123(3)	398-401
magnetic field		Yost MG	2011	A recurring question: are there health effects of power frequency magnetic fields	Archives of paediatric and adolescent medicine	165 (10)	959-961
magnetic field		Giorgi, G	2011	Effect of extremely low frequency magnetic field exposure on DNA transposition in relation to frequency, wave shape and exposure time	International journal of radiation biology	87 (6)	601-608
magnetic field	Examines studies into ELF-MF and the risk of childhood leukaemia. Concludes that the assessment that ELF-MF are a possible carcinogen and may cause childhood leukaemia remains valid	Schüz, J	2011	Exposure to extremely low-frequency magnetic fields and the risk of childhood cancer: update of the epidemiological evidence	Progress in Biophysics and Molecular Biology	Ahead of print	
magnetic field		Del Seppia C, Mencacci R, Luschi P, Varanini M, Ghione S.	2011	Differential magnetic field effects on heart rate and nociception in anosmic pigeons.	Bioelectromagnetics.	ahead of print	
magnetic field		Houpt TA, Cassell J, Carella L, Neth B, Smith JC.	2011	Head tilt in rats during exposure to a high magnetic field.	Physiol Behav.	105(2)	388-393
magnetic field		Islas R, Heine T, Merino G.	2011	The Induced Magnetic Field.	Acc Chem Res.	ahead of print	
magnetic field		Sulpizio M, Falone S, Amicarelli F, Marchisio M, Di Giuseppe F, Eleuterio E, Di Ilio C, Angelucci S.	2011	Molecular basis underlying the biological effects elicited by extremely low-frequency magnetic field (ELF-MF) on neuroblastoma cells.	J Cell Biochem.	ahead of print	
magnetic field	An evaluation of methods for classifying apartments in exposure categories for ELF-MF based on proximity to the transformer station	Roosli M, Jenni D, Kheifets L, Mezei G.	2011	Extremely low frequency magnetic field measurements in buildings with transformer stations in Switzerland.	Sci Total Environ	409(18)	3364-9

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
magnetic field		de Bruyn L, de Jager L.	2010	Effect of long-term exposure to a randomly varied 50 Hz power frequency magnetic field on the fertility of the mouse.	Electromagn Biol Med	29(1-2)	52-61
magnetic field		McNamee DA, Corbacio M, Weller JK, Brown S, Stodilka RZ, Prato FS, Bureau Y, Thomas AW, Legros AG.	2010	The response of the human circulatory system to an acute 200-uT, 60-Hz magnetic field exposure.	Int Arch Occup Environ Health.	84(3)	267-77
magnetic field		McNamee DA, Corbacio M, Weller JK, Brown S, Prato FS, Thomas AW, Legros AG.	2010	The cardiovascular response to an acute 1800-microT, 60-Hz magnetic field exposure in humans.	Int Arch Occup Environ Health	83(4)	441-54
magnetic field		Bottura, V	2009	Urban exposure to ELF magnetic field due to high, medium and low voltage electricity supply networks	Radiation Protection Dosimetry	137 (3-4)	201-205
magnetic field		Cvetkovic D, Cosic I.	2009	Alterations of human electroencephalographic activity caused by multiple extremely low frequency magnetic field exposures.	Med Biol Eng Comput	47(10)	1063-73
magnetic field		Albert GC, McNamee JP, Marro L, Bellier PV, Prato FS, Thomas AW.	2009	Assessment of genetic damage in peripheral blood of human volunteers exposed (whole-body) to a 200 μT, 60 Hz magnetic field.	Int J Radiat Biol.	85(2)	144-152
magnetic field	Study demonstrates method for classifying apartments into high or low exposure based on their location in relation to transformers	Thuroczy G, Janossy G, Nagy N, Bakos J, Szabo J, Mezei G.	2008	Exposure to 50 Hz magnetic field in apartment buildings with built-in transformer stations in Hungary.	Radiat Prot Dosimetry.	131(4)	469-73
magnetic field		Nevelsteen, S	2007	Effects of information and 50 Hz magnetic fields on cognitive performance and reported symptoms	Bioelectromagnetics	28 (1)	53-63

