8 ELECTRIC AND MAGNETIC FIELDS (EMF)

8.1 INTRODUCTION

1 Electric power is transmitted throughout the country of Ireland over an extensive electrical network that includes over 6,500km of high-voltage transmission lines from generation facilities to networks of medium and low voltage distribution lines.

2 This chapter describes the electric and magnetic fields (EMF) associated with the operation of the proposed development and focuses on topics referenced in public submissions. It describes the characteristics and background levels of EMF found in the everyday environment, and the projected effect of the new transmission circuit on EMF levels under and around the line.

3 The data and methods used to calculate levels of EMF from an existing transmission circuit (the part of the existing Oldstreet-Woodland 400 kV line installed on double circuit towers) and the proposed north-south transmission circuit are described. The EMF calculations for the various aspects of this project are provided in greater detail in **Section 8.7** Technical Calculations.

4 This chapter also discusses the criteria applied within Ireland and elsewhere in the European Union (EU) to assess the potential for any significant health or environmental impacts. The scientific weight-of-evidence process by which health and scientific agencies review and assess research is described and the conclusions of reviews by national and international agencies are summarised. Discussion of known effects from high-level short term exposures, and compliance of the proposed development with the guidelines that are established to prevent such effects are also discussed. To respond to questions from the public, a review of recent scientific research relating to EMF exposures to humans, animals, and plants whose exposures generally fall below these exposure criteria limits is provided. Notwithstanding the absence of any conclusions from health and scientific agencies that exposures to EMF at levels associated with the proposed project are harmful, a consideration of precautionary actions that address the concerns of some stakeholders including landowners and nearby residents is discussed and EirGrid’s response to these recommendations is noted.

5 Except for limited segments of the proposed route, the EMF calculations presented in this section describe the expected levels of EMF associated with the operation of the proposed transmission line for almost the entire route between the existing substation in Woodland, County Meath and the new terminal substation proposed in Turleenan, County Tyrone. More detailed information in respect to EMF levels in the vicinity of the remaining short sections of the alignment are set out in **Section 8.7** as well as in Chapter 5, **Volume 3C** of the EIS, in relation to the few spans of the transposition alignment in the Cavan Monaghan Study Area (CMSA)

and Chapter 5, **Volume 3D** of the EIS, in relation to the levels associated with the last 2.85km of the route that connects to the Woodland Substation in the Meath Study Area (MSA) on double-circuit towers.

8.2 OVERVIEW OF ELECTRIC AND MAGNETIC FIELDS

6 In our modern environment, people are surrounded by both natural and manmade sources of EMF. Natural sources include, for example, the earth's static magnetic field, which has been used for navigation for hundreds of years, and the electric fields present in the atmosphere due to air turbulence, which can increase to very high levels resulting in lightning during thunderstorms. Electricity is also an integral part of life, as brain and nerve functioning and movement of muscles and the heart are all the result of electric impulses. Various manmade sources include, for example, the electricity we use in our homes and radio waves used for communications purposes.

7 Electricity produces two types of fields—electric fields and magnetic fields. Electric fields are created by voltage potentials or differences in voltage between two locations or objects. The unit of measurement for electric field strength is volt per meter (V/m). The greater the potential between two points the higher the resulting electric fields. Higher electric field levels are expressed in kilovolts per meter (kV/m); where 1kV/m is equal to 1,000V/m. Typical electric field levels at ground level in fair weather are around 100V/m.

8 Magnetic fields are created by the flow of electric current (i.e. by the flow of electrical charges). Magnetic field strength is expressed by flux density and measured in units of Tesla (T). Levels of magnetic fields common in our environments are expressed in microtesla (μT); where 1,000,000μT is equal to 1T. The earth's magnetic field is approximately 50μT in Ireland. In some parts of the world, magnetic fields are expressed in units of milligauss (mG); where 10mG is equal to 1μT.

9 A common feature of electric and magnetic fields is that they both diminish quickly with distance from the source. One main distinction is that electric fields are effectively blocked by conducting objects—trees, shrubbery, fences, buildings, even the human body—while magnetic fields are not effectively blocked by conducting objects.

8.2.1 Electromagnetic Spectrum

10 Electromagnetic energy is characterised by frequency (i.e. the number of times electromagnetic energy changes direction and completes a full cycle per second). Frequency is expressed in hertz (Hz) or multiples of Hz, such as kilohertz (kHz), megahertz (MHz), or gigahertz (GHz). A related characteristic of electromagnetic energy is its wavelength, which is inversely associated

with frequency. Low frequency energy has a long wavelength, while high frequency energy has a short wavelength. The frequency and wavelength of electromagnetic energy are key factors in its interaction with objects and living things. The coupling of an electromagnetic field to an object is greatest when the wavelength of the field is similar to the size of the object. The electromagnetic spectrum includes frequencies from 0Hz (static fields associated with direct current (DC)) and the extremely low frequencies (ELF) of 3-300Hz[76] at the lower end, through radio waves and microwaves (frequencies in the several hundred kHz to MHz and GHz) and visible light, up to X-rays and gamma rays with frequencies of billions of Hz. The energy level of electromagnetic fields is dependent on the frequency and wavelength of the fields. High frequency fields have high energy and are able to ionise atoms, that is, they are able to dislodge electrons from their path around their atomic nucleus, potentially causing damage in living cells. Frequencies in the radio wave and microwave range (which is used, for example, in microwave ovens) may be able, at very high levels, to result in tissue heating. On the other hand, lower frequency fields, such as ELF EMF, have very little energy and have no ionizing or tissue heating effects.

11 On the electromagnetic spectrum, electric and magnetic fields associated with the power system are in the ELF range. Electricity, which is a source of electric and magnetic fields, is transmitted in the power system in Ireland primarily as alternating current (AC) at a frequency of 50Hz with a wavelength of approximately 6,000km. These ELF fields do not couple well to organisms because of their long wavelength. As a contextual reference, a radiofrequency field at a frequency of 800MHz, has a wavelength of 37cm, more similar to the diameter of the human body, which allows for more efficient coupling. At sufficiently high intensities, radio frequency energy in the very high frequency range can heat tissue, while ultraviolet light and higher frequency energy can damage cells directly. Electromagnetic energy with a low frequency and long wavelength, such as ELF EMF, needs to be considered separately from energy at these higher frequencies and shorter wavelengths when evaluating the potential health effects of interactions with living things.

8.2.2 ELF EMF Sources and Exposure Considerations

12 All components of the AC electric power system in Ireland and the rest of Europe that generate and transmit electricity, such as generating stations, substations, transmission and distribution lines, and domestic wiring, produce 50Hz ELF EMF. In addition, anything that uses electricity in our homes, schools, and workplaces (for example, household appliances, power tools, and

[76] The primary source of ELF fields in most environments is AC electricity supplied by the electric power system.

various types of electric equipment) is also a source of ELF EMF. Both electric and magnetic fields diminish quickly from the source. Electric fields are produced due to voltage potential between two points, even when there is no flow of electricity. For example, electric fields are present when an electric appliance is plugged in, even if it is not turned on. Magnetic fields are produced due to the flow of current; for example, an appliance needs to be turned on to produce a magnetic field. Electric fields are easily shielded or blocked by conductive objects, such as trees and other vegetation, and building materials. Consequently, indoor exposure to electric fields is largely dependent on indoor sources. Magnetic fields are not effectively shielded by conductive objects; therefore, even indoor exposure may be influenced by both indoor and outdoor sources. Magnetic fields are also easier to measure in practice. These are among the reasons that most of the EMF health research over the past 30 years has focused on magnetic fields rather than electric fields. In 2007, the World Health Organisation (WHO) concluded "*Following a standard health risk assessment process, the Task Group concluded that there are no substantive health issues related to ELF electric fields at levels generally encountered by members of the public*" (WHO, 2007a).

8.2.2.1 Background Levels

13 Electricity increasingly has become part of daily life over the past 100 years and modern life could not be imagined without it. Sources of common exposure are the wiring in homes and buildings, electrical appliances and equipment used in the home or in work environments, the transmission lines that carry electricity from generating stations to substations, and the distribution lines that deliver power locally.

14 Distribution lines have a lower voltage and carry less current, but are more common and can be a greater source of ELF EMF because of their closer proximity to homes than transmission lines. The equipment within substations is not a common source of exposure because EMF levels drop off quickly with distance, so the exposure levels at the fence lines around substations, generally, are at background levels (i.e. the levels typically measured at distances from all sources in one's environment). The dominant sources near substations are the power lines that connect to them.

15 There are no surveys of background levels of magnetic fields that have been conducted in Ireland, but several have been conducted in the United Kingdom. Since the power grid and household characteristics are similar to that of Ireland, the information is useful to evaluate typical background levels. The Health Protection Agency (HPA) estimates background magnetic field levels in the United Kingdom are between 0.01µT and 0.2µT. An evaluation of three studies in which spot measurements were recorded in 684 homes in Great Britain, computed a geometric mean magnetic field level of 0.038µT (Swanson and Kaune, 1999).

Based on limited data, they calculated that personal exposure of most persons is approximately 40% higher than these spot measurements, which is consistent with the HPA's determination.

8.2.2.2 Exposure from Appliances

16 The strongest sources of magnetic fields encountered indoors are electrical appliances, power tools, and other electrical equipment. While the intensity of these fields may diminish with distance from the source more rapidly than fields from transmission lines, they are nonetheless a very important contributor to a person's overall background magnetic field because of the proximity and frequency of use. Preece et al. (1999) sampled magnetic field levels of a variety of common appliances in 50 homes in the United Kingdom. Measurements were taken at a distance of 50cm using a procedure that best characterised exposure in normal use (see **Table 8.1**). In a separate analysis, Mezei et al. (2001) showed that domestic appliances may be substantial contributors to personal magnetic field exposures, particularly at higher exposure levels.

Table 8.1: Average Magnetic Field Level from Appliances Measured at 50cm

Appliance	Magnetic Field (µT)
Clock radio	0.05
Dishwasher	0.82
Electric shower	0.48
Microwave	1.65
Washing machine	1.00
Vacuum cleaner	0.78

Source: Preece et al., 1999, p. 73

8.2.2.3 Transmission and Distribution Lines

17 In outdoor environments, among the most common sources of magnetic fields are distribution and transmission lines. Since the intensity of magnetic fields diminishes quickly with distance from the source, however, the contribution to indoor magnetic field levels from transmission lines is usually not extensive or common as they are typically situated farther from buildings than distribution lines and other lower voltage sources. Magnetic field levels from transmission and distribution lines depend on the amount of current carried at any one time and the various engineering and design characteristics of the lines. In an AC transmission system, the amount of current (load) depends on customer demand, so magnetic field levels are commonly reported

at average load and peak load. Generally, peak load operates about 1% of the time and is about twice the level of average load (NIEHS, 2002).

18 Transformers and other equipment within substations are sources of magnetic fields, but, as mentioned above, they have little or no impact on exposure of the general public because experience indicates that EMF levels from substations "*attenuate sharply with distance and will often be reduced to a general ambient level at the substation security fencing. The exception is where transmission and distribution lines enter the substation"* (IEEE Std. 1127-1998). A survey conducted by the National Radiological Protection Board[77] in 2004 of representative local substations in the United Kingdom supports this conclusion (HPA, 2004). Magnetic field levels at enclosure boundaries overall were 1.1µT, while at distances of 5m to 10m outside the substation fence, the magnetic field was not detectable above between 0.02µT and 0.05µT. Consistent with the finding of the Institute of Electrical and Electronics Engineers (IEEE), along the path of cables entering the substation, the magnetic field was measured at 1µT. The National Grid in the United Kingdom conducted a similar survey of suburban substations. Magnetic field levels of 1.9µT diminished by more than half at 1.3m. In the vicinity of nearby housing at about 5m, the fields could not be distinguished from other background sources (HPA, 2004).

8.2.2.4 Personal Exposure

19 Each person's exposure to magnetic fields is determined by the environments where they spend time, the sources encountered in those environments, and the duration of exposure. Personal exposure during any given period may be characterised in several ways. For example, one can use measures of central tendency, such as mean and median; measures of peak exposures, such as the maximum levels, or fraction of time spent above certain exposure levels; or rate of change metrics, indicating how field levels fluctuate over time. Each of these exposure metrics are specific to the time period they represent, may change over time, and may rank the same individuals in different orders. Since it is not known which of these exposure metrics, if any, exerts any potential influence on biological processes and health, research studies most commonly describe and evaluate time-weighted average (TWA) exposures.

[77] The National Radiological Protection Board was merged into the Health Protection Agency of Great Britain in 2005 and the Health Protection Agency has since been folded into Public Health England in 2013.

20 Numerous exposure assessment methods have been developed to estimate personal exposure to magnetic fields. These methods include calculated historical fields based on transmission line characteristics near the subject's residence; wearing personal exposure meters by the study subjects; short term stationary, so called, spot measurements; wire code categories; residential distance to transmission facilities; and job-exposure matrices. The methods that use surrogates of actual magnetic field measurements—calculated historical fields, wire code categories, distance, and job exposure matrices—are commonly used in epidemiology studies of magnetic field exposure and health because participation of individuals is not required and data are easy and inexpensive to collect. These methods, however, are indirect and do not take into account all sources of exposure. In addition, it is often unclear whether the study subjects were actually exposed at the levels estimated.

21 Monitoring a person's personal exposure levels with a recording magnetic field meter is more accurate, but this type of measurement is often utilised for a short period (24 or 48 hours). This method will capture all magnetic field exposure from all sources while the meter is worn, but does not take into account short- or long term variations a person experiences from day to day or year to year, so may not fully represent past exposure (WHO, 2007b). This is especially problematic in studies of childhood diseases, when the children's exposure may be measured after disease development, long after the time period when the exposure may potentially be etiologically relevant.

22 Brief encounters with high magnetic field levels, such as while walking under a transmission line, in front of the refrigerator at home, or at a grocery store next to a freezer, would not significantly alter a person's TWA exposure because such a small amount of time is spent at these locations. On the other hand, an appliance such as a clock-radio on the nightstand in a bedroom, which produces a relatively weak magnetic field, may contribute more to a person's TWA exposure because of the many hours spent in bed. A failure to distinguish between spot measurements of magnetic fields at one location at one point in time and long term exposure from many sources over time is a common source of confusion when assessing environmental exposure levels (Bailey and Wagner, 2008).

8.3 ELECTRIC AND MAGNETIC FIELDS (EMF) FROM THE PROPOSED DEVELOPMENT

23 The portion of the proposed interconnector occurring within Ireland (referred to as the North-South 400 kV Interconnection Development – 'the proposed development') has been evaluated as one project, however, for the purposes of presenting the information in this EIS, it has been subdivided into two sections, the CMSA (**Volume 3C** of the EIS) and the MSA (**Volume 3D** of the EIS). For a full understanding of the development being proposed by EirGrid all volumes of this EIS and the Consolidated Environmental Statement (ES) should be read.

24 In addition to being addressed in this chapter of the EIS, EMF is addressed in Chapter 5, **Volumes 3C** and **3D** of the EIS. In the ES prepared by NIE, EMF is addressed in Chapter 7, **Volume 2** of the ES. A map of the proposed interconnector, highlighting the CMSA and MSA in Ireland, as well as the portion in Northern Ireland, is shown in **Figure 8.1**. Also highlighted in this figure are the proposed Turleenan Substation in County Tyrone and the existing Woodland Substation in County Meath.

25 The EMF from the proposed transmission development is determined by the particular configuration and tower-type used in different portions of the route rather than by reference to a particular study area. The discussion of the EMF from the proposed transmission line therefore is divided into these separate transmission line tower cases. Over the vast majority of the project route, the proposed transmission line will be supported on intermediate lattice towers, as shown in **Figure 8.2**. In short portions elsewhere along the route, the transmission line is proposed to be built in two additional configurations: Double-Circuit Lattice Towers in the MSA portion of the route and Single-Circuit Transposition Towers in the CMSA portion of the route. These configurations are discussed further in **Section 8.7** as well as in Chapter 5 of **Volumes 3C** and **3D** of the EIS, respectively.

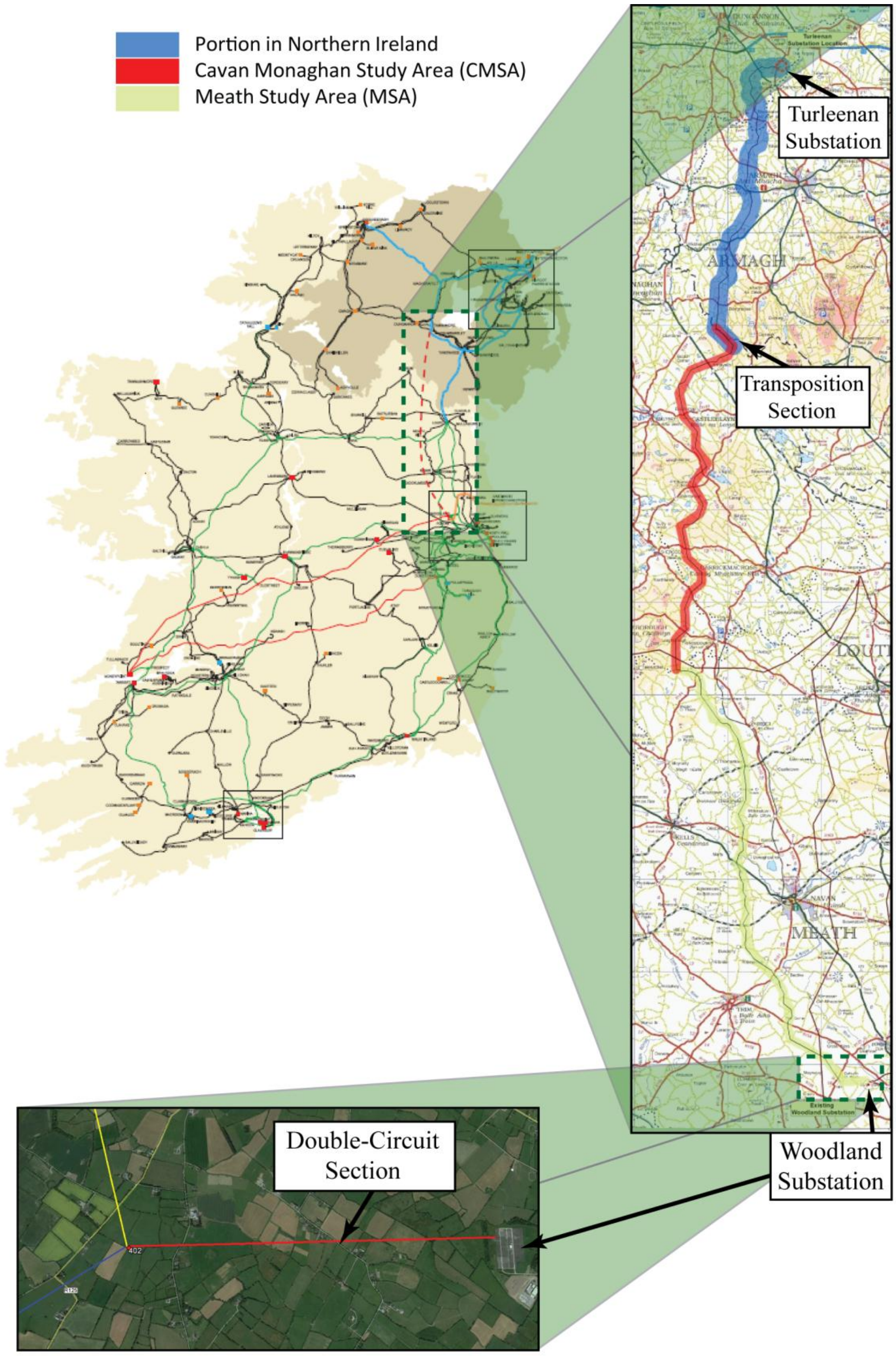

Figure 8.1: Map of the Proposed Interconnector Showing the Proposed Transmission Line Route

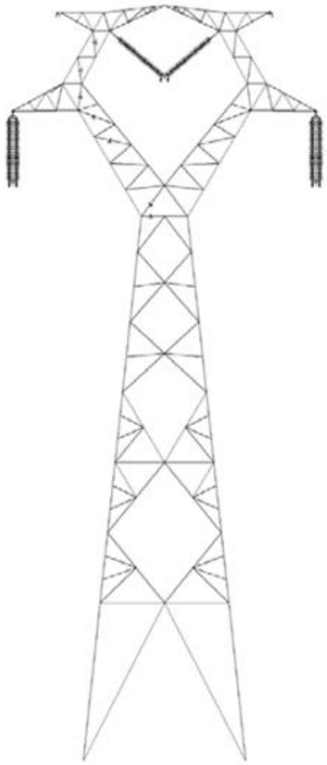

Figure 8.2: Intermediate 400 kV Lattice Towers for the Proposed Development

8.3.1 Magnetic Fields

26 The magnetic field associated with the Single-Circuit Intermediate Lattice Tower portion of the transmission line is shown in **Figure 8.3** for both average and peak loading[78]. The maximum magnetic field is calculated directly beneath the lines to be approximately 16μT at average loading. The magnetic field intensity diminishes with distance to about 1.0μT at a distance of 50m and to approximately 0.25μT at a distance of 100m from the centreline, a reduction by a factor of 64. Under peak loading conditions, the magnetic field levels will be higher. Peak loading is expected to occur rarely, perhaps only for a few hours per decade. Nevertheless, it is considered here in order to assess the conditions likely to produce the highest magnetic field

[78] The term 'average' loading used in this EIS is intended to convey the same meaning as 'indicative typical' loading used in the Consolidated ES.

levels[79] for the purpose of demonstrating that even in such emergency loading conditions of short duration, the proposed development will comply with applicable EMF guidelines. Under this rare scenario, the maximum magnetic field level beneath the line is calculated to be approximately 48μT, well below the restriction levels specified in the guidelines shown in **Table 8.2**. The maximum magnetic field level, as well as field levels at ±50m and ±100m from the centreline are shown in **Table 8.5** and **Table 8.6** in **Section 8.7** for average and peak loading, respectively.