Theme	Overview / Notes	Author	Date Published	Title	Journal	Volume, chapter	Page number
Updated literature search results for epidemiological studies of childhood leukaemia and EMF published in 2013 to March 2014							
epidemiological	Pooled analysis of nine existing studies.	Zhao, L. *et al*	2014	Magnetic fields exposure and childhood leukemia risk: A meta-analysis based on 11,699 cases and 13,194 controls	Leukemia Research	38 (3)	269-274
epidemiological	Based on distance from overhead lines.	Sermage-Faure, C. *et al*	2013	Childhood leukaemia close to high-voltage power lines – the Geocap study, 2002–2007	British Journal of Cancer	108	1899-1906
epidemiological	Danish study following approach of Draper study	Pedersen, C. *et al*	2014	Distance from residence to power line and risk of childhood leukemia: a population-based case–control study in Denmark	Cancer Causes and Control	25 (2)	171-177
epidemiological	Second update to Draper study, adding data from Scotland and for 132 kV lines, and investigating risk trend over time.	Bunch, L. *et al*	2014	Residential distance at birth from overhead high-voltage powerlines: childhood cancer risk in Britain 1962–2008	British Journal of Cancer	110	1402-1408
epidemiological (methodology)	Methodology for replication of Draper study in California. Results not yet published.	Kheifets, L. *et al*	2013	Epidemiologic study of residential proximity to transmission lines and childhood cancer in California: description of design, epidemiologic methods and study population	Journal of Exposure Science and Environmental Epidemiology	Ahead of print	
epidemiological	Investigated population mixing hypothesis, previously suggested for excess childhood leukaemia risk associated with nuclear sites	Swanson, J.	2013	Residential mobility of populations near UK power lines and implications for childhood leukaemia.	Journal of Radiological Protection	33 (3)	9-14
epidemiological	[Article is in Dutch]. English abstract indicates that a cancer cluster investigation for childhood leukaemia was undertaken including review of data regarding a local high-voltage power line.	Hegger, C. and Reedjik, A.	2013	Childhood leukaemia in a residential area with a high-voltage power line: approach according to the Dutch Community Health Services' guideline 'Cancer Clusters'	Nederlands Tijdschrift voor Geneeskunde	157	

Appendix 2: Measurement Locations Map



Appendix 3: Narda EHP-50D Calibration Documents

863

narda Safety Test Solutions
an L3 Communications Company

Narda Safety Test Solutions S.r.l.
Sales & Support: Via Leonardo da Vinci 21/23
20090 Segrate (MI)
Tel.: +39 02 2699871 Fax: +39 02 26998700
Manufacturing Plant: Via Benessea, 29/B
17035 Cisano sul Neva (SV)
Tel.: +39 0182 58641 Fax: +39 02 586400

CERTIFICATE OF CALIBRATION
Certificato di taratura

Number *Numero* **20734**

Item *Oggetto*	Electric and Magnetic field Probe - Analyzer
Manufacturer *Costruttore*	Narda S.T.S. / PMM
Model *Modello*	EHP50D
Serial number *Matricola*	120WX20734
Calibration procedure *Procedura di taratura*	Internal procedure PTP 09-31
Date(s) of measurements *Data(e) delle misure*	25.09.2012
Result of calibration *Risultato della taratura*	Measurements results within specifications

This calibration certificate documents the traceability to national/international standards, which realise the physical units of measurements according to the International System of Units (SI). Verification of traceability is guaranteed by mentioning used equipment included in the measurement chain. This equipment includes reference standard directly traceable to (inter)national standard (accuracy rating A) and working standard calibrated by the calibration laboratory of Narda Safety Test Solutions (accuracy rating B) by means of reference standard A or by other calibration laboratory.
The measurement uncertainties stated in this document are estimated at the level of twice the standard deviation (corresponding, in the case of normal distribution, to a confidence level of about 95%). The uncertainties are calculated in conformity to the ISO Guide (Guide to the expression of uncertainty in measurement).The metrological confirmation system for the measuring equipment used is in compliance with ISO 10012-1. The applied quality system is certified to UNI EN ISO 9001.

Questo certificato di taratura documenta la tracciabilità a campioni primari nazionali o internazionali i quali realizzano la riferibilità alle unità fisiche del Sistema Internazionale delle Unità (SI). La verifica della tracciabilità è garantita elencando gli strumenti presenti nella catena di misura.La catena di riferibilità metrologica fa riferimento a campioni di prima linea direttamente riferiti a standard (inter)nazionali (classe A), di seconda linea, tarati nel laboratorio metrologico della Narda Safety Test Solutions con riferibilità ai campioni di prima linea oppure tarati da Enti esterni accreditati (classe B).
Le incertezze di misura dichiarate in questo documento sono espresse come due volte lo scarto tipo (corrispondente, nel caso di distribuzione normale, a un livello di confidenza di circa 95%). Le incertezze di misura sono calcolate in riferimento alla guida ISO. La conferma metrologica della strumentazione usata è conforme alla ISO 10012-1. Il sistema di qualità è certificato ISO 9001.

COMPANY WITH QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV
= ISO 9001:2008 =

Date of issue *Data di emissione*	**Measure operator** *Operatore misure*	**Person responsible** *Responsabile*
27.09.2012	F. Ferrari	G. Basso

The calibration was carried out at an ambient temperature of (23 ± 3)°C and at a relative humidity of (50 +10/-20)%.