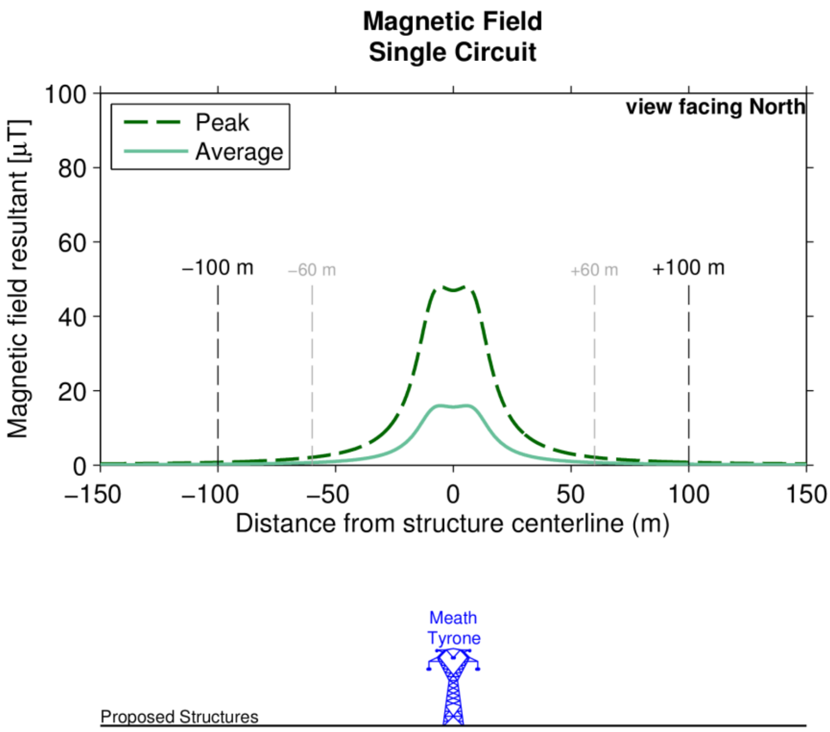

Figure 8.3: Calculated Magnetic Field Profile for the Proposed Intermediate Lattice Tower Configuration for Average and Peak Loading

[79] This scenario is the combination of a number of factors including 1,500MVA loading, 400 kV operating voltage and 9m minimum midspan conductor clearance. This is estimated to occur for only a few hours per decade, and only in limited locations.

8.3.2 Electric Fields

27 The electric field level associated with the Single-Circuit Intermediate Lattice Towers is shown in **Figure 8.4.** The maximum electric field levels beneath the transmission line is calculated to be approximately 7.9kV/m, and decreases to 0.20 kV/m at 50m, a 40-fold decrease, and below 0.04kV/m beyond approximately 100m from the transmission centreline, almost 200-fold lower than under the line. The electric field level is not directly affected by transmission line loading and results are presented for 400 kV operating voltage and 9m minimum midspan conductor height. The highest calculated electric field level, as well as field levels at ±50m and ±100m are shown in **Table 8.7** in **Section 8.7**.

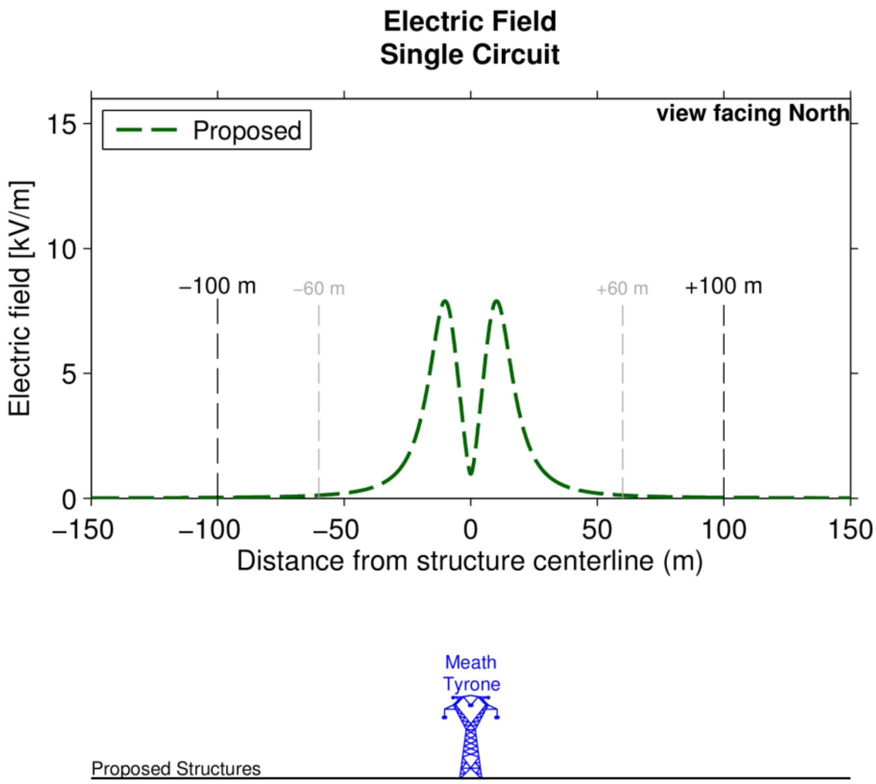

Figure 8.4: Calculated Electric Field Profile for the Proposed Intermediate Lattice Tower Configuration

8.4 COMPLIANCE WITH EXPOSURE GUIDELINES

8.4.1 Exposure Guidelines from International Organisations

28 International guidelines for both public and occupational exposure to ELF EMF were issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1998 and updated in 2010 (ICNIRP 1998, 2010). The EU used the 1998 guideline as the basis for guidelines on human exposure to ELF EMF from power sources that they incorporated into their recommendation for locations where people spend significant time (EU, 1999) and their directive on occupational exposure (EU, 2004). Numerous countries worldwide have also adopted or follow the ICNIRP guidelines. In Ireland, the Communications Regulator and the Commission for Energy Regulation have adopted the ICNIRP guidelines (DCMNR, 2007). A new directive on occupational exposure to ELF EMF, Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 which is based on the 2010 ICNIRP guidelines, has been passed by the EU.

29 In determining its guidelines, ICNIRP's main objective was "*to establish guidelines for limiting exposure to electric and magnetic field (EMF) that will provide protection against all established adverse health effects*." ICNIRP conducted a thorough weight-of-evidence review of the cumulative research at the time (in both 1998 and 2010) and concluded that the epidemiologic data were too weak and not sufficient to establish any guidelines. The evidence on chronic effects of long term exposures did not conclusively indicate that ELF EMF exposure contributed to any health effect, including cancer. They did determine, however, that short term, neurostimulatory effects could occur at very high field levels and established guidelines to protect against these effects, which include perception, annoyance, small electrical discharges (microshocks), and the stimulation of nerves and muscles. These responses to exposure are transitory and non-life threatening. To allow for uncertainties that may be present in scientific data, further reductions in limits by safety factors have also been applied when exposure guidelines were established. The ICNIRP guidelines are summarised in **Table 8.2**.

30 The International Committee on Electromagnetic Safety (ICES), which operates under the rules and oversight of the IEEE Standards Association Board, also published guidelines for limiting public exposure to ELF EMF (ICES, 2002). They also adjudged that evidence for effects from long term exposure to low levels of EMF was insufficient for setting an exposure standard. The reference levels for whole body exposure to 50Hz fields for the general public are presented in **Table 8.2**.

31 Both ICNIRP and ICES set limits on exposure based on the physical quantities directly related to the established health effects. These are internal doses, termed ‘basic restrictions’ that should not be exceeded. For EMF exposure, the basic restriction is specified in internal electric field strength. Since internal doses are difficult to measure directly, ICNIRP establishes and publishes ‘reference levels’ that set forth levels of environmental exposures that, if not exceeded, would guarantee that the basic restrictions are met. These basic restrictions are listed in **Table 8.2**. For comparison, maximum permissible exposures (MPE) recommended by ICES and exposure levels required to produce the basic restriction on internal electric fields are also included in **Table 8.2.**

32 If environmental exposures exceed the reference levels or MPE values that does not mean that the basic restriction is exceeded; rather additional dosimetric determination is needed. Both organisations incorporate large safety factors, that is, basic restrictions in the guidelines are set at levels well below levels where effects are known to occur. These safety factors are implied to account for scientific uncertainty, potential variability in the population, and a hypothesised greater likelihood of effects in susceptible populations.

8.4.2 EirGrid’s Compliance with Exposure Guidelines

33 EirGrid regards the protection of the health, safety, and welfare of its staff and the general public as a core company value in all of its activities. It is EirGrid’s policy to design and operate the network to the highest safety standards and to continually review and update its standards in light of new developments and research findings. EirGrid will continue to implement the following mitigation measures:

- Design and operate the transmission system in accordance with the most up-to-date EU recommendations and guidelines of the various independent authoritative international expert bodies;
- Closely monitor and support engineering and scientific research in this area, and;
- Provide information to the general public and to staff on the issue of ELF EMF.

34 In addition, EirGrid’s standard route planning criteria complies with all authoritative international and national guidelines for ELF EMF exposure and generally seeks to avoid heavily populated areas. Thus, the proposed line will be routed as far from existing homes as is reasonably possible.

35 EirGrid’s position on ELF EMF and health is based solely on the conclusions and recommendations of established national and international health and scientific agencies that have reviewed the body of literature. These panels have consistently concluded that the

research does not suggest that ELF EMF causes any adverse health effects at the levels encountered in our everyday environment and compliance with the existing standards from ICNIRP provides sufficient public health protection.

Table 8.2: General Public Reference Levels (ICNIRP) and Maximum Permissible Exposure (ICES) and Exposure Levels Estimated to Produce Internal Current Densities and Electric Fields Equal to Basic Restrictions at 50 Hz

Agency	Magnetic Field (µT)	Electric fields (kV/m)
ICNIRP (1998)		
Reference Level	100	5
Basic Restriction[a] exposure	364 [c]	9.22 [c]
ICNIRP (2010)		
Reference Level	200	5
Basic Restriction[b] exposure	412[c]/ 1242[f]	5.9 [c] /36.4[f]
ICES (2002)		
Maximum Permissible Exposure	904	5 or 10[d]
Basic Restriction[e] Exposure	915[f]	26.8[f]

[a] Basic Restriction is 2mA/[m2] in the head.

[b] Basic Restriction is 20mV/m in CNS of head.

[c] Calculated field levels from Dimbylow (2005).[d] ICES determined an exception of 10kV/m within transmission line rights-of-way because persons do not spend any significant amount of time here and very specific conditions are needed for a response to occur (ICES, 2002, p. 27).

[e] Basic Restriction is 14.7mV/m in the brain.

[f] Field levels calculated from Kavet et al (2012).

8.5 ELF EMF HEALTH RESEARCH

36 Research on potential health effects related to ELF EMF has been conducted for several decades. Studies prior to the 1970s mostly focused on direct effects of short term exposures, the basic nature of ELF EMF, and its interaction with the human body. Concerted research effort on potential health effects of low level, long term exposure to ELF EMF started following the publication of an epidemiology study that suggested a statistical association between childhood cancer and distribution power line characteristics near the children's homes (Wertheimer and Leeper, 1979). This study was followed by a large number of publications in the peer-reviewed scientific literature on various aspects of potential health effects of ELF EMF. The ensuing studies include numerous epidemiology studies on various health outcomes among both adults and children—cancers and non-cancerous diseases, such as heart disease and reproductive effects—and consider various degrees of residential, occupational, and

environmental exposure to ELF EMF. The published ELF EMF literature also includes a large number of experimental studies of both humans and laboratory animals (in vivo studies) and studies of potential effects on cells and tissues (in vitro studies). Over the past four decades, potential effects of ELF EMF on a number of health endpoints were suggested, but to date no causal link has been confirmed with any health outcome.

8.5.1 The Weight of Evidence Review Process

37 Scientific agencies and organisations have developed standard scientific methods to guide systematic evaluations of research and promote unbiased assessments of potential risk for developing exposure limits to protect human health (NRC, 1983; HCN, 2009, Section 3; IARC, 2002, preamble; ICNIRP, 2003; USEPA, 2005; S SCENIHR, 2009b, SCENIHR, 2012, 2013. Adherence to standard scientific methods helps to minimise or eliminate subjectivity in the evaluation and interpretation of scientific data. These methods require a systematic identification of relevant peer-reviewed literature[80] including epidemiology studies in humans, studies in laboratory animals (in vivo), and studies in cells and tissues (in vitro). Each identified study then needs to undergo a systematic review to assess the quality of study design and methods of analysis and evaluation. Flaws in the design or completion of a study may affect its reliability. Since no study is perfect, more weight is given to studies of higher quality—thus, the term weight-of-evidence review.

38 For proper health risk assessments, national and international scientific and health agencies put together multidisciplinary panels of scientists with the relevant expertise (e.g. epidemiology, neurophysiology, exposure assessment, and toxicology) to conduct weight-of-evidence reviews. Each of the three types of research studies has complementary strengths and limitations, thus the integration of the results of the different approaches are important in weighing evidence by the expert panels. While epidemiology studies are conducted in the species of interest (humans), they tend to be limited due to their observational nature and because they are not conducted under controlled exposure conditions. In vivo studies are valuable because they are conducted under controlled exposure conditions, and often are designed to include high levels of exposures frequently well above levels to which people are exposed; however, they result in some scientific uncertainty since the predictive value of extrapolating animal data to human health effects may vary. In vitro research is conducted to determine the potential mechanism

[80] The inclusion of peer-reviewed studies ensures that they have already passed a quality control review. Scientific journals typically have manuscripts reviewed by two or more experts in the field in addition to members of the editorial board to scrutinise for scientific merit and appropriateness of study design, analytical methods, and presentation of results prior to publication. While peer review is one measure to ensure that papers with inappropriate methods or flawed conclusions are screened out, publication of a paper in a peer-reviewed journal by no means guarantees the overall validity of the published study. The system of peer review has its limitations, and, in fact, true peer review in a wider sense starts with the publication of the scientific manuscript (Poole 1996; Bohannon, 2013).

for an adverse effect. It is, however, difficult to directly extrapolate results from in vitro studies to what actually would occur in the human body, as in vitro studies are not able to consider the body's overall compensatory and regulatory mechanisms.

39 Conclusions by multi-disciplinary review panels are reached considering the cumulative body of research, giving more weight to studies of higher quality. The conclusions of these reviews typically represent a consensus opinion of the experts participating in the panel.

8.5.2 The Weight of Evidence Evaluation of Carcinogenicity

40 The International Agency for Research on Cancer (IARC) is an agency of the WHO and is considered the primary organisation for cancer risk assessment. IARC regularly and systematically reviews various physical and chemical agents and exposure scenarios, such as various occupations, to determine their potential for carcinogenicity in humans. In their evaluations, IARC considers two main streams of evidence—epidemiology and laboratory animal (in vivo) studies. IARC also considers studies in cells and tissues (in vitro studies) to provide additional input on potential mechanism of effects, and exposure assessment studies to better understand potential impacts of the exposure in our daily life.

41 The IARC process applies a weight-of-evidence review to evaluate potential risk, which first includes classification of the evidence obtained from epidemiology and in vivo studies into one of the following categories.

- The evidence is considered *sufficient* when a causal relationship can be established between exposure and cancer; in epidemiology studies, a positive relationship has been observed between the exposure and cancer in studies in which chance, bias, and confounding could be ruled out with reasonable confidence; and for in vivo studies, increased incidence of cancer was observed in high quality studies in at least two species or from two independent laboratories.

- The evidence is *limited* if a credible positive association is observed but chance, confounding, or bias could not be excluded as explanations in epidemiology studies, and if the association is limited to one experiment or there are unresolved questions regarding adequacy of design features in laboratory animal studies.

- The evidence is *inadequate* if there is insufficient quality, consistency, or statistical power in epidemiology studies, and if there are major qualitative or quantitative limitations or lack of data from *in vivo* studies. In vitro research provides ancillary information and, therefore, is used to a lesser degree in evaluating carcinogenicity and is classified simply as strong, moderate, or weak.

42 Based on the above assessments, the agents are then classified into five overall categories (listed from highest to lowest risk): (1) carcinogenic to humans, (2) probably carcinogenic to humans, (3) possibly carcinogenic to humans, (4) not classifiable, and (5) probably not carcinogenic to humans. The category “possibly carcinogenic” typically denotes exposures for which there is limited evidence of carcinogenicity in epidemiology studies, and in vivo studies provide limited or inadequate evidence of carcinogenicity. IARC has reviewed over 900 substances and exposure circumstances to evaluate their potential carcinogenicity. Over 80% of exposures fall in the categories possibly carcinogenic (29%) or not classifiable (52%). This occurs because in science it is nearly impossible to prove the absence of an effect (i.e. that something is completely safe). Few exposures show a clear-cut or probable risk, so most agents will end up in either of these two categories. Throughout the history of the IARC, only one agent has been classified as probably not carcinogenic to humans, which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

8.5.3 Weight-of-evidence Reviews of ELF EMF Health Studies

43 Over the years, numerous reviews were performed to thoroughly evaluate and synthesize available scientific evidence on whether exposure to ELF EMF may result in potential adverse health effects. These reviews were performed periodically by multidisciplinary expert panels of national and international scientific and governmental health organisations and followed the weight-of-evidence review process that considers and weighs the available evidence in the respective scientific area. These weight-of-evidence evaluations guide future research priorities, lead scientific organisations to recommend limits and guidelines, and assist governmental organisations to establish regulations to reduce or limit exposure that may result in adverse effects.

8.5.3.1 Conclusions of International Review Bodies

44 In the past decade, weight-of-evidence reviews of the ELF EMF health research literature have been conducted by a number of international and national expert panels, including those by the IARC, WHO, and ICNIRP.