Calibration method

The magnetic calibration was set up with the probe in a region of uniform magnetic field at the centre of a calibrated Helmholtz coil system. The magnetic flux density is calculated from the current flowing in the coil. The current waveform was sinusoidal. The current in the Helmholtz coil system was adjusted to produce a series of indicated magnetic flux densities on the instrument at various frequencies. The calibration procedure agrees with the indication of IEC 61786 "Measurement of low frequency magnetic and electric fields with regard to exposure of human beings- Special requirements for instruments"
The instrument readings were recorded and the actual values of magnetic flux density were calculated from the measured currents.
The magnetic correction factor (CF) is defined as rapport between actual and indicated magnetic flux density.

$$CF = \frac{Bo}{Bmis}$$

where Bo is the applied magnetic flux density and Bmis is the indicated magnetic flux density

For the electric calibration the probe is positioned inside a big TEM cell (section 1.8x1.8 mete
For each measurement, the input voltage was adjusted so that the field strength was set to a specified reading on the monitor.
The actual field strength, at the plane of reference of the probe was then determined and the correction factor calculated using the following definition.

$$CF = \frac{Eo}{Emis}$$

where Eo is the applied field strength and Emis is the indicated field strength

The correction factor data are permanently stored in the internal EEPROM.

Calibration equipment and traceability

ID Number	Description	Manufacturer	Model	Trace
PMM 391	Digital multimeter	Agilent	34401A	/SIT
CMR 169	Electric and Magnetic ref. Probe	Narda	EHP50C-REF	/INRIM
CMR 090	Standard resistor	Narda	PMM BSD250	/NPL
CMR 095	Current Trasformer	Frer	AP10-1TAC010	/INRIM
CMR 001	TEM Cell	Narda	1818	/Narda
CMR 020	Helmholtz coil	Narda	HCSS001	/Narda

Uncertainty of measurements

The statement of uncertainty (see first page) does not make any implication or include any estimation as to the long term stablity of the calibrated monitor. The relative expanded uncertainty result are given below

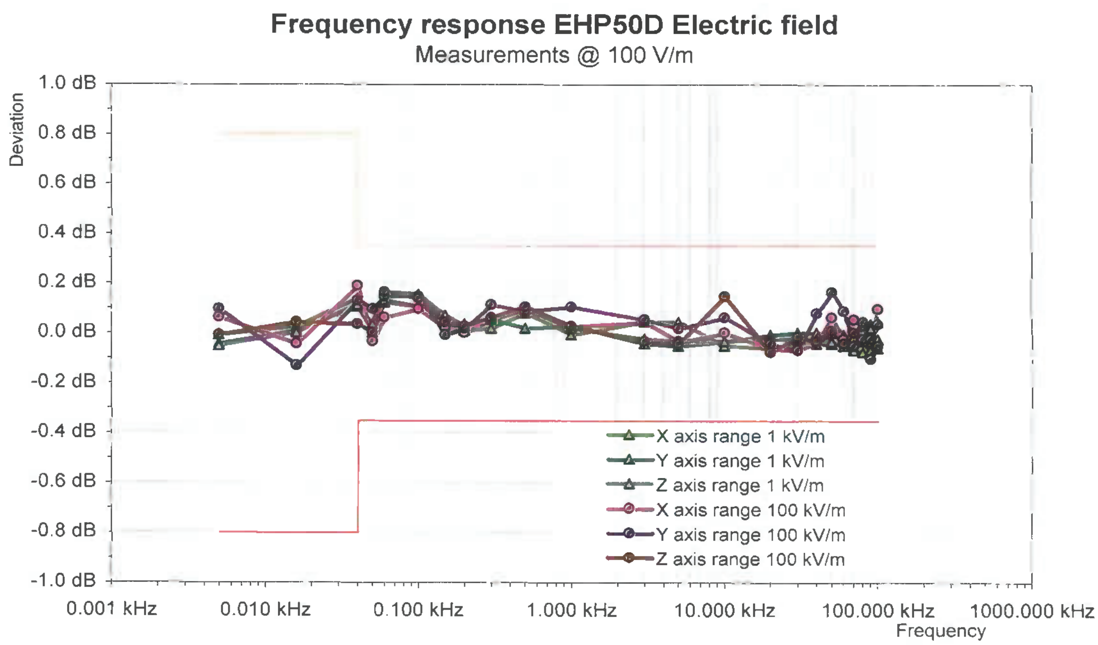
E field	3% at 50 Hz
	7.5% other frequencies
H field	2% at 50 Hz with 100μT range
	3.5% at 50 Hz with 10mT range
	3% other frequencies

Results

The results of measurements in the following pages were obtained after calibration data storing and indicates the residual of the reciprocal CF.
The results given on the tables were obtained with the axis aligned at the electric vector for electric measurements and with axis concatenated at the magnetic flux density for magnetic mesurements
The shown limits of the EHP50D specification in the diagrams are in orange.

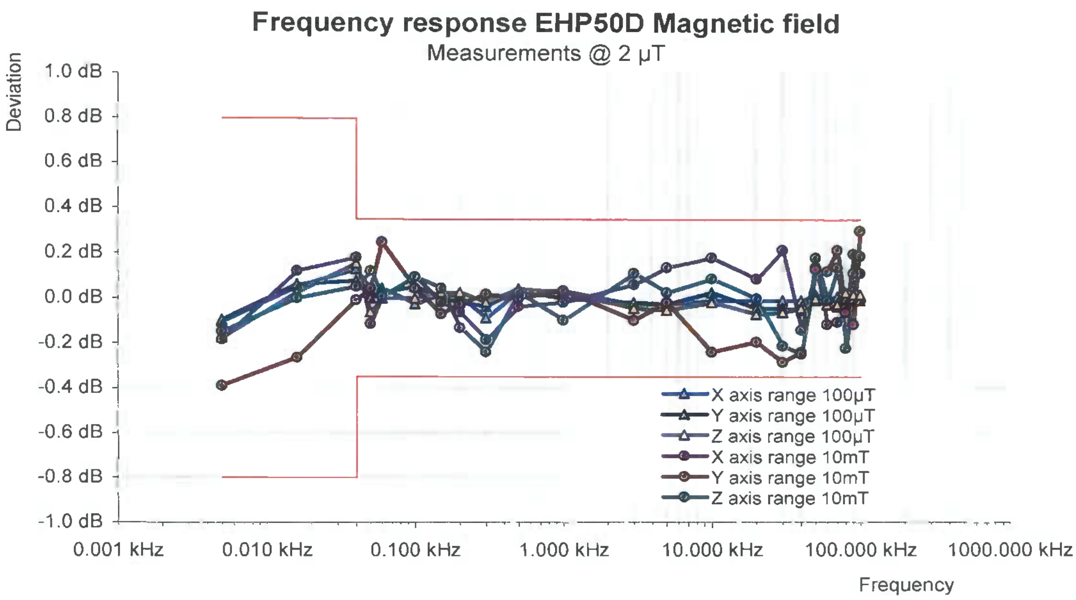
Electric field Frequency response for each axis at nominal field of 100 V/m.
The instrument was set as electric field measure with 100 Hz span up to the frequency of 100 Hz, 200 Hz span up to the frequency of 200 Hz, 500 Hz span up to the frequency of 500 Hz, 1 kHz up to 1000 Hz, 10 kHz up to 10 kHz and 100 kHz span for frequency over 10 kHz

Freq. (kHz)	Deviation with 1kV/m range			Deviation with 100 kV/m range		
	X axis	Y axis	Z axis	X axis	Y axis	Z axis
	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
0.005	-0.01	-0.04	-0.05	0.06	0.10	-0.01
0.016	0.03	0.01	0.00	-0.04	-0.13	0.04
0.04	0.14	0.10	0.11	0.19	0.13	0.03
0.05	0.02	0.00	0.03	-0.03	0.10	0.00
0.06	0.12	0.13	0.16	0.06	0.15	0.16
0.10	0.10	0.10	0.15	0.10	0.15	0.14
0.15	0.03	0.04	0.07	0.02	-0.01	0.04
0.20	0.01	0.03	0.03	0.00	0.02	0.03
0.30	0.02	0.05	0.06	0.05	0.11	0.06
0.50	0.08	0.02	0.10	0.10	0.09	0.10
1.00	-0.01	0.03	0.02	0.03	0.10	0.03
3.00	0.04	-0.04	-0.03	0.04	0.05	-0.03
5.00	0.04	-0.05	-0.03	-0.03	0.02	-0.04
10.00	-0.05	-0.03	-0.03	0.00	0.06	0.15
20.0	-0.06	-0.01	-0.03	-0.06	-0.04	-0.08
30.0	-0.04	0.00	-0.03	-0.07	-0.07	-0.02
40.0	-0.04	0.00	-0.03	-0.03	0.08	-0.03
50.0	-0.04	0.00	-0.03	0.06	0.16	0.01
60.0	-0.05	-0.01	-0.05	-0.03	0.09	-0.04
70.0	-0.06	-0.02	-0.07	0.05	-0.05	0.00
80.0	-0.08	-0.03	0.04	0.04	-0.03	0.04
90.0	0.03	-0.07	0.02	-0.02	-0.03	-0.10
100.0	-0.06	-0.03	0.04	0.10	0.03	-0.05



Magnetic Field Frequency response for each axis at nominal magnetic flux density of 2µT.
The instrument was set as magnetic field measure with 100 Hz span up to the frequency of 100 Hz, 200 Hz span up to the frequency of 200 Hz, 500 Hz span up to the frequency of 500 Hz, 1 kHz up to 1000 Hz, 10 kHz up to 10 kHz and 100 kHz span for frequency over 10 kHz