45 IARC evaluated the ELF EMF literature for carcinogenicity in 2001 (IARC, 2002). Overall, ELF magnetic field exposure was classified in the 2B category as ‘possibly carcinogenic to humans’, based on limited evidence from childhood leukaemia epidemiology studies and inadequate evidence from laboratory animal studies. The IARC conclusion was heavily influenced by two pooled analyses that combined and analysed data from available childhood leukaemia epidemiology studies (Ahlbom et al., 2000; Greenland et al. 2000). While the pooled analyses showed a statistical association, neither in vivo laboratory studies including lifetime rodent

bioassays, nor mechanistic studies provided any support for a carcinogenic effect. Evidence for all cancers, other than childhood leukaemia, was considered inadequate for ELF magnetic fields as was evidence for all cancers with respect to ELF electric fields.

46 The Environmental Health Criteria (EHC) published by the WHO in 2007 contains a weight-of-evidence evaluation of the scientific literature relevant to potential effects of ELF EMF on both cancer and non-cancer human health outcomes. For ELF electric fields at the levels generally encountered by members of the public, the EHC concluded that there are no substantive health issues and did not recommend future epidemiologic research related to electric fields.

47 With respect to ELF magnetic fields and cancer outcomes, the EHC concluded that recent studies did not change the IARC classification of ELF magnetic fields as ‘possibly carcinogenic’ based on limited epidemiologic evidence and inadequate evidence from in vivo studies. The WHO panel recognised the statistical association between childhood leukaemia and estimates of exposure to high levels of magnetic fields, but could not rule out the possible effect of other factors (chance, bias, and confounding) on these results. Thus, when limited epidemiologic data were considered along with the largely negative findings from experimental studies, the WHO panel stated that the cumulative evidence was not strong enough to conclude that magnetic fields are a known or probable cause of childhood leukaemia. For all other cancers and non-cancer health endpoints, including potential effects on the neuroendocrine system, reproductive effects, and neurodegenerative diseases, the available evidence were deemed inadequate. For cardiovascular diseases and breast cancer specifically, the EHC concluded that the evidence does not support an association with ELF magnetic fields.

48 ICNIRP, in its 2010 review, concluded that there are well-established acute effects of exposure to ELF EMF due to direct stimulation of nerves and muscles, induction of retinal phosphenes, and surface electric charges. Guidelines are set accordingly to prevent these effects. ICNIRP, however, in agreement with conclusions from IARC and WHO, also concluded that other than the limited epidemiologic evidence from studies of childhood leukaemia and ELF EMF, the evidence for other diseases are inconclusive or not in support for a potential causal association. With respect to the childhood leukaemia literature they conclude that “*the currently existing scientific evidence that prolonged exposure to low frequency magnetic fields is causally related with an increased risk of childhood leuk[a]emia is too weak to form the basis for exposure guidelines*.”

49 Likewise, none of the additional recent reviews of the scientific literature, conducted by the European Commission's (EC) Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR, 2009a, 2013), the European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN, 2010a), the National Radiological Protection Board of Great Britain (NRPB, 2004), the Health Council of the Netherlands (HCN, 2009), and the Swedish Radiation Protection Authority (SSM, 2013), concluded that magnetic fields are not a known, probable, or even a likely cause of any adverse health effect at the long term, low exposure levels found in the everyday environment.

50 In summary, the national and international agencies with the responsibility for protecting the health of persons in Ireland, Europe, and other countries have stated that the evidence does not indicate that ELF EMF causes any adverse health effect. They recognise that the main source of uncertainty lies with a weak but consistent association observed in some epidemiology studies that has not been confirmed or explained in experimental studies. They all recommend further well-designed research studies and continue to monitor the research and re-examine their positions periodically as new data become available.

8.5.3.2 Expert Group Evaluation of ELF EMF Health Studies for Ireland

51 The Irish Department of Communications, Marine and Natural Resources assembled an expert group in 2007 that reviewed the evidence on ELF EMF and health effects. The conclusions of this group were consistent with the conclusions noted above:

> *"There is limited scientific evidence of an association between ELF magnetic fields and childhood leukaemia. This does not mean that ELF magnetic fields cause cancer, but the possibility cannot be excluded. However, considerable research carried out in laboratories has not supported this possibility, and overall the evidence is considered weak, suggesting it is unlikely that ELF magnetic fields cause leukaemia in children. Nevertheless the evidence should not be discounted and so no or low cost precautionary measures to lower people's exposure to these fields have been suggested*" (DCMNR, 2007, p. 3).

52 The report answers many questions commonly raised by the public in relation to EMF and health. The report confirms that the EU (1999) guidelines have been adopted by the Communications Regulator and the Commission for Energy Regulation in Ireland. One of the important points addressed in this report clarifies that "*the ICNIRP limit values apply to all exposure situations, including long-term exposures"* (DCMNR, 2007, p. 20).

8.5.3.3 Reviews of ELF EMF Health Studies by Other Groups

53 A few other groups that reviewed the literature have reached differing conclusions. For example, one review and risk evaluation was conducted by three scientists from the California Department of Health Services (CDHS) in 2002. They expressed a 'degree of certainty' as to whether the increased risks of certain diseases due to exposure to ELF EMF are 'real'. Another review was conducted by a self-organised group of individuals from academic institutions and public interest groups. They were collectively called the BioInitiative Working Group and they published their report in 2007 and updated it in 2012. The conclusion of both of these reviews differed from the previously described weight-of-evidence reviews, and suggested that in addition to childhood leukaemia, a number of other health outcomes are linked to ELF EMF exposure. While the CDHS study was completed by scientists at a government health agency, the BioInitiative reports are a self-organised effort and were not sanctioned by any professional or scientific organisation. These reviews, particularly the BioInitiative reports, did not follow the weight-of-evidence approach and attributed importance mostly or only to studies showing some effect and discounted those that did not. These reviews also differed from previous reports in that the conclusions were not developed as consensus opinions, but were opinions of individual authors.

8.5.4 Epidemiology Research into Potential Association between ELF EMF and Childhood Cancer

54 In 1979, Wertheimer and Leeper published the first epidemiology study to suggest a statistical association between childhood cancer and residential proximity to power lines, indicating that case children with leukaemia or brain tumour lived in homes with higher 'wire configuration codes' than did healthy control children.[81]

55 Some of the subsequent epidemiology studies on childhood leukaemia have shown great improvements in methodology of case ascertainment, control selection, exposure assessment, and analytical techniques. Exposure assessment in these studies included distance and calculated magnetic fields from power lines, short term and long term measurements in homes, and personal exposure measurements. When a number of relevant studies were combined in a single analysis, no association was evident at lower exposure levels, but small differences in the proportion of children with and without leukaemia that had average magnetic field exposure

[81] Wire configuration code is a classification system developed by the authors based on proximity and type of power lines in the vicinity of the children's residences.

greater than 0.3-0.4µT suggested a possible relationship or association (Ahlbom et al., 2000; Greenland et al., 2000). However, because of the inherent uncertainty associated with observational epidemiology studies, the results of these pooled analyses were considered to provide only limited epidemiologic support for a causal relationship. Various hypotheses were developed to explain the apparent statistical association (e.g. Fews et al., 1999), but none were considered likely or were supported by consequent epidemiology studies. Chance, bias, and confounding could not be ruled out with reasonable confidence. Further, in vivo studies (summarised in **Section 8.5.7**) have not found that magnetic fields induce or promote cancer in animals exposed for their entire lifespan under highly-controlled conditions, nor have in vitro studies (summarised in **Section 8.5.8**) found a cellular mechanism by which magnetic fields could induce carcinogenesis.

56 More recent epidemiology studies of childhood leukaemia have not materially changed the overall evidence. In 2010, Kheifets and colleagues conducted a pooled analysis of childhood leukaemia studies published between 2000 and 2010 to evaluate if more recent studies provide new insight regarding the nature of the association. While it also showed a positive association at exposure levels above 0.3 and 0.4µT, the association was statistically not significant and weaker than in the Ahlbom et al. (2000) and Greenland et al. (2000) pooled analyses. A recent meta-analysis (Zhao et al., 2013), that relied upon reported numbers of cases and controls in nine case-control studies published between 1997 and 2013, indicated a statistical association with exposure above 0.4 µT. The analysis, as it relied on published numbers and not on individual data from the original studies, provided little new insight following the publication of the earlier pooled analyses.

57 Several recent epidemiology studies examined residential proximity to power lines and childhood leukaemia risk, but overall provided no new evidence for an association. Sermage-Faure et al. (2013) reported on residential proximity to high voltage transmission lines and childhood leukaemia development using geocoded information on residential addresses of childhood leukaemia cases and controls and power line locations in France. Overall no association was observed between childhood leukaemia risk and residential proximity to high voltage transmission lines. The authors, however, also reported a statistically not significant association in a sub analysis within 50m of 225-400 kV lines based on a small number of cases (n=9). Pedersen et al. (2014) conducted a similar study in Denmark including 1,698 childhood leukaemia cases and 3,396 healthy control children; the authors reported no statistically significant association between risk and residential proximity to 132 kV, 220 kV, and 400 kV power lines. In the largest study to date, Bunch et al. (2014) provided an extension and update to the 2005 UK study by Draper et al. The authors extended the study period by 13 years (1962-2008), included lower voltage lines (132 kV) in addition to 275 /400 kV lines, and included Scotland in addition to England and Wales in their analyses. Bunch et al. included over 53,000 childhood cancer cases and over 66,000 healthy control children and reported no overall

association with residential proximity to 132 kV, 275 kV, and 400 kV power lines for leukaemia or any other cancer among children. The statistical association with distance that was reported in the earlier Draper et al. (2005) study was not apparent in the extended analysis.

58 Another recent pooled analysis by Schüz and colleagues (Schüz et al., 2012) followed up on suggestions from earlier studies (Foliart et al., 2006, Svendsen et al., 2007) that exposure to ELF magnetic fields may promote growth of leukaemia cells and thus affect survival of children diagnosed with leukaemia. The Schüz et al. pooled analysis combined data on more than 3,000 cases of childhood leukaemia from Canada, Denmark, Germany, Japan, the United Kingdom, and the United States. Based on their results the authors concluded that exposure to ELF magnetic fields had no impact on the survival probability or risk of relapse in children with leukaemia. A study by Yang et al. (2008) assessed the genetic variation of five genes among children with leukaemia in Shanghai, China, living in the vicinity of power lines and transformers. In addition, as it has been discussed by Ioannidis et al. (2011), genetic epidemiology is particularly prone to reporting false positive associations, that is, associations that are not replicated in follow-up investigations. This is primarily due to the large number of potential genes that could be tested.

59 Unlike childhood leukaemia, no consistent associations were reported for childhood brain cancer in epidemiology studies. Both the IARC and WHO assessments concluded that the evidence for an association with childhood brain cancer is inadequate. Nevertheless, the WHO EHC recommended that, similar to the childhood leukaemia pooled analyses, a pooled analysis of available childhood brain cancer epidemiology studies also be conducted. A pooled analysis following up on this recommendation in 2010 (Kheifets et al., 2010b) included primary data from 10 studies on a total of over 8,000 children diagnosed with a brain tumour. No consistent risk increase or exposure-response relationship was observed regardless of the type of exposure metrics, cutpoints, adjustment for confounders, exclusion of particular studies, and analytical methods used.

8.5.5 Epidemiology Research into Potential Association between ELF EMF and Diseases in Adults

8.5.5.1 Breast Cancer

60 Breast cancer is the most common cancer among women in industrialised countries; thus a potential relationship with ELF EMF would have a significant public health impact. Interest in

ELF EMF and breast cancer research was further motivated by a hypothesised biological mechanism operating through the melatonin pathway.[82] It was proposed by Stevens (1987) that exposure to ELF magnetic fields may decrease production of night-time melatonin, a pineal gland hormone with tumour suppressor effects, and suppression of circulating melatonin levels was hypothesised to increase the risk of breast cancer.

61 Some observational studies in humans reported associations between decreased melatonin metabolite excretion in urine and ELF EMF exposure, particularly in certain subgroups of people. Human laboratory studies, however, were not able to consistently confirm these findings. Overall the WHO EHC concluded that available data do not indicate that ELF EMF has an effect on the neuroendocrine system.

62 Epidemiology studies of ELF EMF and breast cancer examined potential effects of residential exposure (residential proximity to power lines, estimated fields in homes), electric blanket use, and occupational exposures. While in the earlier studies there were suggestions of risk increases in subgroup analyses, more recent studies with large sample sizes, improved exposure assessment methodologies, and less potential for bias weakened the evidence for an association. In 2007, the WHO evaluation concluded that with the addition of the newer studies the evidence does not support an association between ELF EMF and breast cancer. Other scientific organisations have similarly concluded that there is strong evidence in support of no relationship between magnetic fields and breast cancer or magnetic fields and cardiovascular disease (WHO, 2007b; SSI, 2008; ICNIRP, 2010; EFHRAN, 2010a; SSM, 2010). Three recent large and well-conducted epidemiology studies of both residential (Elliott et al., 2013) and occupational exposure (Li et al., 2013, Koeman et al., 2014) to ELF magnetic fields confirmed the lack of an association with female breast cancer.

8.5.5.2 Adult Leukaemia and Brain Cancer

63 Adult leukaemia and brain cancer are among the most studied diseases in ELF EMF epidemiology. After reviewing a large number of residential and occupational epidemiology studies, both IARC and WHO concluded that the evidence linking adult leukaemia and brain cancer to ELF EMF is inadequate. Results from neither *in vivo* nor *in vitro* experimental studies, nor mechanistic considerations, provide any support for a carcinogenic effect. Although some research questions remain, the epidemiologic evidence does not support a cause-and-effect

[82] Melatonin plays a primary role in the diurnal cycle. Melatonin production is suppressed by light during the day and increased in the dark at night. With age, nocturnal melatonin production gradually decreases, sometimes to very low levels. In addition to light, which is the main determinant of melatonin production, lifestyle and dietary factors (e.g. tryptophan and alcohol) may also modify circulating melatonin levels.

relationship between magnetic fields and adult leukaemia or brain cancer (WHO, 2007b; SCENIHR, 2009a, 2013; EFHRAN, 2010).

64 Of note is a recent updated meta-analysis (Kheifets et al., 2008), conducted in response to recommendations in the WHO EHC, which combined relevant published studies on occupational ELF EMF exposure and adult leukaemia and brain cancer. While a small statistically significant increase of leukaemia and brain cancer in relation to the highest estimate of magnetic field exposure in the individual studies was observed, the authors concluded that "*the lack of a clear pattern of EMF exposure and outcome risk does not support a hypothesis that these exposures are responsible for the observed excess risk"* (Kheifets et al., 2008, p. 677).

65 The recent large case-control study of residential ELF EMF exposure and adult cancer in the United Kingdom (Elliott et al., 2013) and a large cohort study of occupational ELF EMF exposure and adult cancers in the Netherlands (Koeman et al., 2014). In another recent study, Sorahan (2012), examining cancer incidence in a cohort of 81,842 electricity generation and transmission workers, reported no excess risk of leukaemia or brain cancer with estimated occupational exposure to ELF EMF.

66 Turner et al. (2014) examined the relationship between occupational ELF EMF exposure and brain cancer in a large international case-control epidemiologic study. While the authors reported both an increase (with exposure 1-4 years prior to diagnosis) and a decrease (with the highest maximum exposure) in associations with brain cancer in some of the sub-analyses, overall there was no association with lifetime cumulative or average exposure for either main types of brain cancer (glioma or meningioma).

8.5.5.3 Other Adult Cancers

67 A number of other cancers, such as prostate, pancreatic, lung, kidney, and testicular cancers, were also investigated in relation to ELF EMF exposure. The associations, however, remain sporadic and largely inconsistent providing no basis for an association with ELF EMF exposure.

8.5.6 Potential Non-cancer Outcomes

68 In addition to various cancer types, scientists have investigated a number of non-cancer health outcomes in relation to ELF magnetic field exposure. Among those are cardiovascular disease, reproductive outcomes, neurodegenerative disease, and electromagnetic hypersensitivity.

8.5.6.1 Cardiovascular Disease

69 According to a proposed hypothesis, ELF EMF may affect heart rate variability, which is considered to be a risk factor for heart disease and acute cardiac death (Sastre, 1999). In some laboratory studies of human volunteers, ELF magnetic field exposure was associated with decreased heart rate variability (Sastre et al., 1998). In other studies no association was observed (Graham, 2000a, 2000b). While the first occupational epidemiology study (Savitz et al., 1999) specifically following up on this hypothesis appeared to support it, later studies were not able to confirm the association (Sahl et al., 2002; Johansen et al., 2002; Ahlbom et al., 2004). The overall assessment of the literature led the WHO to conclude in 2007 that “the evidence does not support an association between ELF [EMF] exposure and cardiovascular disease” (WHO, 2007b, p. 8).

8.5.6.2 Reproductive Outcomes

70 A potential link with various reproductive outcomes was also extensively investigated. The early studies on this topic did not consistently identify an association between ELF EMF and any reproductive outcome in humans (NIEHS, 1998). Two epidemiology studies published in 2002 (Lee et al., 2002; Li et al., 2002) reported an association with peak exposure to ELF magnetic fields above 1.6μT during a 24-hour personal measurement day and risk of miscarriage. No association with TWA exposure was observed in the same studies. Methodological limitations (measurements taken after, but not prior to miscarriage) pointed out by scientific expert panels (NRPB, 2004; WHO, 2007b), and the possibilities that the association may be explained by behavioural differences between women with healthy pregnancies and women who miscarried (Savitz, 2002), however, limit the interpretation of the studies and prevents the drawing of causal inference. According to the proposed ‘mobility hypothesis’, increased frequency of nausea experienced during early pregnancies and the cumbersomeness during late pregnancies would reduce the physical activity of women with healthy pregnancies, which in turn would reduce the opportunity for exposure to elevated peak magnetic fields compared to women who miscarry. While the mobility hypothesis could not be directly evaluated in the original pregnancy studies, more recent studies demonstrated that physical activity is associated with an increased likelihood of experiencing higher peak magnetic field exposures (Mezei et al., 2006; Savitz et al., 2006). These findings, while they do not exclude the possibility of a potential effect, provide support for the mobility hypothesis. New research evaluated by SCENIHR (2013) did not show an effect of ELF fields on the reproductive function in humans. A recently published study from England (de Vocht et al., 2014) did not observe statistically significant associations between any adverse clinical birth outcomes (such as preterm birth, small for gestational age, or low birth weight) and the mother’s residential proximity to power lines during pregnancy.

8.5.6.3 Neurodegenerative Disease

71 Among neurodegenerative disease, Alzheimer's disease and amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease, have been studied most extensively in the ELF EMF research literature. Most of these studies evaluated the relationship of neurodegenerative disease and estimates of occupational exposure to ELF EMF. The earlier studies of Alzheimer's disease, based on patients identified at clinics and treatment centres, showed an association with estimated occupational exposure to ELF EMF. The main limitation of these studies was reliance on recall for occupational exposure assessment, which is prone to bias. Later studies, some based on occupational cohorts of electric company workers and others based on census information to identify occupations with exposure to ELF EMF, showed mixed results and could not consistently confirm the association. A major limitation of these studies was that they relied on death certificates (mortality data) to identify cases with Alzheimer's disease.

72 Epidemiology studies of ALS also tended to rely on mortality data and assessed disease risk in relation to exposure estimates based on the study subjects' occupations. In some of the studies, ALS appeared to be associated with occupations deemed 'electrical' in nature. Since most of the workers in 'electrical' occupations were prone to electric shocks, in addition to exposure to ELF magnetic fields, it has been suggested that electric shocks may be a possible confounder in the association. However, recent studies did not provide convincing evidence for an association with electric shocks (van der Mark et al., 2014; Vergara et al., 2014).