Freq. (kHz)	Deviation with 100µT range			Deviation with 10mT range		
	X axis	Y axis	Z axis	X axis	Y axis	Z axis
	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
0.005	-0.10	-0.10	-0.18	-0.18	-0.39	-0.15
0.016	0.05	0.06	0.03	0.12	-0.26	0.00
0.04	0.13	0.08	0.15	0.18	-0.01	0.05
0.05	0.03	0.00	-0.06	-0.11	0.04	0.12
0.06	0.04	0.03	0.00	0.01	0.25	0.01
0.10	-0.03	0.05	0.00	0.10	0.04	0.10
0.15	0.02	0.00	0.03	-0.02	-0.07	0.04
0.20	0.01	-0.02	0.03	-0.06	-0.03	-0.13
0.30	-0.09	-0.03	-0.02	-0.18	0.02	-0.24
0.50	0.03	0.03	0.04	-0.03	0.00	0.03
1.00	0.03	0.00	0.03	-0.02	0.03	-0.10
3.00	-0.03	-0.02	-0.04	0.06	-0.10	0.11
5.00	-0.03	-0.03	-0.05	0.14	-0.02	0.03
10.00	-0.01	0.03	-0.02	0.18	-0.24	0.09
20.0	-0.01	-0.04	-0.07	0.09	-0.19	0.00
30.0	-0.01	-0.04	-0.06	0.21	-0.28	-0.21
40.0	-0.01	-0.05	-0.04	-0.14	-0.24	-0.25
50.0	0.02	-0.01	0.00	0.14	0.13	0.18
60.0	0.00	0.00	-0.03	-0.11	0.12	-0.01
70.0	-0.03	0.01	-0.03	-0.10	0.21	0.14
80.0	-0.02	0.00	0.03	-0.04	-0.06	-0.22
90.0	-0.01	0.00	0.02	0.20	-0.11	0.11
100.0	0.01	-0.01	0.02	0.11	0.30	0.19

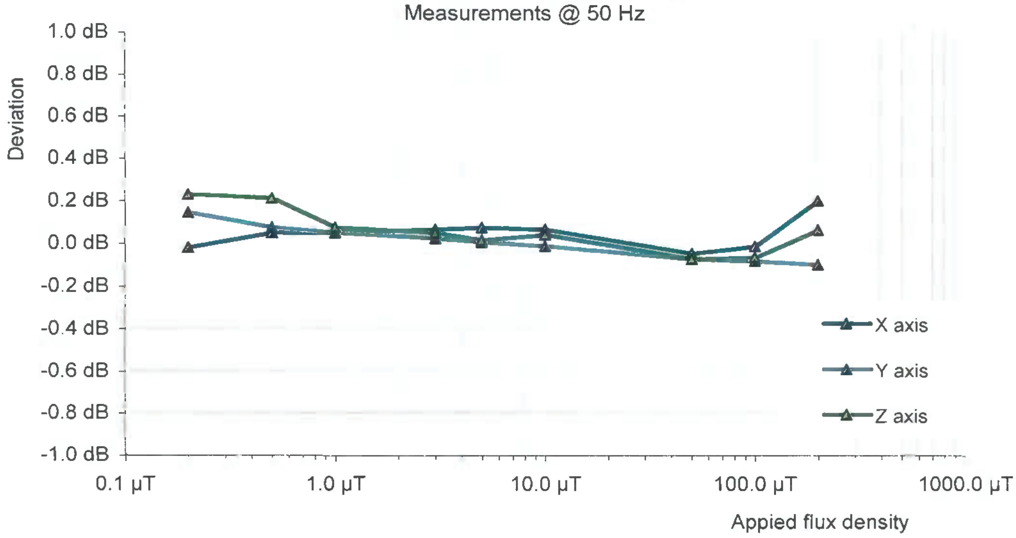


Magnetic Field Linearity response for each axis at applied frequency of 50 Hz and magnetic flux density below
The instrument was set with 100 Hz span.

Applied flux density (µT)	Deviation		
	X axis (dB)	Y axis (dB)	Z axis (dB)
0.2	-0.02	0.15	0.23
0.5	0.05	0.08	0.21
1.0	0.05	0.05	0.08
3.0	0.07	0.03	0.05
5.0	0.08	0.01	0.02
10	0.07	-0.01	0.04
50	-0.04	-0.07	-0.07
100	-0.01	-0.08	-0.06
200	0.21	-0.10	0.07

X axis linearity 0.12 dB
Y axis linearity 0.12 dB
Z axis linearity 0.15 dB

Linearity response EHP50D Magnetic field
Measurements @ 50 Hz



narda
Safety Test Solutions
an L3 Communications Company

Determining the Recalibration Due Date

Determinazione della data di ricalibrazione

The Certificate of Calibration accompanying this product states the date that this unit was calibrated according to Narda Safety Test Solutions procedures. We have determined that the calibration of this product is not affected by storage prior to its initial receipt by the customer.
The recalibration of this unit should be based on the date when the product is put into service, plus the recommended calibration interval.

The Narda Safety Test Solutions recommended calibration interval is 24 months. To determine the date for recalibration, the customer should use the appropriate start date, and apply either the Narda Safety Test Solutions calibration interval, or an interval that satisfies their own organization's internal quality system requirements.

Il certificato di taratura che accompagna questo strumento attesta la data di taratura, quest'ultima eseguita in accordo alle procedure interne. La Narda Safety Test Solutions assicura che la taratura dello strumento non viene alterata da eventuali tempi di attesa prima del ricevimento da parte del cliente.
La ri-taratura di questo strumento dovrebbe essere effettuata adottando appropriati intervalli di taratura, a partire dalla data di messa in servizio.

La Narda Safety Test Solutions raccomanda un massimo intervallo di taratura di 24 mesi. Per determinare la data di ri-taratura, l'utente dovrebbe considerare l'intervallo raccomandato dalla Narda Safety Test Solutions o un intervallo che soddisfa i requisiti interni di qualità della propria organizzazione.

Model
Modello ____________

Serial Number
Matricola ____________

Put into service date
Data di messa in servizio ____________

For additional information please contact
Per informazioni aggiuntive

Narda S.T.S. Calibration Laboratory
Via Benessea, 29/B
17035 Cisano sul Neva (SV) - Italy
Tel.: +39 0182 58641 Fax: +39 0182 586400

References

[1] Department of Communications, Marine and Natural Resources, “Health Effects of Electromagnetic Fields,” Dublin, Ireland, 2007.

[2] Health Protection Agency, “Ionising radiation and how we are exposed to it,” 04 09 2008. [Online]. Available: http://www.hpa.org.uk/Topics/Radiation/UnderstandingRadiation/UnderstandingRadiationTopics/RisksFromLowLevelsOfIonisingRadiation/risks_Exposure/. [Accessed 04 05 2012].

[3] WHO, “What is ionising radiation?,” 2012. [Online]. Available: www.who.int/ionizing_radiation/about/what_is_ir/en/index.html. [Accessed 04 05 12].

[4] M. Maslanyj, T. Mee and S. Allen, “Investigation and Identification of Sources of Residential Magnetic Field Exposures in the United Kingdom Childhood Cancer Study (UKCCS),” 2005.

[5] ICNIRP, “Guidelines for Limiting Exposures to Time-Varying Electric, Magnetic and Electromagnetic Fields (Up to 300 GHz),” *Health Physics,* vol. 74, no. 4, pp. 494-522, 1998.

[6] ICNIRP, “Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz to 100 kHz),” *Health Physics,* vol. 99, no. 6, pp. 818-836, 2010.

[7] EirGrid, “Information on Electric and Magnetic Fields,” Dublin, Ireland, 2007.

[8] ESB, “Electric and Magnetic Fields in the Environment,” Dublin, Ireland, 1999.

[9] J. Swanson, “Magnetic Fields From Transmission Lines: Comparison of Calculations and Measurements.,” *IEE Proceedings, Generation, Transmission and Distribution,* vol. 42, no. 5, pp. 481-486, 1995.

[10] R. Wilkinson and M. (. Marmot, “Social determinants of health: the solid facts. 2nd edition.,” World Health Organisation, Denmark, 2003.

[11] WHO, “Environmental Health Criteria 238. Extremely Low Frequency Fields,” WHO, 2007.

[12] WHO International Agency for Research on Cancer, “IARC Monoghraphs on the Evaluation of Carcinogenic Risks to Humans, Volume 80 Non-ionising Radiation, Part 1: Static and Extremely Low-Frequency (ELF),” IARCPress, 2002.

[13] UK Childhood Cancer Study, “Childhood Cancer and Residential Proximity to Power Lines,” *British Journal of Cancer,* vol. 83, no. 11, pp. 1573-1580, 2000.

[14] G. Draper, T. Vincent and J. Swanson, “Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case control study,” *British Medical Journal,* vol. 330, no. 7503, p. 1290, 04 06 2005.

[15] J. Swanson, T. Vincent, M. Kroll and G. Draper, “Childhood cancer and magnetic fields from high-voltage power lines in England and Wales: a case control study,” *British Journal of Cancer,* vol. 103, pp. 1122-1127, 2010.

[16] D. O'Sullivan, “A Review of Recent Investigations into the Possible Health Effects of Exposure to Electromagnetic Fields (EMF) from Power Lines,” Dublin Institute for Advanced Studies, 2011.

[17] International Commission on Non-ionizing Radiation Protection., “ICNIRP guidelines for Limiting Exposure to Time Varying Electric and Magnetic Fields (1 Hz 0 100 kHz),” *Health Physics,* vol. 99, no. 6, pp. 818-836, 2010.

[18] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), “Health Effects of Exposure to EMF,” European Comission, 2009.

[19] Health Protection Agency, “Power Frequency Electromagnetic Fields. Melatonin and the Risk of Breast Cancer. Report of an Independent Advisory Group on Non-ionising Ratiation.,” Health Protection Agency, 2006.