73 A recent meta-analysis of a large number of epidemiology studies on occupational exposure to magnetic fields and neurodegenerative disease suggested that Alzheimer's disease risk was moderately associated with estimated magnetic field levels (Vergara et al., 2013). There was a statistical indication, however, of publication bias favouring the publication of positive studies, which the authors concluded may at least partially explain the association for Alzheimer's disease. For ALS, the meta-analysis indicated a moderate risk increase as well, but it was stronger in studies using occupational titles than in studies using estimates of magnetic fields, leading the authors to conclude that exposure to magnetic fields probably does not explain the observed association for ALS.

74 Two recent studies also examined the relationship between residential exposure to ELF EMF estimated by residential proximity to power lines and neurodegenerative disease (Huss et al., 2009; Frei et al., 2013). Huss et al. (2009) evaluated mortality due to neurodegenerative disease and distance from residence to the nearest high-voltage power lines in Switzerland between 2000 and 2005. A statistically significant increase in mortality due to Alzheimer's disease was observed among those who lived within 50m of the nearest 220-380 kV transmission line. The association was stronger with longer duration of residence within 50m.

The study in Denmark, of improved design, used hospital discharge records to identify newly-diagnosed cases of neurodegenerative disease between 1994 and 2010 (Frei et al., 2013). No association was reported between neurodegenerative disease (including Alzheimer's disease) and residential proximity to high-voltage power lines.

75 Both studies had the same limitation in that they used distance to power lines as an exposure assessment—no magnetic field levels were estimated, although the distance measurements are reported to be more accurate in the Danish study. The Swiss study was further limited because it relied on mortality data to identify cases. Mortality statistics from a given disease do not only depend on the incidence of the disease, but also on length of survival and case fatality. Death certificates may also underreport the presence of certain diseases, such as Alzheimer's disease. The Danish study identified newly-diagnosed cases, which represents a significant improvement. SCENIR (2013) reported that these new studies do not provide convincing evidence of an increased risk of neurodegenerative diseases or dementia related to ELF-EMF exposure and do not provide support for its previous conclusion that magnetic field exposure increases the risk for Alzheimer´s disease.

76 A large study published in 2014 examined mortality due to neurodegenerative diseases (Alzheimer's, Parkinson's, and motor neurone disease) and occupational exposure to magnetic fields among more than 70,000 electric power company workers in the UK (Sorahan and Mohammed, 2014). The authors reported no statistically significant association between any of the investigated diseases and lifetime, recent or distant exposure to magnetic fields.

8.5.6.4 Electromagnetic Hypersensitivity

77 Since a number of individuals attribute various health symptoms to perceived or real exposure to EMF, a significant amount of research has been conducted and published on the subject of electromagnetic hypersensitivity (EHS) over the years. EHS is characterised by a variety of non-specific symptoms that could vary among individuals. While these symptoms may be real, and in some cases could be severe, well-conducted provocation studies of healthy or self-identified EHS subjects demonstrated that symptoms are not related to exposure to EMF and EHS subjects cannot detect the presence of fields any better than non-EHS subjects (WHO, 2005 WHO, 2007b; SCENIHR, 2007).

8.5.7 In Vivo Research

8.5.7.1 Carcinogenicity

78 The WHO EHC reviewed large-scale, long term bioassays that investigated the potential role of magnetic field exposure in cancer development in which rodents were continuously exposed to high levels of magnetic fields over the course of their lifetime (Mandeville et al., 1997; Yasui et al., 1997; McCormick et al., 1999; Boorman et al., 1999a, 1999b; Otaka et al., 2002) and found the results do not support the hypothesis that chronic magnetic field exposure increases tumour development. They reviewed other similar studies that combined magnetic field exposure with exposure to a known carcinogen to test for promotional or co-carcinogenic activity of magnetic fields (e.g. McLean et al., 1991, 1995; Rannug et al., 1993a, 1993b; Svedenstål and Holmberg, 1993; Sasser et al., 1998; Babbit et al., 2000; Mandeville et al., 2000; Heikkinen et al., 2001) and found that these studies indicate a lack of cancer promotional effect of magnetic field exposure.

79 While a group of studies conducted in a single German laboratory reported an increased incidence of 7,12-dimethylbenz(a)anthracene-induced mammary tumours in F344 rats with magnetic field exposure (Löscher et al., 1993, 1994, 1997; Mevissen et al., 1993a,1993b, 1996a, 1996b, 1998; Baum et al., 1995; Löscher and Mevissen, 1995), the results have not been replicated in a subsequent series of experiments conducted in the United States (Anderson et al., 1999; Boorman et al.1999a, 1999b). A follow-up study in the German laboratory (Fedrowitz et al., 2004) reported that magnetic field exposure enhanced mammary tumour development in one sub-strain of rats (F344) but not in another, which argues against a general promotional effect of magnetic fields.[83] Overall, the reason for the discrepancy between the studies of the German laboratory and other studies investigating the tumour-promoting potential of magnetic fields remains elusive. The overwhelming evidence available, however, indicates that magnetic fields do not act as tumour promoters. A review of more recent studies does not change this assessment (SCENIHR, 2013).

8.5.7.2 Oxidative Stress and Altered Gene Expression

80 In addition to animal bioassays of tumour development, the WHO EHC also reviewed the results of studies conducted in animals to investigate biological processes related to cancer development, including genotoxicity and non-genotoxic mechanisms (e.g. oxidative stress,

[83] The WHO concluded with respect to the German studies of mammary carcinogenesis, "*Inconsistent results were obtained that may be due in whole or in part to differences in experimental protocols, such as the use of specific substrains"* (WHO, 2007b, p. 321).

altered gene expression). Overall, the WHO concluded that the available evidence did not suggest that magnetic field exposure causes genetic damage. Further, they judged the evidence for non-genotoxic mechanisms to be limited and inconclusive. Since the WHO EHC was released, numerous additional in vivo studies have been conducted to examine the ability of magnetic fields to cause non-genotoxic and genotoxic damage (e.g. Akdag et al., 2010; Goraca et al., 2010; Okudan et al., 2010; Mariucci et al., 2010; Martínez-Sámano et al., 2010, 2012; Chu et al., 2011; Ciejka et al., 2011; Miyakoshi et al., 2012; Kiray et al., 2013). Overall, it is hard to draw any conclusions from most of these studies because of the low numbers of animals per group (i.e. low statistical power of the studies), the lack of blinded analyses in most cases,[84] variability in the exposure parameters and effect markers examined, and contradictory findings across studies.

81 Two recent well-conducted studies, however, are worth mention here. In a double-blind study, Kirschenlohr et al. (2012) reported no alterations in gene expression in white blood cells from pairs of subjects exposed to magnetic fields for 2 hours on 4 different days for 2 weeks. Gene expression was determined via microarray analysis with an emphasis on genes previously reported to respond to magnetic field exposure. In a similarly well-conducted study, Kabacik et al. (2013) looked for changes in the expression of genes in the bone marrow of juvenile mice exposed to magnetic fields. In order to confirm consistent changes with exposure, gene expression in these replicate samples was analysed in a blinded manner using multiple methods and in different laboratories. Again, no consistent changes in gene expression in response to magnetic field exposure were found. SCENIHR (2013) noted that despite new studies that have investigated potential molecular and cellular mechanisms, particularly regarding effects on reactive oxygen species, none that would operate at levels of exposure found in the everyday environment has been firmly identified.

8.5.7.3 Childhood Leukaemia Models

82 The limited epidemiologic evidence suggesting a possible link between higher than average magnetic field exposure and childhood leukaemia has led researchers to conduct studies to investigate whether certain transgenic animal models are predisposed to developing a disease condition similar to acute lymphoblastic leukaemia. The WHO EHC discusses two studies that used such model systems (Harris et al., 1998; McCormick et al., 1998), both of which reported no effects of magnetic field exposure on lymphoma development. While another study (Fam and Mikhail, 1996) reported increased lymphoma in mice with magnetic field exposure over

[84] In a blinded analysis, the investigators are not aware of the exposure status of the samples being analysed.

successive generations, it was found to be unreliable due to numerous experimental deficiencies.

83 Four similar well-conducted studies in rodents genetically predisposed to develop hematopoietic cancers or chemically initiated to develop such cancers were published since the WHO EHC. These studies involved long term exposure, sham-treatment of controls, interim sacrifices, large sample sizes, and were conducted in a blinded fashion.

84 Chung et al. (2008) reported that 21 hour per day exposure for 40 weeks to high levels of magnetic fields had no effect on the incidence of lymphoma in AKR mice; markers of genetic damage also were unaffected.[85] Similarly, Sommer and Lerchl (2006) reported that neither continuous exposure nor exposure for 12 hours per day for 32 weeks had an effect on lymphoblastic leukaemia incidence or survival time in AKR mice. Negishi et al. (2008) chemically initiated mice to develop cancer shortly after birth; then, shortly after weaning, they were exposed to magnetic fields for 22 hours per day for 30 weeks with no effect on the incidence of lymphoma development. Finally, Bernard et al. (2008) co-exposed rats to both a cancer initiator and high levels of magnetic fields, both of which were found to have no effect on the incidence of leukaemia or survival time of the animals.[86]

8.5.7.4 Melatonin Production

85 As discussed in **Section 8.5.5.1**, the melatonin hypothesis posits that exposure to ELF EMF could affect susceptibility to develop breast cancer by inhibiting melatonin production. Three recent reviews address this hypothesis (Touitou and Selmaoui, 2012; Naziroğlu et al., 2012; Halgamuge, 2013) by summarising in vivo data (both animal and human) on EMF exposures and melatonin levels with conflicting conclusions. Many of the data included in these reviews, however, also were reviewed in the WHO EHC, which concluded that the available evidence was inadequate to show an adverse effect of ELF EMF exposures on melatonin secretion or other parameters of neuroendocrine function.

[85] This study also examined the ability of magnetic fields to affect development of neurogenic tumours. Pregnant rats were initiated with an injection of ethylnitrosourea to initiate cancer and the resulting offspring exposed to high magnetic field levels for 28 or 38 weeks beginning shortly after weaning. In this case, brain tumour development was similar across three ELF EMF exposed treatment groups and sham-exposed controls.

[86] This last study is of particular interest in that the animal model used develops the B-cell acute lymphoblastic leukaemia, the same type as observed in children.

8.5.7.5 Neurobiological Effects

86 The WHO EHC found only a few field-dependent responses tentatively identified from in vivo data regarding neurobiological effects, and even the most consistent effects appeared small in magnitude and transient in nature. Since then, various in vivo studies have been performed to examine the possible effects of magnetic fields on neurobiological functions; a few of these studies have involved human subjects.

87 Barth et al. (2010) quantitatively summarised the results of seven human experimental studies of cognitive performance in which subjects were exposed to high magnetic field levels. The authors concluded that in aggregate the studies provided little evidence for any effects of magnetic fields on cognitive function.

88 Other studies in humans have examined the effects of magnetic field exposures on electroencephalogram readings, event-related potentials, and evoked potentials. The results of some of these studies are reviewed in a recent paper by Di Lazzaro et al. (2013), who suggest that the findings may be indicative of "a slight influence on human brain activity" from magnetic fields. The authors acknowledge, however, that these studies generally suffer from a lack of reproducibility and specificity of effects.

89 One recent study investigated the possible role of magnetic field exposure on the pathogenesis of Alzheimer's disease in the aluminium-overloaded rat (Zhang et al., 2013).[87] Rats were fed an aluminium chloride solution, or exposed to high magnetic field level, or combined exposure for 12 weeks. The experiment was repeated three times and analyses were conducted in a blinded fashion. Although the aluminium-overloaded rats showed deficits in learning and memory as well as neuronal loss and increased concentrations of amyloid-β in certain regions of the brain, the rats exposed to the magnetic field did not. Further, rats that underwent the combined exposure did not exhibit increased pathogenesis or behavioural deficits compared to the rats exposed to aluminium alone. Although more research is needed to confirm these findings, the study suggests that magnetic field exposure does not precipitate development of symptoms or lesions in a model of Alzheimer's disease.

[87] Aluminum exposure causes symptoms and brain lesions in animals that are similar to those seen with Alzheimer's disease.

8.5.7.6 Reproductive and Developmental Effects

90 Based on the data available at the time, the WHO EHC concluded that the existing in vivo studies were inadequate for drawing conclusions regarding potential reproductive effects. Further, studies conducted in mammalian models showed no adverse developmental effects associated with magnetic field exposure. Since that time, additional studies have been done to investigate the potential effects of magnetic fields on the female and male reproductive systems and on development of prenatally-exposed offspring (e.g. Yao et al., 2007; Al-Akhras et al., 2008; Khaki et al., 2008; Aydin et al., 2009; Dundar et al., 2009; Kim et al., 2009; Bernabò et al., 2010; Rajaei et al., 2010).

91 In general, these studies suffer from various methodological deficiencies (e.g. low numbers of animals, inappropriate treatment of controls, and the absence of blinded analyses) and report conflicting findings. In particular, the studies of offspring development failed to incorporate methods to control for potential litter effects (littermates are known to be more similar to each other than offspring derived from separate litters). Further, although certain changes in reproductive organs or hormone concentrations were reported, none of the studies necessarily showed that the findings were associated with any adverse reproductive or developmental outcomes. Overall, the results of studies conducted since the WHO EHC provide little to alter the original judgment of the Working Group that the data are inadequate to show potential reproductive or developmental effects in association with magnetic field exposure. A recent review of studies reported "*recent results do not show an effect of the ELF fields on the reproductive function in humans."* (SCENIHR, 2013).

8.5.8 In Vitro Research

92 Compared to in vivo studies, in vitro studies in isolated cellular or tissue systems are relatively inexpensive and require less laboratory space and staff. For this reason, copious in vitro studies of magnetic field exposures are available in the literature. While in vitro investigations allow for the control of various confounding factors in the experimental design of a study, they suffer from substantial limitations including the lack of whole body feedback mechanisms and protective processes.

93 The in vitro studies of magnetic field exposure, using a variety of different exposure conditions and examining a plethora of different biological endpoints, generally have shown positive findings only at magnetic field exposures of ≥1,000μT, well above levels to which people are typically exposed (SSM, 2013). Overall, while in vitro studies can be informative for understanding the potential effects of magnetic field exposures on underlying biological processes, in vitro exposures cannot necessarily be extrapolated to the in vivo condition, thus the results of such studies cannot be used for making regulatory policies.

94 In addition, recent studies have not aimed at elucidating a potential mechanistic link between magnetic field exposures and the increased risk of childhood leukaemia observed in epidemiology studies. As discussed in the EC's health effects review of EMF exposures, more hypothesis-driven in vitro studies into the role of magnetic fields exposure are needed because "*despite several decades of research into biological effects of EMF, there are still no generally accepted biological effects or interaction mechanisms that would explain human health effects below the thresholds for thermal effects and nerve stimulation"* (SCENIHR, 2009a). This assessment is unchanged following review of new research, "no mechanism that operates at levels of exposure found in the everyday environment has been firmly identified and experimentally validated." (SCENIHR, 2013).

95 In its review of the available in vitro research on potential mechanisms of carcinogenesis, the WHO concluded that these studies generally fail to show genotoxicity at magnetic-field exposures below 50,000µT (WHO, 2007b). One recent in vitro genotoxicity study (Burdak-Rothkamm et al., 2009) used blinded analyses to examine the effects of multiple magnetic field strengths produced by two different exposure systems and administered as either continuous or intermittent fields up to 1,000µT (50Hz). This study was conducted in an attempt to replicate positive genotoxic findings reported in a series of studies conducted under the European Union's REFLEX programme (Ivancsits et al., 2002, 2003a, 2003b), which were discussed in detail in the WHO EHC. Burdak-Rothkamm et al. (2009) evaluated multiple genotoxic endpoints, all of which were unaffected by magnetic field exposures of multiple field strengths; thus, the results of this comprehensive and well-conducted analysis do not support the findings of the earlier studies by Ivancsits et al.

96 Reviews published since the WHO EHC also suggest that magnetic field exposure alone is not genotoxic, although magnetic field intensities of ≥100µT have been suggested to interact with other chemical and physical agents to enhance the genotoxic responses resulting from those exposures (Juutilainen et al., 2006; Juutalainen, 2008; Ruiz-Gómez and Martínez-Morillo, 2009). The potential for magnetic fields to interact with genotoxic agents was also noted in the WHO EHC. This possibility was reiterated in the subsequent EC review on EMF (SCENIHR, 2009 a, 2013), which recommended more research into the potential for magnetic fields to alter the cellular response to other genotoxic agents.

97 In its report, the WHO further noted that studies of other potential carcinogenic mechanisms (e.g. cell proliferation, malignant transformation, altered gene expression) were inconsistent or inconclusive (WHO, 2007b). Since the WHO EHC was released, numerous additional studies investigating mechanisms of carcinogenesis have been published (e.g. Gottwald et al., 2007; Girgert et al., 2008, 2009, 2010; Koh et al., 2008; Markkanen et al., 2008; Jian et al., 2009; Frahm et al., 2010; Polaniak et al., 2010). These studies have examined the effects of magnetic fields on such biological processes as cellular proliferation, oxidative stress,

apoptosis, gene expression, and immune cell responses. Many of these studies suffer from experimental deficiencies such as small sample sizes, the absence of sham-exposure of controls, no control of confounding variables (e.g. temperature), and the lack of blinded analyses. Further, findings are generally inconsistent across the body of studies. As such, the results of recent in vitro studies do not alter the previous conclusions of the WHO EHC. This assessment of the in vitro data is also consistent with that of EFHRAN (2010b), which found the in vitro studies of cellular functions provided 'inadequate' evidence for cancer processes and 'limited' evidence for other select cellular functions.

8.5.9 Potential Interference with Implanted Medical Devices

98 The most common implanted medical devices are pacemakers and implantable cardioverter defibrillators (ICD). Pacemakers are designed to maintain a regular heart rate, which they achieve by delivering electric impulses to the heart muscle to trigger regular heartbeats. ICDs are designed to deliver an electric impulse or shock to control life-threating arrhythmias.

99 These devices typically contain a metallic casing, a built-in battery, electronic circuitry, and electric leads leading to the heart tissue. Cardiac pacemakers may have a single lead (unipolar devices) or two leads (bipolar devices). Modern pacemakers are almost exclusively bipolar devices. Detection and sensing of the heart's intrinsic electric activity is an integral part of both pacemakers and ICDs to ensure that electric impulses are delivered at the right time, but external electric signals may potentially interfere with or disrupt the normal functioning and operation of pacemakers and ICDs, a phenomenon called electromagnetic interference (EMI). While most external sources of EMF are too weak, interference may potentially occur from various electric appliances, medical and industrial equipment (e.g. magnetic resonance imaging), radio communication technologies (e.g. cell phones), and magnets. Patients are advised to keep these sources away from their implants.

100 The probability of interference and the mode of response depend on the strength of the interference signal, the distance from the signal, signal duration, its frequency and the patient's orientation in the electromagnetic field, the type and design of the device, and the variable parameters and settings of the device. Modern devices incorporate various technological safeguards (e.g. shielding by titanium casing and electrical filtering) to minimise the potential for EMI (Dyrda and Khairy, 2008).

101 Pacing abnormalities were shown to occur at magnetic field levels that are much higher than the levels a person would encounter on a daily basis. While electric fields did produce interference at levels that can be produced by certain electrical sources (Toivonen et al., 1991; Astridge et al., 1993; Scholten and Silny, 2001; Joosten et al., 2009), most pacemakers were not affected by high levels of electric fields (up to 20kV/m) and did not exhibit any pacing

abnormalities. Joosten et al. showed that the most sensitive unipolar pacemakers may be affected by electric field levels between 4.3kV/m and 6.2kV/m. However, most modern pacemakers are bipolar devices, which are designed specifically to reduce the potential for EMI. Joosten et al. (2009), for example, found that in Germany, only 6% of the pacemakers in use have a unipolar sensing system.