[20] A. Schüz and A. Ahlbom, “Exposure to Electromagnetic Fields and the Risk of Childhood Leukaemia: A Review.,” *Radiation Protection Dosimetry,* vol. 132, no. 2, pp. 202-211, 2008.

[21] J. Schüz, “Exposure to Extremely Low-Frequency Magnetic Fields and the Risk of Childhood Cancer: Update of the Epidemiological Evidence,” *Progress in Biophysics and Molecular Biology,* vol. 107, pp. 339-342, 2011.

[22] M. Otto and K. Ernst Von Muhlendahl, “Electromagnetic Fields (EMF): Do they play a role in Chldren’s Environmental Health (CEH),” *International Journal of Hygiene and Environmental Health,* vol. 210, pp. 635-644, 2007.

[23] A. Ahlbom, “A Pooled Analysis of Magnetic Fields and Childhood Leukaemia,” *British Journal of Cancer,* vol. 83, pp. 689-692, 2000.

[24] L. Kheifets, “Pooled Analysis of Recent Studies on Magnetic Fields and Childhood Leukaemia,” *British Journal of Cancer,* vol. 103, pp. 1128-1135, 2010.

[25] M. Maslanyj, J. Simpson, E. Roman and J. Schüz, “Power Frequency Magnetic Fields and Risk of Childhood Leukaemia: Misclassification of Exposure from the Use of the ‘Distance from Power Line’ Exposure Surrogate.,” *Bioelectromagnetics,* vol. 30, pp. 183-188, 2009.

[26] K. Bunch, T. Keegan, J. Swanson, T. Vincent and M. Murphy, “Residential distance at birth from overhead high-voltage powerlines: childhood cancer risk in Britain 1962-2008,” *British Journal of Cancer,* vol. 110, pp. 1402-1408, 2014.

[27] C. Pedersen, O. Raaschou-Nielsen, N. Rod, P. Frei, A. Poulsen, C. Johansen and J. Schüz, “Distance from residence to power line and risk of childhood leukemia: a population-based case-control study in Denmark,” *Cancer Causes and Control,* vol. 25, no. 2, pp. 171-177, 2014.

[28] L. Kheifets, C. Crespi, C. Hooper, M. Oksuzyan, T. Ly and G. Mezei, “Epidemiologic study of residential proximity to transmission lines and childhood cancer in California: description of design, epidemiologic methods and study population,” *Journal of Exposure Science and Environmental Epidemiology,* vol. Ahead of print, 2013.

[29] C. Sermage-Faure, C. Demoury, J. Rudant, S. Goujon-Bellec, A. Guyot-Goubin, F. Deschamps and J. Clavel, “Childhood leukaemia close to high-voltage power lines - the Geocap study, 2002-2007,” *British Journal of Cancer,* vol. 108, pp. 1899-1906, 2013.

[30] L. Zhao, L. Xiaodong, W. Chunpeng, Y. Kangkang, L. Xueiun, L. Shuang, B. Honghong and L. Xin, “Magnetic field exposure and childhood leukemia risk: a meta-analysis based on 11,699 cases and 13,194 controls,” *Leukemia Research,* vol. 35, no. 3, pp. 269-274, 2014.

[31] J. Swanson, “Residential mobility of populations near UK power lines and implications for childhood leukaemia,” *Journal of Radiological Protection,* vol. 33, no. 3, pp. 9-14, 2013.

[32] L. Kinlen, “Childhood leukaemia, nuclear sites, and population mixing,” *British Journal of Cancer,* vol. 104, pp. 12-18, 2011.

[33] C. Hegger and A. Reedjik, “Childhood leukaemia in a residential area with a high-voltage power line: approach according to the Dutch Community Health Services' guideline 'Cancer Clusters',” *Nederlands Tijdschrift voor Geneeskunde,* vol. 157, 2013.

[34] I. Baldi, G. Coureau, A. Gruber, A. Jaffre, S. Ducamp, D. Provost, P. Lebailly, A. Vital, H. Loiseau and R. Salamon, “Occupational and Residential Exposure to Electromagnetic Fields and Risk of Brain Tumours in Adults: A Case-Control Study in Gironde, France,” *International Journal of Cancer,* vol. 129, pp. 1477-1484, 2011.

[35] L. Kheifets, A. Ahlbom, C. Crespi, M. Feychting, C. Johansen, J. Monroe, M. Murphy, S. Oksuzyan, S. Preston-Martin, E. Roman, T. Saito, D. Savitz, J. Simpson, J. Schüz, J. Swanson, T. Tynes, P.

Verkasalo and G. Mezei, “A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors,” *American Journal of Epidemiology,* vol. 172, no. 7, pp. 752-761, 2010.

[36] L. Kheifets, D. Renew, G. Sias and J. Swanson, “Extremely Low Frequency Electic Fields and Cancer: Assessing the Evidence,” *Bioelectromagnetics,* vol. 31, pp. 89-101, 2010.