102 A more recent study tested the function of 31 pacemakers placed in human shaped phantoms directly under a 400 kV transmission line (Korpinen et al., 2012). The results showed no interference with bipolar sensing and interference with only one unipolar pacemaker. The electric field level was 6.7-7.5kV/m at the time of this interference. Souques et al. (2011) investigated electric utility workers with ICDs at electric substations in France. No interference with ICDs was observed with a magnetic field as high as 650µT and electric fields as high as 12.2kV/m. Tiikkaja et al. (2013) tested 11 volunteers with pacemakers and 13 volunteers with ICDs in an experimental setting at ELF magnetic field levels up to 300µT. No interference was observed with ICDs or pacemakers with bipolar sensing, while three pacemakers with unipolar sensing experienced some form of interference.

103 Suggested exposure levels have been recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) to prevent against pacemaker EMI—below 1kV/m for electric fields and 100µT for magnetic fields (ACGIH, 2001). These are general recommendations and do not address the classes of pacemakers that are quite immune to interference even at levels much greater than these recommended guidelines. ACGIH recommends that patients consult their physicians and the respective pacemaker manufacturers before following the organisation's guidelines.

104 The European Committee for Electrotechnical Standardization (CENELEC) has developed specific procedures to assess the potential risk to workers with an active implantable medical device (AIMD) and provides guidelines to determine when reference levels are sufficient to ensure compliance (CENELEC 50527-1:2010).[88] In the ELF band of EMF exposure, recommended reference levels not to be exceeded are 5.0kV/m and 100µT for general exposure (Council Recommendation 1999/519/EC).

[88] An AIMD is defined by the EU to be "*any active medical device which is intended to be totally or partially introduced, surgically or medically, into the human body or by medical intervention into a natural orifice, and which is intended to remain after the procedure"* (Council Directive 90/385/EEC).

105 For the transmission line configurations proposed as part of this project, the general magnetic-field reference levels will not be exceeded over any portion of the line and the electric field level will be above the 5.0kV/m reference level only within approximately 17m of the transmission tower centreline. For the majority of people, exposure to field levels in excess of the reference level would occur only for a very short term or transient periods in which case these exposures may be acceptable for AIMD. For persons with an AIMD and who will spend significant time very close to the transmission line centreline, or who may work in the open air (e.g. outside a metal vehicle or at higher distances off the ground), a consultation with their physician may be warranted to determine the compatibility of their specific AIMD with higher electric fields.

106 In a survey of almost 1,000 physicians who dealt with patients with active implanted medical devices in France, 16% of the physicians were aware of at least one incident of electromagnetic interference between the implanted device and an EMF source (Hours et al., 2014). However, none of the reported sources were high-voltage transmission lines, the main sources being electronic security systems and medical electromagnetic devices. A German survey of 110 patients with implanted cardioverter-defibrillators evaluated the threshold for interference with 50 Hz electric and magnetic fields (up to 30 kV/m and 2,550 µT, respectively) in clinical settings (Napp et al., 2014). No interference occurred at exposure levels below limits set by the European Union for the general public or at exposure scenarios that could be experienced near 400-kV transmission lines. A Finnish study using old designs (>10 years old) of implantable cardioverter-defibrillators in human shaped phantoms observed a potential interference at exposure levels above the current European Union limits of with one unit out of the investigated 10 units (Korpinen et al., 2014). The authors acknowledged that they were not able to replicate the interference in the following day with the same unit, the designs were old, and the use of phantoms instead of humans limit the interpretation of their findings.

107 A query of the database of the Medicines and Healthcare Products Regulatory Agency, the relevant regulatory body in the United Kingdom, and the Manufacturer and User Facility Device Experience (MAUDE) database maintained by the United States Food and Drug Administration (FDA) has not identified any reports, up until August 2014, that would suggest episodes where electromagnetic interference occurred with implanted cardiac devices due to electric or magnetic fields from electric power lines.

8.5.10 Potential Effects of ELF EMF on Plants

108 Electric currents are suggested to play a role in cell to cell communication in plants (Framm and Lautner, 2007). Significant scientific literature has accumulated, both from laboratory and field studies, on potential effect of ELF EMF from transmission lines on plants, including agricultural crops and trees, and forest and woodland vegetation. The various investigations include seed germination, seedling emergence and growth, leaf area per plant, flowering, seed production,

longevity, and biomass production. Some studies showed changes with EMF exposure to plant size and weight in radish (Davies, 1996), growth rate of mung bean (Huang and Wang, 2008), and yield of tomato plants (Costanzo, 2008; De Souza et al., 2010). These findings, however, were not consistently observed. Overall, no confirmed adverse effects on plants were reported due to EMF exposure at levels comparable to what could be observed near high-voltage transmission lines (e.g. Hodges et al., 1975; Bankoske et al., 1976; McKee et al., 1978; Miller et al., 1979; Rogers et al., 1980; Lee and Clark, 1981; Warren et al., 1981; Rogers et al., 1982; Greene 1983; Hilson et al., 1983; Hodges and Mitchell, 1984; Brulfert et al., 1985; Parsch and Norman, 1986; Conti et al., 1989; Krizaj and Valencic 1989; Ruzic et al., 1992; Reed et al., 1993; Smith et al., 1993; Mihai et al., 1994; Davies 1996; Zapotosky et al., 1996). The only confirmed adverse effect was damage to the tops of trees growing under or within 12.92m of an experimental transmission line operating at a voltage of 1,200 kV. This effect was attributed to corona-induced damage to branch tips. The clearance of tall growing trees under and near transmission lines that are set to prevent flashover and other interference would be sufficient to prevent effects on trees. This literature does not provide a basis to confirm any adverse effects of EMF on plant life (SCENIHR, 2009).

8.5.11 Potential Effects of ELF EMF on Animals

109 Similar to human health concerns, concerns have been expressed about potential effects of ELF EMF from transmission facilities on animal health, welfare, behaviour, and productivity. Both economically important domesticated animal species and wildlife have been investigated since the 1970s. Studies include a variety of study designs including observational studies of animals in their natural habitats, such as farms, and highly-controlled experimental studies. Overall, the research conducted to date does not suggest that ELF EMF have any adverse effects on the health, behaviour, or productivity of animals, including livestock (e.g. dairy cows, sheep, and pigs) and a variety of other species (e.g. small mammals, deer, elk, birds, bees, or marine life).

8.5.11.1 Dairy Cows and Cattle

110 Cows have been one of the most investigated species in scientific studies. The most notable series of experimental studies, under controlled settings, were conducted at McGill University by request of the government of Québec (e.g. Rodriguez et al., 2002, 2003, 2004; Burchard et al., 2003, 2004, 2007). The studies were designed to assess the potential effect of electric field and magnetic fields, separately and in combination, on dairy cattle’s milk production, fertility, and hormone levels. The experiments were conducted in a laboratory setting to control extraneous factors, and exposed the cows to magnetic fields up to 30µT and electric fields up to 10kV/m. While some of the studies showed differences in milk fat content and dry matter intake, these differences were not consistently observed in the series of experiments and none

of these differences were in excess of normal variations. Various measures of fertility of investigated pregnant heifers were not affected by ELF EMF exposure. The research team also investigated potential changes in various hormone levels (including progesterone, melatonin, cortisol, and thyroid hormones). They did not find an association with the majority of the investigated variables. Some subgroup analyses showed minor changes, but according to the authors' conclusions, these were small, within the range of normal for dairy cattle, and unlikely to represent adverse health effects.

111 More recently, two studies on cattle orientation have been published by the same research team (Begall et al., 2008; Burda et al., 2009). Both studies used publicly available satellite images to identify cattle on various pastures in Africa, Asia, Australia, Europe, North America, and South America. In the first study, the researchers report that cattle tend to orient themselves in the north-south direction, which the authors argue is due to magnetic alignment in response to the earth's geomagnetic field. In the second publication, the authors suggest that in the immediate vicinity of high-voltage power lines this alignment is changed by the ELF EMF from the conductors. No mechanism exists to explain a potential basis for magnetoreception by cows. The papers were later criticised by other investigators who performed their own analyses (Hert et al., 2011) were unable to replicate the initial findings. They also pointed out methodological shortcomings, such as the limited quality of the publicly available satellite images, the unblended nature of herd and animal selection and evaluation, and that potential alternative explanations to magnetoreception were ignored. A recently published study that was specifically designed to replicate the original findings reported mixed results and was unable to confirm the earlier findings (Slaby et al., 2013).

8.5.11.2 Sheep

112 Sheep were also evaluated in a number of studies to investigate the potential effect of ELF EMF from high-voltage transmission lines on hormone levels (melatonin, cortisol), weight gain, wool production, behaviour, onset of puberty and immune function (Stormshak et al., 1992; McCoy et al., 1993; Lee et al., 1993; Thompson et al., 1995; Hefeneider et al., 2001). While some parameters showed variation, no changes were consistently observed or replicated in these studies.

8.5.11.3 Pigs

113 Pigs were assessed by one research group for possible effects of ELF EMF from a 345 kV transmission line on production parameters, carcass quality, and reproductive performance (Mahmoud and Zimmerman, 1983, 1984). No differences with exposure were observed in body weight, carcass quality, behaviour, food intake, rate of pregnancy, number of pigs born alive, average birth weight, or rate of weight gain after birth.

8.5.11.4 Bees

114 Potential effects of ELF EMF on commercial honeybees also have been investigated since farmers may often place hives on fields near transmission lines. Greenberg et al. (1981) studied the effect of a 765 kV transmission line on honeybee colonies placed at varying distances from the transmission line's centreline. Exposed hives were compared to hives shielded from electric fields. Differences between the exposed and unexposed hives were reported at exposures above 4.1kV/m, including: decreases in hive weight, abnormal amounts of propolis at hive entrances, increased mortality and irritability, loss of the queen in some hives, and a decrease in the hive's overwinter survival. These adverse effects, however, were indirect as they were attributed to small shocks induced on the metallic components of the hives due to the electric fields (Rogers et al., 1980, 1981, 1982), thus the effects were not direct effects of EMF on bees. Further studies indicated that field levels greater than 200kV/m were required to affect the behaviour of free-flying bees (Bindokas et al., 1988a, 1988b, 1989). Prevention of electric field induced microshocks is easily accomplished by placing a grounded metal cover on top of the hive. As for magnetic fields, laboratory studies indicate that bees are unable to discriminate 60Hz magnetic fields reliably at intensities less than 430µT, although they can detect fluctuations in the earth's static geomagnetic field as weak as 26 nanotesla (Kirschvink et al., 1997).

115 A study of native bees in Maryland found that within AC transmission line corridors there were more spatially and numerically rare species and richer bee communities than at the grassy fields away from transmission lines (Russell et al., 2005). Power line sites also had more parasitic species and more cavity-nesting bees. There were no EMF measurements in the study and no direct evaluation of EMF effects was undertaken. A more recent similar study conducted by some of the same investigators in Maryland, Wisconsin, and Oregon, also included measurements of EMF and aimed to evaluate potential EMF effects on native bees, as well (Russell et al., 2013). There was no indication of any effect of EMF on bee abundance, diversity, larval development, or behaviour such as floral visitation and pollination success.

8.5.11.5 Fish and Marine Species

116 A variety of salmon, other fish, and eels are among marine species for which there is some evidence that they make use of the earth's geomagnetic field in navigation. While salmon may detect the geomagnetic field, their behaviour appears to be governed by multiple stimuli including light, smell, current flow, and other factors. The principal hypothesis as to how these species are able to detect the earth's geomagnetic field involves the movement of tiny magnetic crystals coupled to sensory nerves in the head. The rate of oscillation of a 50Hz magnetic field, however, is too fast for a force to be effectively coupled mechanically to magnetite particles and it is unlikely that the brief and relatively low levels of exposure to 50Hz AC magnetic fields from

the line would overcome other thermal and biological processes that govern migration (Adair, 1994). This is consistent with the finding that Atlantic salmon and American eels do not show evidence of detection or behavioural response to 75Hz magnetic fields at an intensity of 50μT (Richardson et al., 1976). This conclusion is supported by recent experimental studies by the Oak Ridge National Laboratory in the United States in which few detectable behavioural responses to 60Hz magnetic fields at intensities below 670μT were observed in any of six freshwater fish species, including two known to exhibit electrosensitivity (Bevelhimer et al., 2013).

117 The exposure of fish to EMF beneath the conductors, where the line crosses rivers and streams, will be relatively low. The electric field in water will be 500,000 to 1,000,000 times lower than in the air above, thereby preventing any meaningful exposure to fish and other species in the water. While the magnetic field will not be appreciably attenuated by water, the intensity in the water will be lower since the conductors at locations over rivers and streams are higher than the minimum conductor heights that were assumed for modelling magnetic fields. For example, over the rivers Boyne and Blackwater the clearance from the highest bank of the Blackwater is approximately 13m and the clearance from the highest bank of the Boyne is approximately 16m. Additionally, prolonged exposure is not a critical issue for most river species of interest because their normal activities take them away from the area directly under the line where the magnetic field levels are the highest. Furthermore, there is no data to suggest that ELF–EMF will adversely impact salmon.

118 The scientific literature on sensitivity of marine species to EMF has been recently reviewed for the Bureau of Ocean Energy Management of the U.S. Department of Interior (Normandeau et al., 2011). Evidence suggests that a number of marine species have the ability to sense electric or magnetic fields, including some marine mammals, sea turtles, many groups of fishes (including elasmobranchs), and several invertebrate groups. The authors of the report also conclude, however, that most marine species may not sense low intensity AC magnetic fields (<5μT).

8.6 THE PRECAUTIONARY PRINCIPLE AND EMF

119 Even though everyone is exposed to magnetic fields daily in their homes and workplaces from many sources, the idea of a new transmission line can raise public concern. While the WHO points out that "*exposure of people living in the vicinity of high voltage transmission lines differs very little from the average exposure of the population*" (WHO, 2014), some persons may express concern about the perceived risk of exposure from such lines (Repacholi, 2012).

120 The precautionary principle was developed as a policy measure for risk management of possible but unproven adverse effects, such as those perceived to be associated with magnetic field exposure. The WHO has outlined precautionary measures that involve no cost or low cost actions that adhere to the general recommendation that "*any actions taken should not compromise the essential health, social and economic benefits of electric power*" (WHO, 2007b, p. 372).

121 The following specific measures were suggested (adapted from WHO, 2007b, pp. 372-373):

- Countries are encouraged to adopt international science-based guidelines;
- Provided that the health, social, and economic benefits of electric power are not compromised, implementing very low-cost precautionary procedures to reduce exposures is reasonable and warranted;
- Policy-makers and community planners should implement very low-cost measures when constructing new facilities and designing new equipment including appliances;
- Changes to engineering practice to reduce ELF exposure from equipment or devices should be considered, provided that they yield other additional benefits, such as greater safety or involve little or no cost;
- When changes to existing ELF sources are contemplated, ELF field reductions should be considered alongside safety, reliability, and economic aspects;
- Local authorities should enforce wiring regulations to reduce unintentional ground currents when building new or rewiring existing facilities, while maintaining safety. Proactive measures to identify violations or existing problems in wiring would be expensive and unlikely to be justified;
- National authorities should implement an effective and open communication strategy to enable informed decision-making by all stakeholders; this should include information on how individuals can reduce their own exposure;
- Local authorities should improve planning of ELF EMF-emitting facilities, including better consultation between industry, local government, and citizens when siting major ELF EMF-emitting sources; and
- Government and industry should promote research programs to reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure.

122 In the review conducted by an expert scientific panel for the Department of Communications, Marine and Natural Resources, specific precautionary recommendations were made in relation to the siting of power lines and community input:

> "*Where possible new power lines should be sited away from heavily populated areas so as to minimise 50 Hz field exposure. Where major new power lines are to be constructed, there should be stakeholder input on the routing. This could take the form of public hearings or meetings with interested parties"* (DCMNR, 2007, p. 5).

123 The above precautionary goals have been achieved by reducing the fields from the adjacent 400 kV lines by recommending a line phasing that reduces the magnetic field away from the lines, and constructing the transmission line on existing towers where possible. Other actions by EirGrid during siting have resulted in the lines of the project being located as far from existing residences as is reasonably possible and have incorporated stakeholder input during the consultation process as described in the *Planning Report*, **Volume 2A** of the application documentation.

8.7 TECHNICAL CALCULATIONS AND RESULTS - EMF ASSOCIATED WITH THE PROPOSED DEVELOPMENT

8.7.1 INTRODUCTION

124 The proposed development is a 400 kV transmission line intended to link the existing 400 kV substation in Woodland, County Meath, with a planned substation in Turleenan, County Tyrone. The portion of the project in Northern Ireland will be constructed by SONI while the portion in Ireland is being proposed by EirGrid.

125 The proposed OHL in the CMSA extends over a distance of approximately 46km from the Northern Ireland border to Tower 236 in the townland of Clonturkan, County Cavan. The transmission line comprises a single circuit 400 kV overhead transmission circuit supported by 134 towers, the vast majority of which (78%) are Intermediate Lattice Towers.[89] An example of an Intermediate Lattice Tower is shown in **Figure 8.5** for reference.

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[89] The remaining towers are primarily 'Angle Towers', which are used when the transmission line must change direction.

126 The proposed OHL in MSA extends a distance of approximately 54.5km from the townland of Clonturkan, County Cavan to Bogganstown (ED Culmullin), County Meath. The transmission line comprises a new single circuit 400 kV overhead transmission circuit supported by 165 new towers, 72% of which are Intermediate Lattice Towers as shown in **Figure 8.5**. It also includes the addition of a new 400 kV circuit for some 2.85km along the currently unused (northern) side of the existing double circuit 400 kV OHL (the Oldstreet to Woodland 400 kV transmission line) extending eastwards from Tower 402 in the townland of Bogganstown (ED Culmullin), County Meath to Tower 410 and the Woodland Substation in the townland of Woodland, County Meath. An example of the Double-Circuit Lattice Tower is shown in **Figure 8.6**.

127 In addition, due to the length of the alignment, EirGrid has determined that the proposed transmission line would benefit from a transposition approximately 40-50km south of the proposed substation at Turleenan. This transposition would involve rearranging the location of the three conductor bundles. The transposition would occur over an alignment consisting of four towers, two Transposition Lattice Towers, specifically designed for this purpose and two Angle Towers. An outline drawing of the Transposition Lattice Tower is shown in **Figure 8.7**. The EMF from the transmission line on this segment of the route will differ from the transmission line on the Intermediate Lattice Towers and therefore is considered as a separate case.

128 As described above, the proposed transmission line is proposed to be constructed in three primary configurations:

1. Single-circuit on Intermediate Lattice Towers;
2. Single-circuit on Transposition Lattice Towers; and
3. Double-circuit on Double-Circuit Lattice Towers.

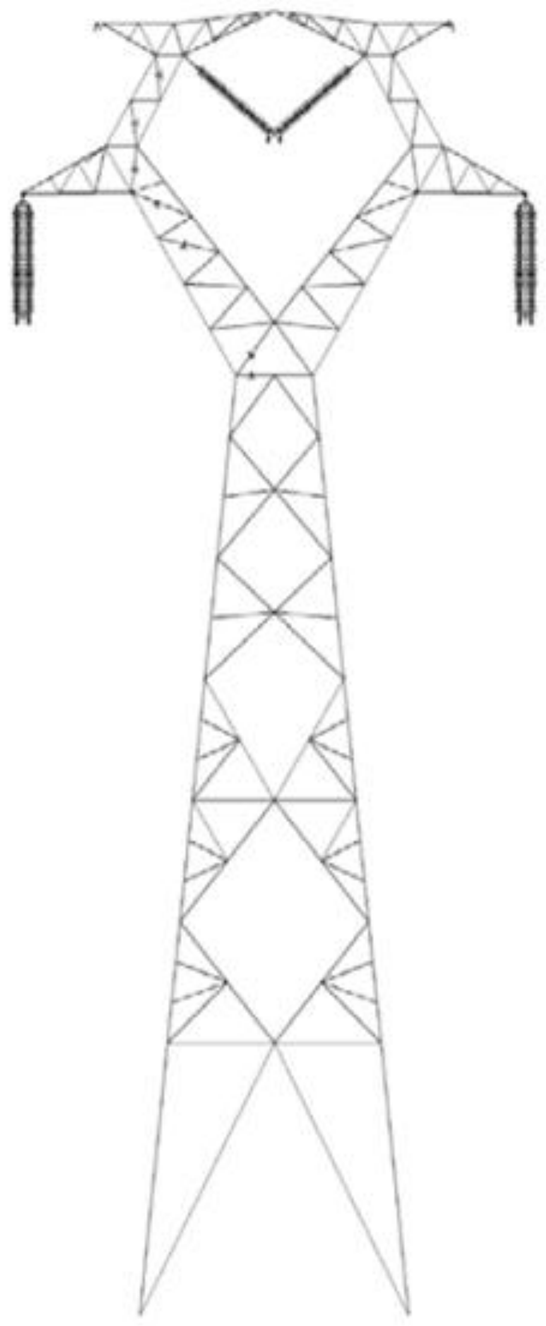

Figure 8.5: Proposed 400 kV Intermediate Single-Circuit Lattice Tower (Not to Scale) for the Proposed Development

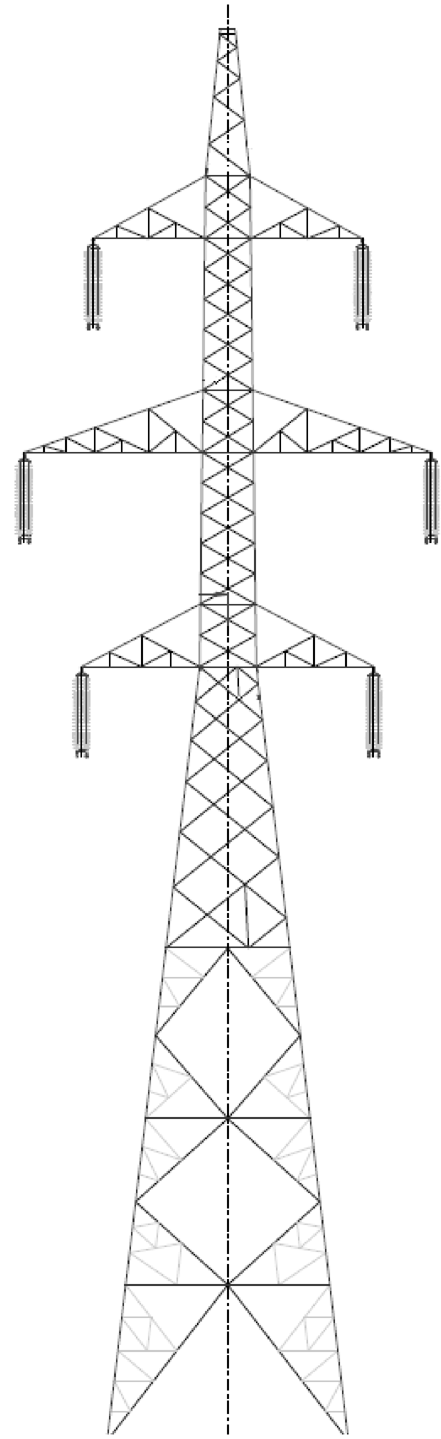

Figure 8.6: Proposed 400 kV Double-Circuit Lattice Tower (Not to Scale) for the Proposed Development

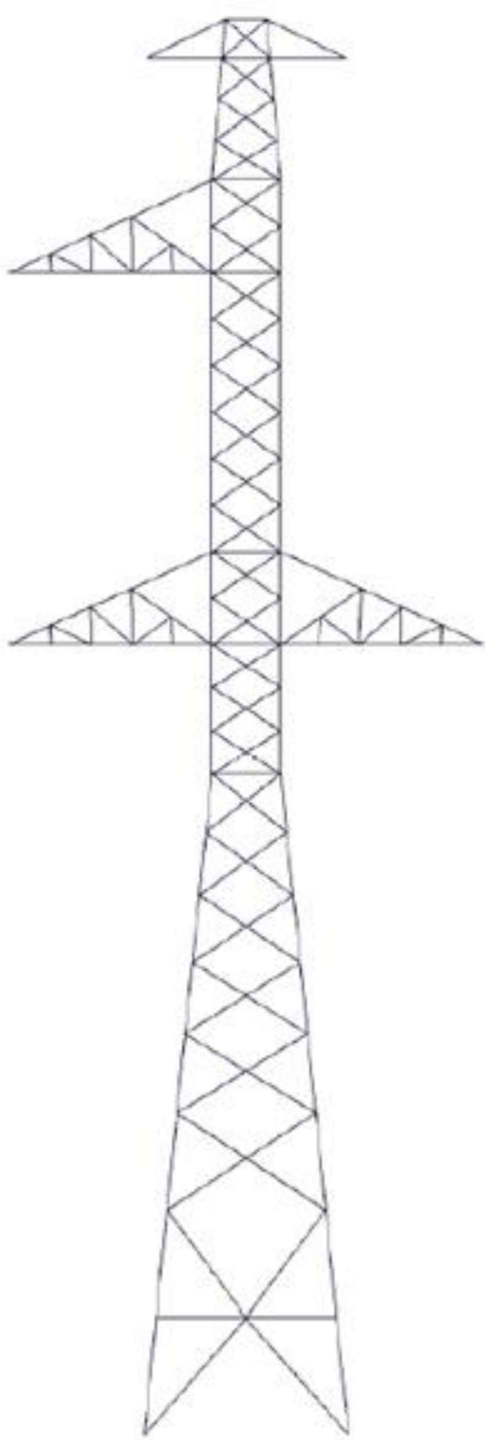

Figure 8.7: Proposed 400 kV Transposition Lattice Tower (Not to Scale) for the Proposed Development

8.7.2 METHODS

129 This section provides calculations of the 50Hz resultant EMF produced by the 400 kV OHL discussed above, all calculated by algorithms developed by the Bonneville Power Administration (BPA) of the U.S. Department of Energy (BPA, 1991). This evaluation is performed for three separate tower configurations encountered along the route. Calculations are made both under average and peak loading operation along cross sections perpendicular to the route. In locations along the route where there are existing transmission lines, the existing and proposed conditions are compared to assess project-related changes to EMF levels.

130 Magnetic fields are the result of the flow of electric currents through wires and electrical devices. The strength of a magnetic field is expressed as magnetic flux density in units called Tesla (T), or in microtesla (μT), where 1-T = 1,000,000μT. In general, the strength of a magnetic field increases as the current increases, but at any point also depends on characteristics of the source, including the arrangement and separation of the conductors. Electric fields are produced by voltage applied to electrical conductors and equipment. The electric field is expressed in units of volts per meter (V/m) or kilovolts per meter (kV/m); 1kV/m is equal to 1,000V/m. The electric field level increases as the voltage increases. Electric fields are present if an appliance is still connected to the power source even when it is turned off.

131 Electric and magnetic fields were calculated at 1m above ground, in accordance with IEC Std. 61786 (1998), and are reported as the root-mean-square resultant quantities of the field ellipse at each location along a transect perpendicular to the transmission line's centreline at distances out to ±150m. Data for the proposed transmission line's geometrical configurations, conductor type, and loading were provided to Exponent by EirGrid.

132 The inputs to the BPA program are data regarding voltage, current flow, phasing, and conductor configurations. The circuit loadings, in mega-volt-amperes (MVA), for both average and peak load are summarised in **Table 8.3**. All calculations were performed using modelling assumptions that ensure the calculated values represent the maximum expected values for each of the specified parameters. For the cases analysed, these assumptions include modelling at conductor mid-span, where conductors sag to a level closest to ground and assuming that conductors are infinite in extent.[90] A summary of the transmission line configuration for each portion of the route is summarised in **Table 8.4**.

[90] Near the transposition towers where the phase transposition takes place the assumption of conductors of infinite extent is not satisfied, but field levels in these locations would be lower than those presented in calculations for midspan conductor heights.

Table 8.3: Transmission Line Loading (MVA) for Average- and Peak-Load Cases

From	To	Voltage (kV)	Existing		Proposed	
			Average load (MVA)	Peak load (MVA)	Average load (MVA)	Peak load (MVA)
Meath	Tyrone	400	N/A	N/A	500	1,500
Oldstreet	Woodland	400	500	1,500	500	1,500

133 The ‘peak load’ of 1,500MVA is derived from the nominal maximum power carrying capacity of the OHL. While the OHL would be capable of carrying this level of load for a sustained period, it would not be expected to approach this level other than in emergency situations. Compliance with system planning standards and system operations procedures will ensure that this would rarely occur, perhaps for as little as a few hours per decade. Under normal system conditions the annual peak load for this circuit is not expected to exceed 750MVA and would be expected to occur for about 1% of the time.

134 The term ‘average load’ as used here is similar in meaning to the term ‘indicative typical load’ and at 500MVA is equivalent to 66% of an annual peak load of 750MVA. This would be considered to be a conservative estimate (i.e. on the high side) for average loading (NIEHS, 2002).

Table 8.4: Proposed Transmission Line Configuration and Model Inputs

<table>
<tr><th>Parameter</th><th>Intermediate Lattice Tower</th><th>Transposition Tower</th><th colspan="2">Double-Circuit Lattice Tower[b]</th></tr>
<tr><td>Voltage (kV)</td><td>400</td><td>400</td><td colspan="2">400 / 400</td></tr>
<tr><td>Minimum Conductor Height (m)</td><td>9</td><td>9</td><td colspan="2">9 / 9</td></tr>
<tr><td rowspan="4">Phase Spacing (m)[a]</td><td rowspan="4">H: 9.5
V: 6.0</td><td rowspan="4">H: 6.9
V: 10.5</td><td>V: 10.25</td><td>V: 10.25</td></tr>
<tr><td>H: 6.45</td><td>H: 6.45</td></tr>
<tr><td>H: 9.75</td><td>H: 9.75</td></tr>
<tr><td>H: 7.00</td><td>H: 7.00</td></tr>
<tr><td rowspan="3">Phase Arrangement</td><td rowspan="3">1-2-3</td><td rowspan="3">3
1 2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td></tr>
<tr><td>3</td><td>1</td></tr>
<tr><td>Number and diameter of Conductors
(# x mm)</td><td>2x31.68
(Curlew)</td><td>2x31.68
(Curlew)</td><td colspan="2">2x31.68 / 2x31.68
(Curlew / Curlew)</td></tr>
<tr><td>Conductor Separation (mm)</td><td>450</td><td>450</td><td colspan="2">450</td></tr>
<tr><td>Earth wire midspan height (m)</td><td>18.6</td><td>28.76</td><td colspan="2">42.78</td></tr>
<tr><td>Earth wire diameter (mm)</td><td>19.53
(Keziah)</td><td>19.53
(Keziah)</td><td colspan="2">25.97
(Goat)</td></tr>
</table>

[a] H = horizontal spacing, V = vertical spacing
[b] Oldstreet-Woodland / Meath-Tyrone

135 In the double-circuit portion of the route, the presence of a second transmission line means that the specific arrangement of the new conductors on the tower will have an effect on the calculated levels of EMF beneath and in the vicinity of the transmission line towers. Therefore, at the request of EirGrid, Exponent performed an optimisation analysis in which all possible phase permutations are considered for the two 400 kV circuits. The permutation that results in the lowest total magnetic field level beyond a distance of approximately 6m from the centreline of the Double-Circuit Lattice Tower is identified as the optimal phasing.

8.7.3 RESULTS

136 The results of this modelling effort are summarised in tables and illustrative figures showing the levels of EMF as a function of transverse distance away from the transmission line. Tables of modelling results describing the maximum magnetic field and electric field levels as well as at a distance of ±50m and ±100m from the transmission line centreline are shown in **Table 8.5** to

Table 8.7. The magnetic field levels at average loading are shown in **Table 8.5** and at peak loading in **Table 8.6**. Similarly, the electric field levels are shown in **Table 8.7**. Figures depicting modelling results for EMF for all modelled cross sections are shown in **Figure 8.8** to **Figure 8.15**. Magnetic field levels at average loading are shown in **Figure 8.8** to **Figure 8.11** and electric field levels are shown in **Figure 8.12** to **Figure 8.15**. Each figure shows the transmission line tower together with the calculated field profiles for ease of comparison.[91]

8.7.4 PHASE OPTIMISATION

137 An important parameter in the calculation of the optimal phasing that minimises the magnetic field is the relative direction of current flow between the two transmission lines. In this particular case, both transmission lines will carry electrical current in the same direction. Calculations for all possible permutations provide results describing the range over which the evaluated parameters could vary as a function of the selected phasing. The configuration identified as optimal through this analysis (optimal phasing) was based on minimising the magnetic field level at distances greater than about 6m from the transmission line centreline. This identified configuration has the conductor phasing arrangement of 1-2-3 and 3-2-1 from top to bottom for the Oldstreet-Woodland and Meath-Tyrone transmission lines, respectively. The highest magnetic field values would result from the conductor phasing arrangement of 1-2-3 and 1-2-3 from top to bottom (non-optimal phasing). On infrequent occasions when current flow on one (but not both) of the transmission lines reverses direction, the electric and magnetic fields from the double-circuit portion of the transmission line will change. This current (and voltage) reversal would essentially change the selected phasing from optimal to non-optimal for that brief period, resulting in electric and magnetic field levels slightly elevated compared to the optimal configuration (see non-optimised phasing in **Table 8.8**), but still beneath the EU limits.

8.7.5 MAGNETIC FIELDS

138 As shown in **Figure 8.8** to **Figure 8.11** and **Table 8.5** to **Table 8.6**, the magnetic fields associated with each of the different transmission line towers are quite similar, with the maximum magnetic field (48.46μT) beneath the transmission line calculated to occur beneath the relatively short segment where the line is supported on Transposition Lattice Towers.

[91] In the double-circuit portion of the project, existing transmission line towers and associated EMF are shown in addition to the proposed configuration and associated quantities.

139 At average loading the maximum magnetic field beneath the transmission line is calculated to be approximately 16μT. The magnetic field intensity diminishes rapidly with distance to about 1.0μT at a distance of 50m and to approximately 0.25μT at a distance of 100m from the centreline, a reduction by a factor of 64. Results at peak loading, which might be expected to occur during a few hours a year or even in a decade, show a similar trend with the highest magnetic field level observed directly beneath the transmission lines and decreasing rapidly with distance away from the centreline.

140 Of the three OHL arrangements proposed for this development the magnetic field under the double circuit section of the line is the lowest at 41.6μT at peak load and 13.87μT at average load. Adoption of optimal phasing of the new line at expected loading will diminish the magnetic field the of the proposed arrangement relative to the existing line, and produce magnetic fields lower than or similar to other phasing permutations at distances more than 6m from the tower centreline. If optimal phasing were not adopted for the double-circuit section, the magnetic field for the proposed configuration would be higher than from the existing line at all locations (see **Figure 8.11**). With optimal phasing, the reverse occurs; the magnetic field of the proposed configuration is lower than the existing line at distances greater than 9m south of the transmission line centreline and greater than 40m north of the transmission line centreline (see **Figure 8.10**). The magnetic field level near the transmission line centreline will increase due to the installation of the new circuit on the existing structures. To the south the magnetic field levels will decrease by as much as 1.4μT beyond approximately 10m from the transmission line centreline. To the north of the transmission line the magnetic field levels will not change appreciably (<1μT) beyond approximately 25m from the transmission line centreline and will decrease beyond approximately 40m from the transmission line centreline.

141 The impact of optimising the phases is a 'no or low cost' mitigation measure that may be implemented to reduce magnetic field levels in the double-circuit portion of the route. A summary table describing the variation in magnetic field level at various distances for the optimal and non-optimal phasing configurations is shown in **Table 8.8**.

8.7.6 ELECTRIC FIELDS

142 **Figure 8.12** to **Figure 8.15** show graphical profiles of the electric field associated with the transmission line for the three configurations with results at distances of ±50 and ±100m. The electric field at these locations is summarised in **Table 8.7**. As with the magnetic field, the electric field levels associated with each of the different transmission line configurations are similar, with the maximum electric field (8kV/m) calculated beneath the relatively short portion of the project with the Transposition Lattice Towers. Adoption of optimal phasing of the new line to minimise the magnetic field also minimises the electric field from the new line. With optimal phasing the maximum electrical field will decrease from the existing 7.7kV/m to 7.1kV/m while

non-optimal phasing would result in the maximum electric field increasing from today's 7.7kV/m to 8.8kV/m. The change from existing conditions is <1kV/m beyond approximately 20m from the transmission line centreline. In addition, beyond approximately 40m from the transmission line centreline the proposed configuration results in electric fields which are lower than under existing conditions.

143 The range of the maximum electric field beneath the transmission line is calculated to be between approximately 7.9kV/m - 8.8kV/m for the different configurations. Even for the non-optimised double-circuit portion of the project, however, the electric field decreases to below 0.4kV/m within a distance of 50m from the transmission line centreline. If optimal phasing were not adopted for the double-circuit section, the electric field for the proposed configuration would be higher than from the existing line at virtually all locations (see **Figure 8.15**). With optimal phasing, the reverse occurs; the electric field of the proposed configuration is lower than the existing line at all locations to the south of the transmission line centreline and greater than the existing line approximately 40m north of the transmission line centreline (see **Figure 8.14**).