[37] SCENIHR, “Preliminary opinion on potential health effects of exposure to electromagnetic fields,” European Commission, Luxembourg, 2013.

[38] Australian Radiation Protection and Nuclear Safety Agency, “Electricity and health. Fact sheet 19,” Melbourne, Australia, 2011.

[39] Health Canada, “It's your health. Electric and magnetic fields at extremely low frequencies,” Ottawa, Canada, 2010.

[40] Swedish Radiation Safety Authority (SSM) Scientific Council on Electromagnetic Fields, “Eigth report,” SSM, Stockholm, 2013.

[41] D. McNamee, M. Corbacio, J. Weller, S. Brown, F. Prato, A. Thomas and A. Legros, “The Cardiovascular Response to an Acute 1800-μT, 60-Hz Magnetic Field Exposure in Humans,” *Int Arch Occup Environ Health,* vol. 83, no. 4, pp. 441-454, 2010.

[42] D. McNamee, M. Corbacio, J. Weller, S. Brown, R. Stodkilla, F. Prato, Y. Bureau, A. Thomas and A. Legros, “The response of the Human Circulatory System to an Acute 200- μT, 60-Hz Magnetic Field Exposure,” *Int Arch Occup Environ Health,* vol. 84, no. 3, pp. 267-277, 2011.

[43] A. Huss, A. Spoerri, M. Egger and M. Roosli, “Residence near power lines and mortality from neurodegenerative diseases: longitudinal study of the Swiss population,” *American Journal of Epidemiology,* vol. 15:169, no. 2, pp. 167-175, 2009.

[44] A. Maes and L. Vershaeve, “Can Cytogenetics Explain the Possible Association between Exposure to Extreme Low-Frequency Magnetic Fields and Alzheimer’s Disease,” *Journal of Applied Toxicology,* vol. 32, pp. 81-87, 2011.

[45] M. Corbacio, S. Brown, S. Dubois, D. Goulet, F. Prato, A. Thomas and A. Legros, “Human Cognitive Performance in a 3 mT Power-Line Frequency Magnetic Field,” *Bioelectormagnetics,* vol. 32, pp. 620-633, 2011.

[46] S. e. a. Nevelsteen, “Effects of Information and 50 Hz Magnetic Fields on Cognitive Performance and Reported Symptoms,” *Bioelectromagnetics,* vol. 28, pp. 53-63, 2007.

[47] ICNIRP, “Fact Sheet: On the guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz - 100 kHz),” *Health Physics,* vol. 99, no. 6, pp. 818-836, 2010.

[48] R. Stam, “Comparison of international policies on electromagnetic fields,” Laboratory for Radiation Research, National Institute for Public Health and the Environment, Bilthoven, The Netherlands, 2011.

[49] Government of the Republic of Slovenia, *The Decree on Electromagnetic Radiation in the Natural and Living Environment,* 1996.

[50] Ecofys Germany, “Study on the Comparative Merits of Overhead Electricity Transmission Lines Versus Underground Cables.,” 2008.

[51] The Swiss Bundesrat, “Ordinance on Protection from Non-Ionising Radiation,” 1999.

[52] WHO, *EMF World Wide Standards,* 2011.

[53] Union of the Electricity Industry - Eurelectric, *EMF Exposure Standards Applicable in Europe and Elsewhere,* 2003.

[54] DECC, “Power Lines: Demonstrating compliance with EMF public exposure guidelines. A voluntary Code of Practice,” Department of Energy and Climate Change, 2012.

[55] D. Gee, “Late Leesons from Early Warnings: Towards Realism and Precaution with EMF?,” *Pathophysiology,* vol. 16, no. 2-3, pp. 217-231, 2009.

[56] L. Kheifets, J. Swanson, S. Kandel and T. F. Malloy, “Risk Governance for Mobile Phones, Power Lines, and other EMF Technologies,” *Risk Analysis,* vol. 30, no. 10, pp. 1481-1494, 2010.

[57] M. Maslanyj, T. Lightfoot, J. Schüz, Z. Sienkiewicz and A. McKinlay, “A precautionary public health protection strategy for the possible risk of childhood leukaemia from exposure to power frequency magnetic fields,” BMC Public Health, 2010.

[58] M. Repacholi, “Concern that "EMF" magnetic fields from power lines cause cancer,” *Science of the Total Environment,* vol. 426, pp. 454-458, 2012.

[59] National Grid, “Raw data on fields from overhead lines and underground cables,” undated. [Online]. Available: http://www.emfs.info/Sources+of+EMFs/Overhead+power+lines/data/. [Accessed 20 March 2012].

[60] EirGrid, “EirGrid Grid Code Version 4.0,” EirGrid, Dublin, 2011.

The Oval,
160 Shelbourne Road,
Ballsbridge, Dublin 4.

Telephone +353 (0)1 677 1700
Fax +353 (0)1 661 5375
email info@eirgrid.com

www.eirgrid.com