144 The impact of optimising the phases is a 'no or low cost' mitigation measure that may be implemented to reduce electric field levels in the double-circuit portion of the route. A summary table describing the variation in electric and magnetic field levels at various distances for the optimal and non-optimal phasing configurations is shown in **Table 8.8.**

Table 8.5: Calculated Magnetic Field Values (µT) for Existing and Proposed Configurations at Average Load

Route Portion	Case	Location				
		-100 m from centre	–50 m from centre	Maximum	+50 m from centre	+100 m from centre
Single-Circuit Lattice Tower	proposed	0.25	1.02	15.98	1.02	0.25
	existing	--		--	--	--
Transposition Lattice Tower	proposed	0.24	0.93	16.15	1.01	0.25
	existing	--	--	--	--	--
Double-Circuit Lattice Tower (optimal phasing)	proposed	0.08	0.55	13.87	0.55	0.08
	existing	0.29	1.18	11.94	0.71	0.22
Double-Circuit Lattice Tower (non-optimal phasing)	proposed	0.50	1.85	13.51	1.85	0.50
	existing	0.29	1.18	11.94	0.71	0.22

Table 8.6: Calculated Magnetic Field Values (μT) for Existing and Proposed Configurations at Short Duration Peak Load

Route Portion	Case	Location				
		-100 m from centre	–50 m from centre	Maximum	+50 m from centre	+100 m from centre
Single-Circuit Lattice Tower	proposed	0.76	3.05	47.94	3.05	0.76
	existing	--		--	--	--
Transposition Lattice Tower	proposed	0.73	2.79	48.46	3.02	0.76
	existing	--		--	--	--
Double-Circuit Lattice Tower (optimal phasing)	proposed	0.24	1.66	41.62	1.66	0.24
	existing	0.87	3.53	35.81	2.12	0.65
Double-Circuit Lattice Tower (non-optimal phasing)	proposed	1.50	5.54	40.54	5.54	1.50
	existing	0.87	3.53	35.81	2.12	0.65

Table 8.7: Calculated Electric Field Values (kV/m) for Existing and Proposed Configurations

Route Portion	Case	Location				
		-100 m from centre	–50 m from centre	Maximum	+50 m from centre	+100 m from centre
Single-Circuit Lattice Tower	proposed	0.0	0.2	7.9	0.2	0.0
	existing	--		--	--	--
Transposition Lattice Tower	proposed	0.0	0.2	8.0	0.3	0.1
	existing	--		--	--	--
Double-Circuit Lattice Tower (optimal phasing)	proposed	0.0	0.2	7.1	0.2	0.0
	existing	0.1	0.3	7.7	0.2	0.1
Double-Circuit Lattice Tower (non-optimal phasing)	proposed	0.1	0.4	8.8	0.4	0.1
	existing	0.1	0.3	7.7	0.2	0.1

Table 8.8: Calculated Electric Field (kV/m) and Magnetic Field Values (μT) for Optimal and Non-optimal Phasing Configurations of the Double-Circuit Lattice Tower

Route Portion	Field	Case	Location				
			-100 m from centre	–50 m from centre	Maximum	+50 m from centre	+100 m from centre
Double-Circuit Lattice Tower	Magnetic	Optimal	0.08	0.55	13.87	0.55	0.08
		Non-Optimal	0.50	1.85	13.51	1.85	0.50
Double-Circuit Lattice Tower	Electric	Optimal	0.0	0.2	7.1	0.2	0.0
		Non-Optimal	0.1	0.4	8.8	0.4	0.1

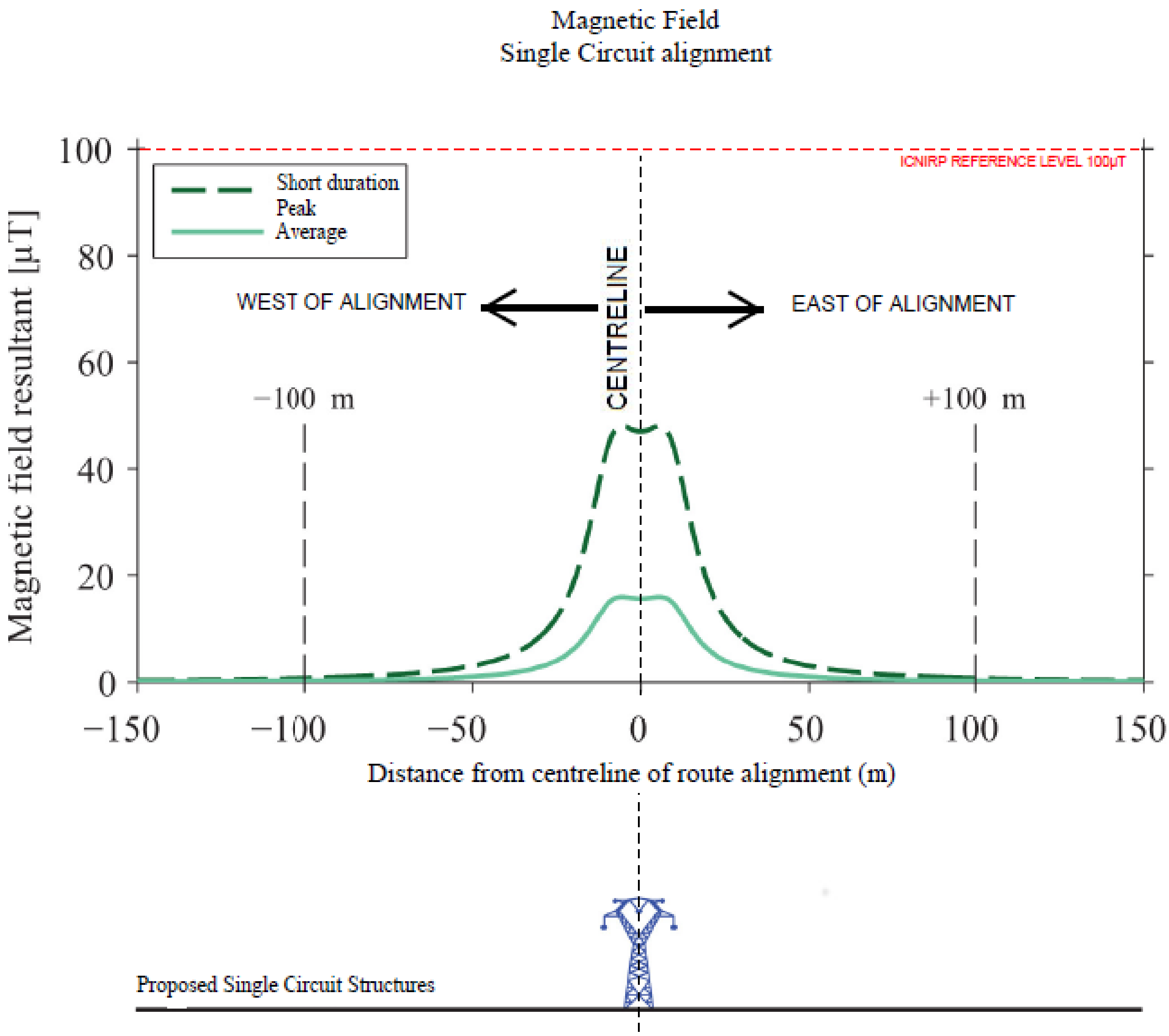

Figure 8.8: Calculated Magnetic Field Profile for the Proposed Intermediate Lattice Tower Configuration for Short Duration Peak and Average Load

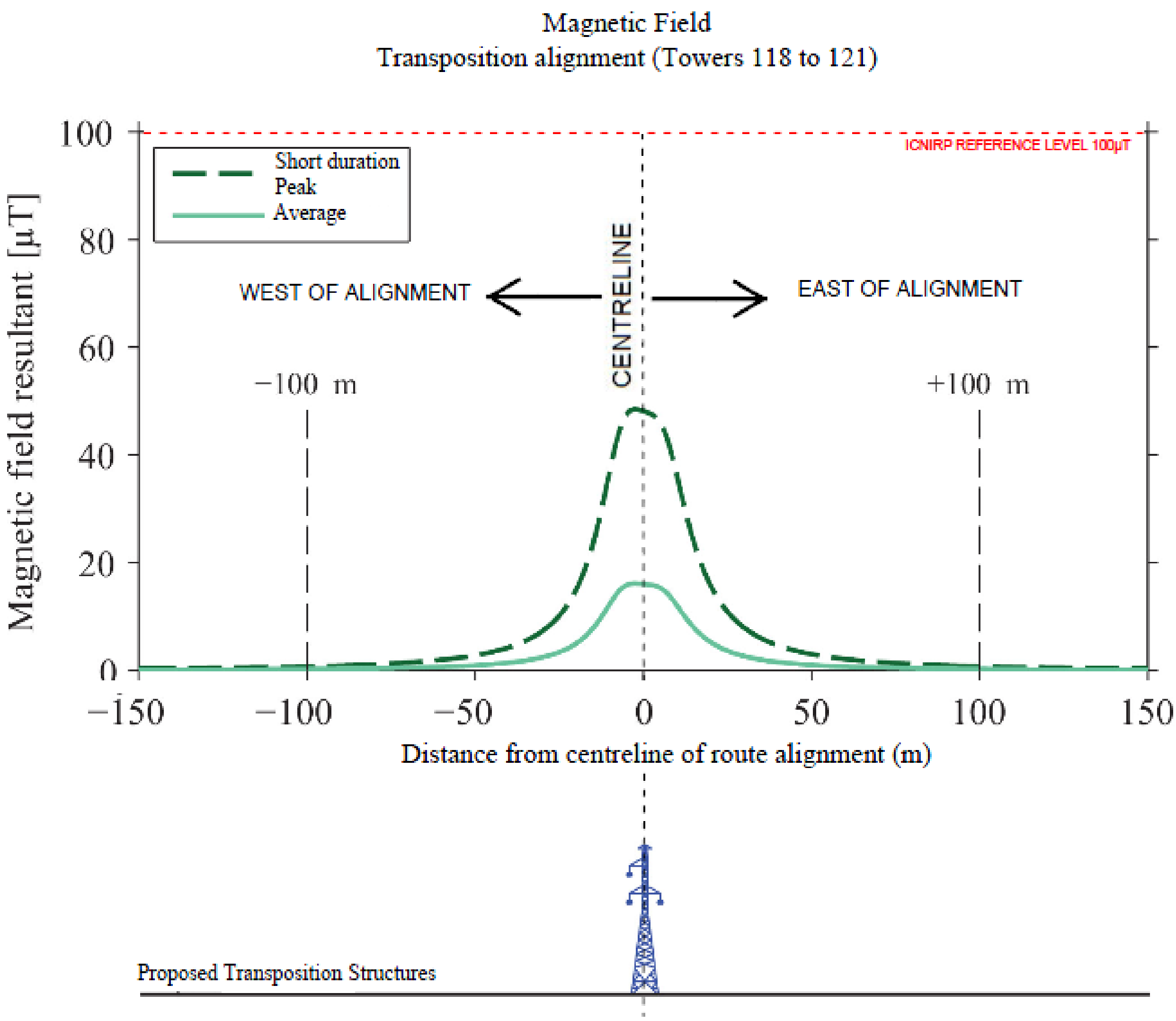

Figure 8.9: Calculated Magnetic Field Profile for the Proposed Transposition Tower Configuration for Short Duration Peak and Average Load

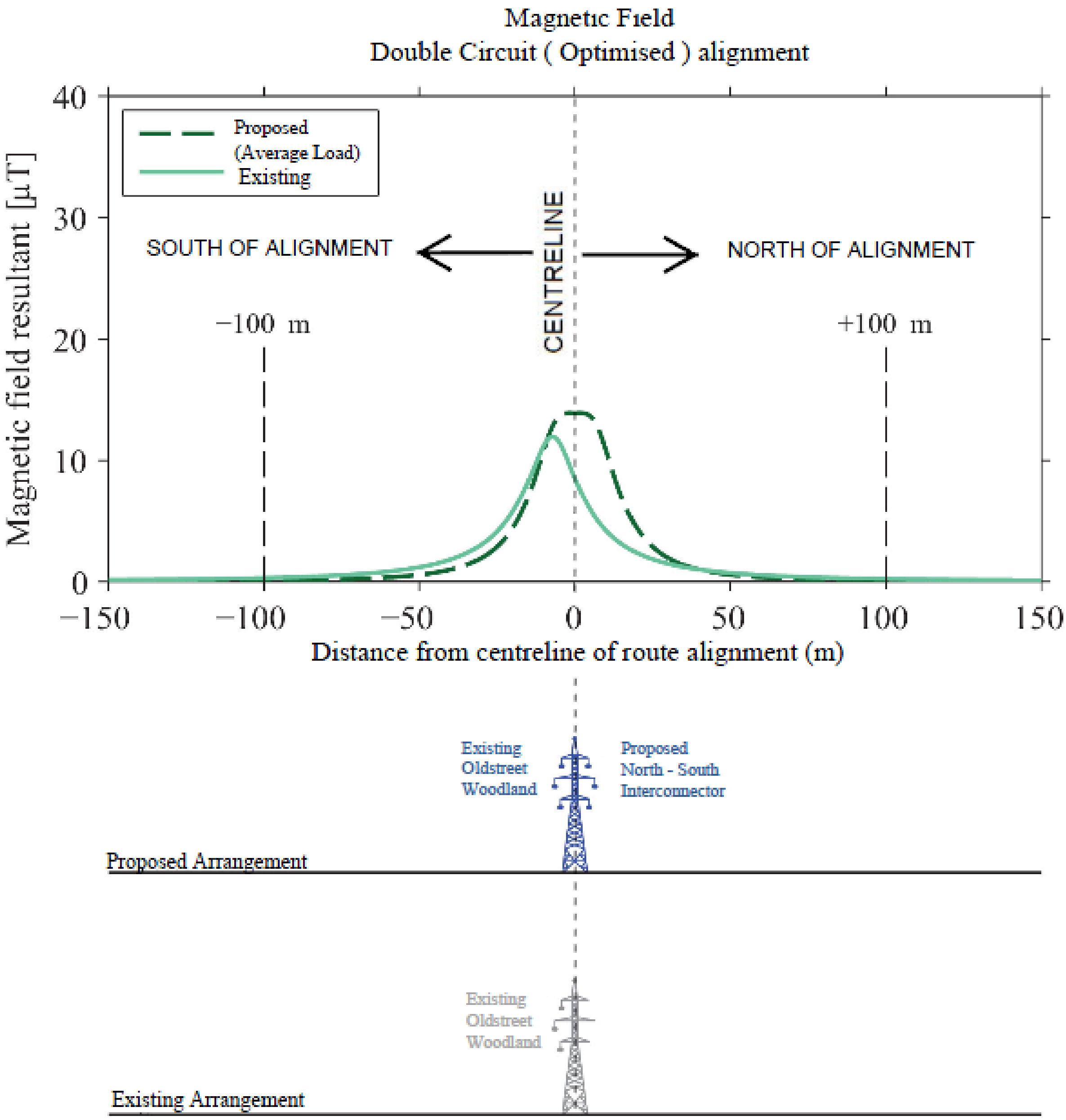

Figure 8.10: Calculated Magnetic Field Profile for the Existing and Proposed Double-Circuit Lattice Tower Configuration for Average Load and Using Optimised Phasing

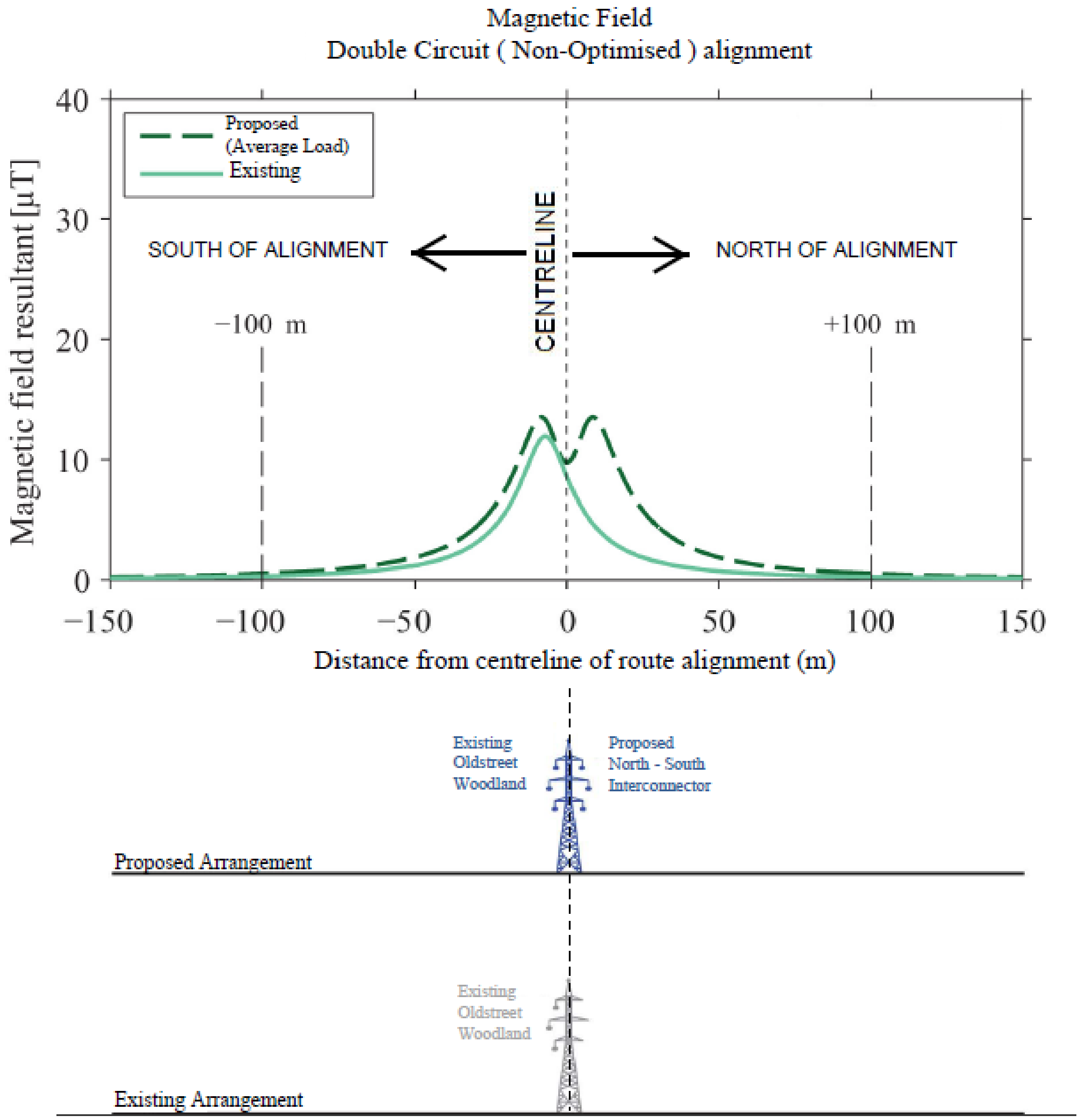

Figure 8.11: Calculated Magnetic Field Profile for the Existing and Proposed Double-Circuit Lattice Tower Configuration for Average Load and Using Non-Optimised Phasing

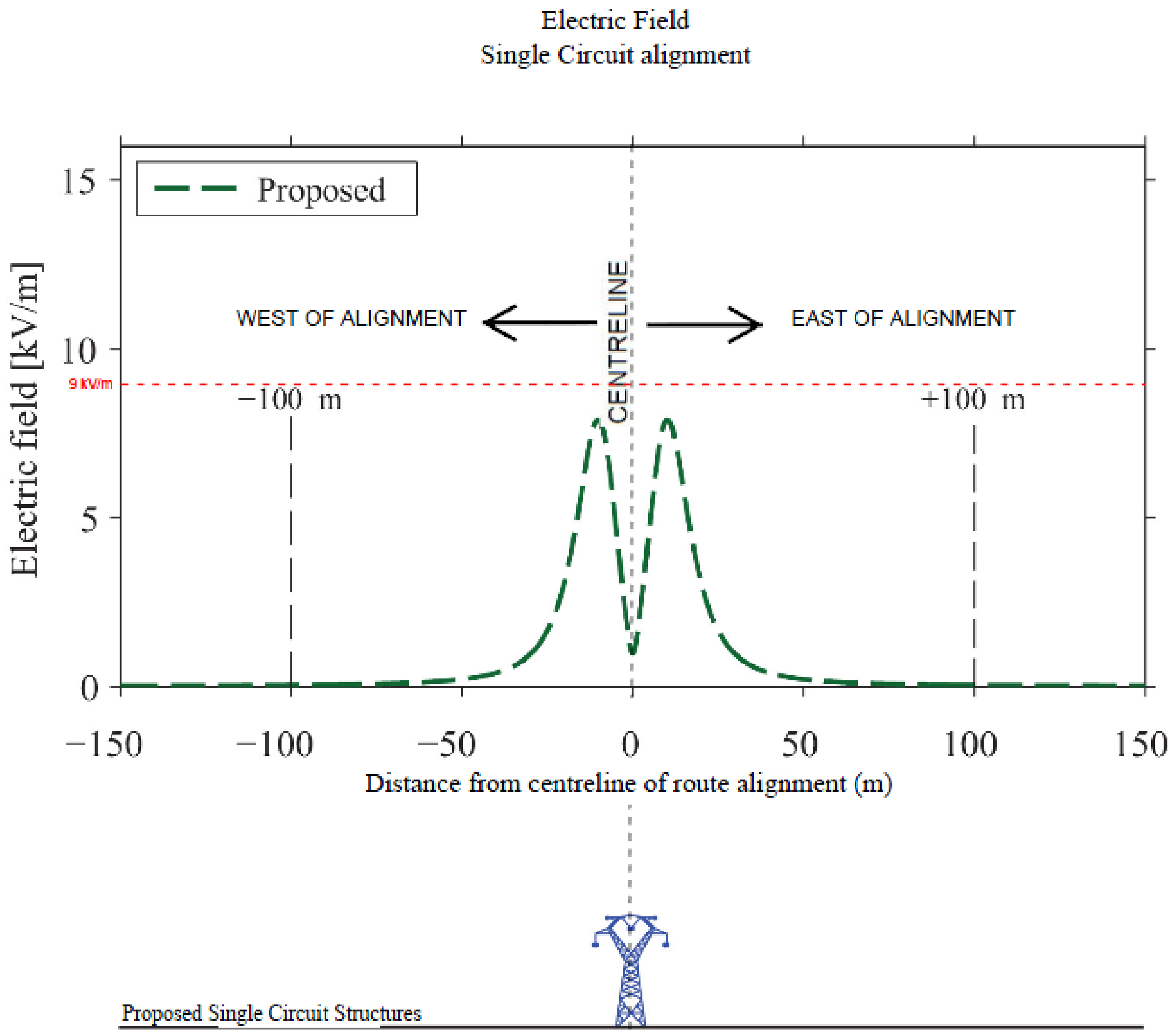

Figure 8.12: Calculated Electric Field Profile for the Proposed Intermediate Lattice Tower Configuration

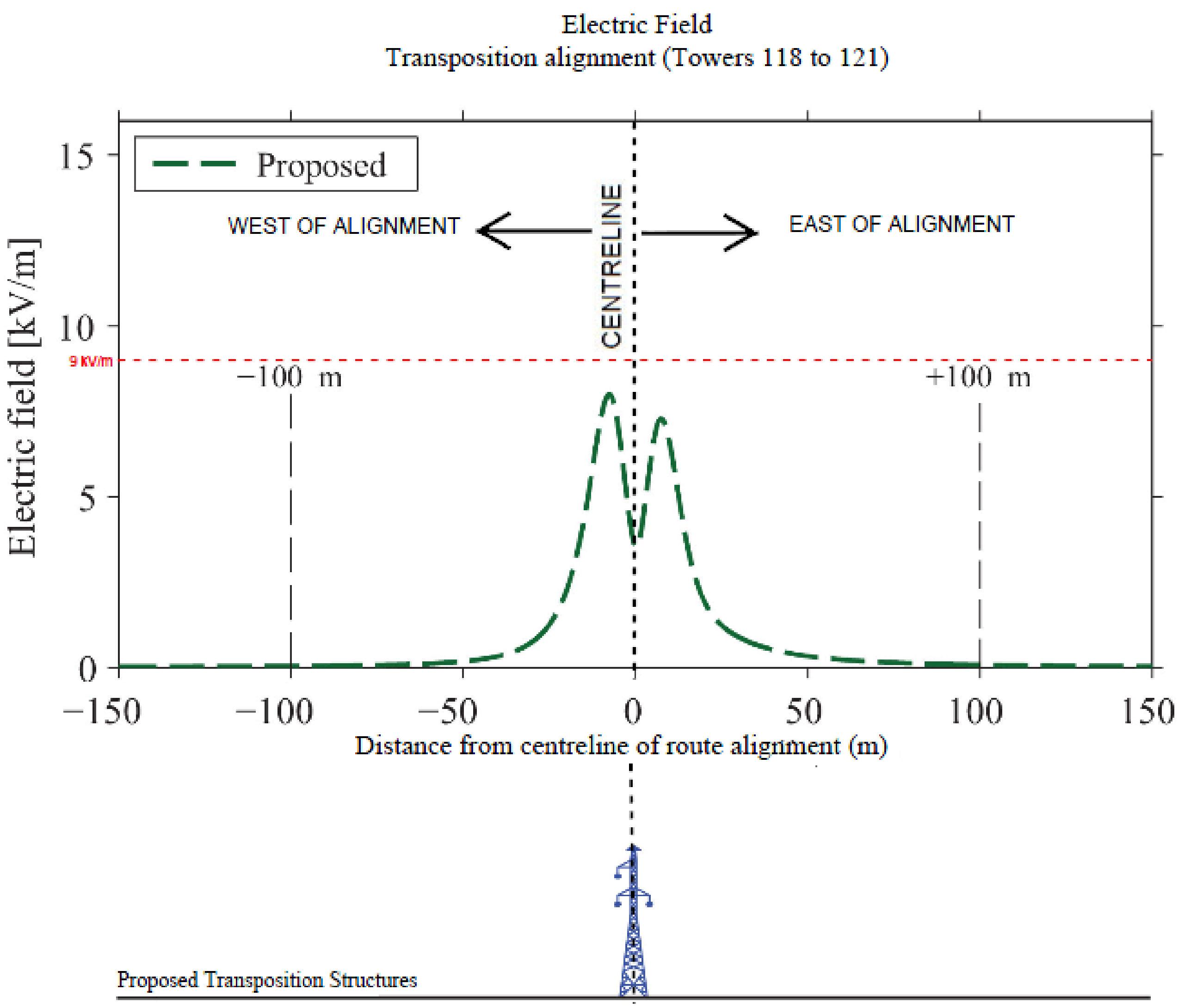

Figure 8.13: Calculated Electric Field Profile for the Proposed Transposition Tower Configuration

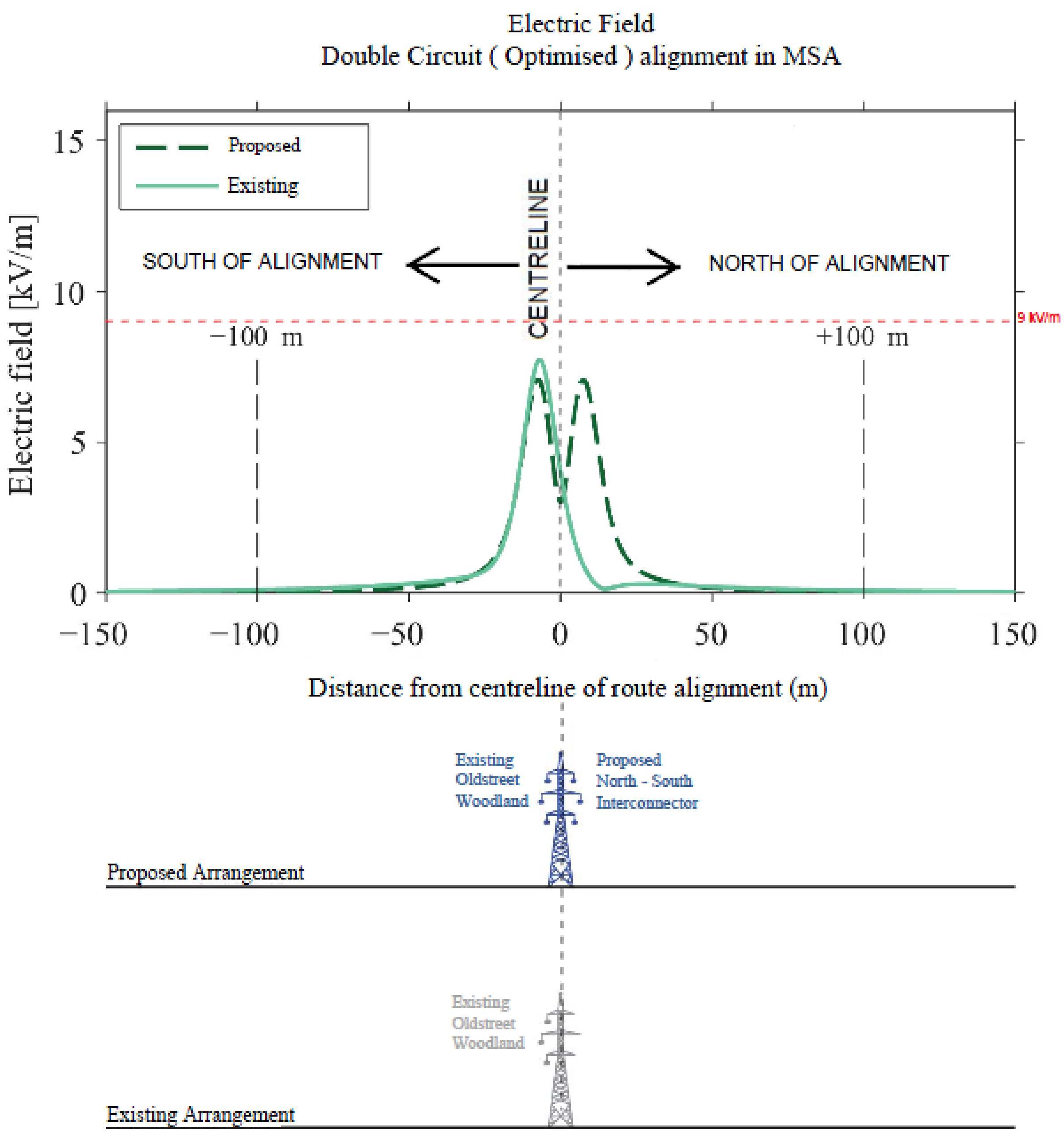

Figure 8.14: Calculated Electric Field Profile for the Existing and Proposed Double-Circuit Lattice Tower Configuration Using Optimal Phasing

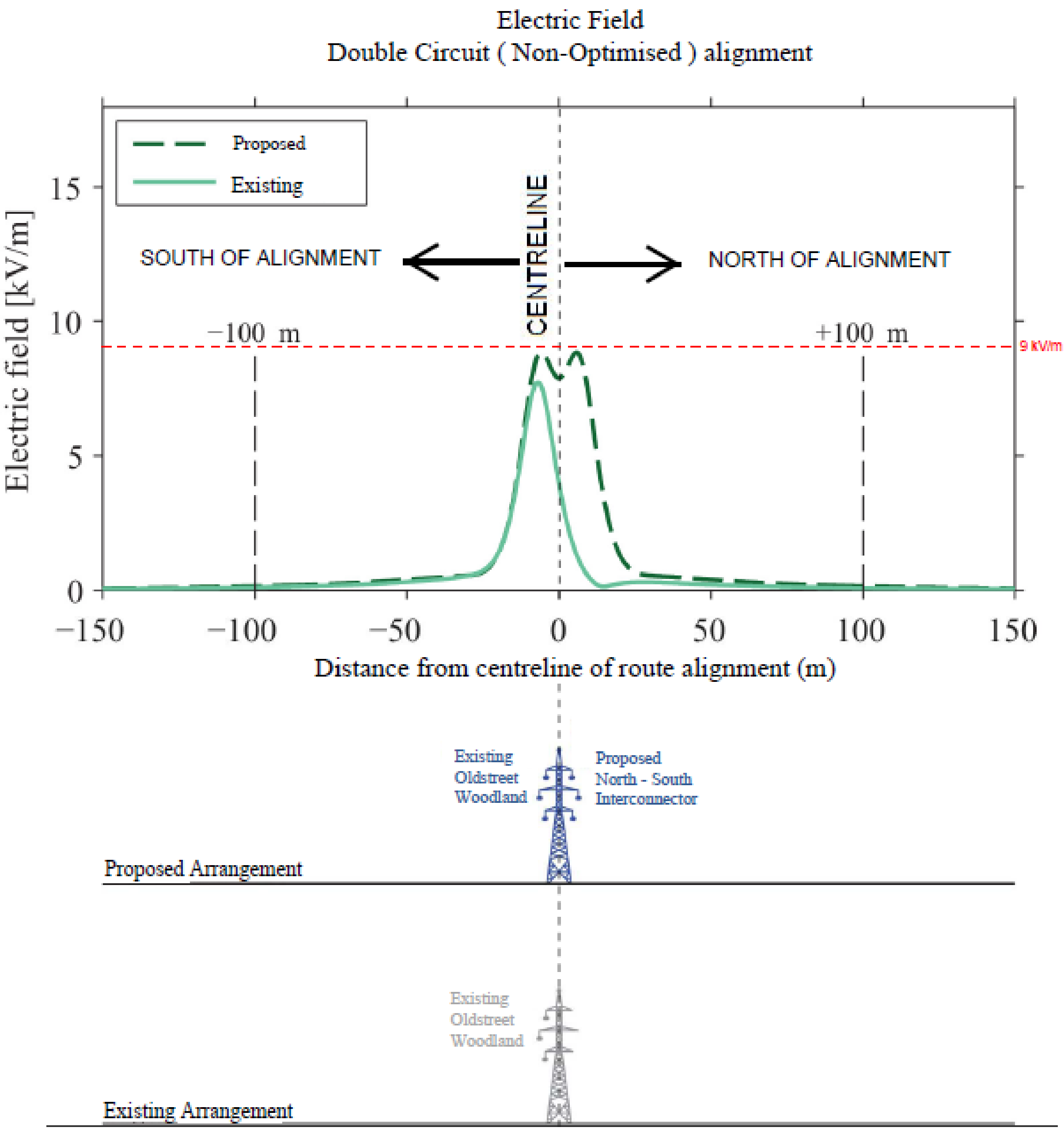

Figure 8.15: Calculated Electric Field Profile for the Existing and Proposed Double-Circuit Lattice Tower Configuration Using Non-Optimal Phasing

8.9 SUMMARY AND CONCLUSIONS

145 Although most people are constantly exposed to background levels of magnetic fields daily from common sources such as appliances, electronic devices, and distribution lines in home and workplace environments, proposed transmission line projects can raise public concern. Perceived risk of exposure from transmission lines is a relatively common response to such projects (Repacholi, 2012), although the WHO points out that "*exposure of people living in the vicinity of high voltage transmission lines differs very little from the average exposure of the population*" (WHO, 2014).

146 This chapter provides information on calculated levels of ELF EMF that can be anticipated in the vicinity of the proposed 400 kV transmission line and summarises the results of scientific research that has been conducted to investigate potential health effects related to ELF EMF. It provides a summary of the conclusions of reviews and exposure guidelines developed by national and international scientific and health agencies to protect the health of workers and the general public and it demonstrates by calculations that the proposed development complies with the relevant exposure guidelines. This information addresses both regulatory requirements and responds to issues raised by stakeholders during the public consultation.

147 EMFs are present in both natural and manmade environments. Natural sources of EMF include, for example, the earth's geomagnetic field and the electric field beneath an active thunderstorm. Electricity used in Ireland is alternating current that oscillates 50 times each second (i.e. at a frequency of 50Hz) and creates both electric and magnetic fields wherever electricity is generated, transmitted, distributed, or used in the home, in the workplace, and other areas.

148 The strength of an electric field is directly related to the voltage of the source and so the electric field under an outdoor power line is higher than the electric field from the low voltage on home wiring. The transmission lines operating at 400 kV will produce a 50Hz electric field of approximately 7.9kV/m beneath the transmission line. The electric field level decreases to 0.04kV/m approximately 100m away from the transmission line centreline, a reduction by a factor of almost 200. Electric fields are easily blocked by conductive objects, such as fences, trees, and even the human body.

149 Magnetic fields are created by the flow of electrical current (i.e. by the flow of electric charges through power lines). The earth's geomagnetic field which is used for navigation by compass is approximately 50µT throughout Ireland. Magnetic fields are not easily blocked by objects, so the range of exposures to ELF EMF encountered in daily life can range widely from as little as 0.01µT away from specific sources and as high as 1-2µT at 50cm from home appliances; exposures greater than 10µT are uncommon except very close to some household appliances

or directly beneath a high voltage transmission line; both of these occasions generally occur for short periods. The ELF magnetic field from the proposed 400 kV transmission line is calculated to be highest directly under the line at the location where the wires are closest to the ground, usually the midspan point, and based on average loading on the line is calculated to have a maximum level of approximately 16μT, but the intensity of the magnetic field diminishes by a factor of more than 50 to approximately 0.25μT at a distance of 100m from the centreline.

150 Since the publication of the first epidemiology study that examined a potential association between ELF EMF sources and childhood cancer in 1979 (Wertheimer and Leeper), researchers in various scientific disciplines have conducted studies to investigate potential health effects of EMF exposure. These studies include both epidemiology studies and laboratory studies of humans, animals, tissues, and cells. Epidemiology studies investigated whether persons with certain health conditions, including cancer, had greater exposure to EMF. Laboratory studies examined whether exposure to EMF in the laboratory could affect the health of persons and animals or produce biological responses in cells and tissue. A summary of recent research on the epidemiology of childhood and adult cancer, and other conditions (e.g. neurodegenerative disease, melatonin production) provides a context for understanding why health and scientific agencies have not concluded that exposures to ELF EMF at levels encountered in our daily life are a health hazard. While some of the epidemiology studies have reported statistical associations between higher average long term exposure to magnetic fields and childhood leukaemia, in particular, the role of chance, systematic error, and confounding by other factors cannot be ruled out as explanations. Moreover, a biological basis for these statistical associations is not supported by studies involving lifelong exposures of laboratory animals to magnetic fields. Similarly, studies of cells and tissues have not confirmed a mechanism by which weak ELF magnetic fields commonly encountered in our environment could have carcinogenic effects by either initiating or promoting cancer.

151 Everyone in developed and in most developing countries has exposure to ELF EMF wherever they live. Numerous national and international scientific and health organisations, including the WHO, the IARC, ICNIRP, the National Institute of Environmental Health Sciences in the United States, and the HPA in the United Kingdom have reviewed the existing scientific literature to assess the potential health risks arising from this widespread exposure to EMF. Following its most comprehensive in-depth review of the scientific literature on potential health effects related to EMF, the WHO made the following statement "*Based on recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields"* (WHO, 2014).

152 Scientifically-based exposure guidelines have been recommended by ICNIRP to protect the public and workers from known effects of EMF that occur at high levels of exposure, such as nerve and muscle stimulation and annoyance due to micro-shocks. The guidelines incorporate

large safety factors to ensure that allowable exposures are far lower than the lowest threshold for confirmed potentially adverse biological effects. ICNIRP also determined that evidence from studies with exposures below these guidelines and from studies of long term health outcomes "*is too weak to form the basis for exposure guidelines*." The guidelines developed by ICNIRP form the basis for the EC's Recommendation (1999/519/EC) which sets out guidelines for member states on limiting the exposure of the public to EMF in locations where people spend significant time. The EC Recommendation is the de facto guideline applicable in Ireland and "*provides adequate protection for the public from any EMF sources*" (DCMNR, 2007).

153 The calculations of EMF provided above clearly demonstrate that the electric and magnetic field levels produced by the proposed 400 kV line meet the EU (1999) exposure limits (basic restrictions) and so would not cause internal electric fields and current density to exceed these biologically-based limits on exposure. Since these calculations are based on conservative assumptions about the operation of the proposed line, they are likely to overestimate levels of EMF from the transmission line.

154 While consideration of low-cost precautionary measures to minimise exposure to EMF in siting or line design have been recommended (DCMNR, 2007; WHO, 2007b) and followed in the case of this proposed development (i.e. avoiding residences to the greatest extent possible and minimising EMF by optimal phasing of the transmission line where it is supported on double-circuit structures), changes to current EMF guidelines were judged inappropriate by the EC "*as there are no clear scientific indications that the possible effects on human health may be potentially dangerous"* (EU, 2002). Undergrounding the proposed line, which might minimise the area where magnetic field exposure occurs, depending upon routing, cannot be considered as a "*reasonable and warranted"* precautionary measure under the WHO's recommendations based on both scientific grounds as discussed above, or on economic grounds (Parsons Brinkerhoff, 2009 and 2013).

155 Other topics that were referenced in public submissions include potential interference with implanted medical devices (such as pacemakers) and potential effects on plants and animals. CENELEC has indicated that exposure to fields below reference levels given by the EU (1999) mentioned above for human exposure also are sufficient to prevent interference with active implanted medical devices (CENELEC 50527-1 2010).

156 Research accumulated over the past 40 years on plants and animals exposed to ELF EMF from transmission lines and research conducted in the laboratory does not confirm any harmful effects of EMF on the health, behaviour, productivity, or reproductive potential of plants and animals.

157 In summary, even making conservative assumptions about the operating conditions assumed for the EMF calculations that would tend to overestimate field levels, the EMF levels from the proposed 400 kV line and for the short section (between towers 402 to 410) carried on the existing double circuit towers are still below EMF limits established by the basic restrictions on public exposure applied within Ireland and the EU.

158 Furthermore, existing electricity infrastructure complies with the European Union (EU) Recommendation on the *Limitation of Exposure of the General Public to Electromagnetic Fields* (1999/519/EC) and will continue to do so where alterations are required for compatibility with the proposed project.

159 A survey of scientific research on topics relating EMF to health of humans and other species did not show that EMF at these levels would have adverse effects on these populations. This assessment is consistent with reviews by national and international health and scientific agencies.