Appendix 3.1 Electromagnetic Field (EMF) Report

Contents

Limitations

As part of the planning application in respect of the Laois-Kilkenny Reinforcement Project, Exponent prepared a summary report on the status of research related to electric and magnetic fields and health as it relates to the Project.

In addition, Exponent conducted specific modeling and evaluations of components of the electrical environment of this project. Appendix A summarizes the modeling work performed to date and presents the findings resulting from that work. In the analysis, we have relied on, but not verified, the transmission line design geometry, usage, specifications, and various other types of information provided by the client. Although Exponent has exercised usual and customary care in the conduct of this analysis, the responsibility for the design and operation of the project remains fully with the client.

The findings presented herein are made to a reasonable degree of engineering and scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Executive Summary

As part of the Laois-Kilkenny Reinforcement Project, EirGrid plans to construct a new substation in the townland of Coolnabacky near the town of Timahoe in County Laois. One new 110 kilovolt (kV) transmission line and three existing transmission lines (110 kV and 400 kV) will be modified as part of this project.

The transmission lines operating at 110 kV will produce an electric field of approximately 1.7 kilovolts per metre (kV/m) beneath these lines and will be over 80 times lower at a distance of 50 metres (m) from the centreline (i.e., 0.02 kV/m or less). The magnetic fields from the 110 kV lines will be relatively unchanged in some portions of the project and increase somewhat in other portions. The magnetic field beneath the conductors will be 6 to 11 microtesla (µT), but will drop 50 to 60-fold to ≤ 0.2 µT at a distance of 50 m from the centreline.

The only section of the project for which electric and magnetic field (EMF) levels will increase above the levels just described is the relatively short section where the two new 400 kV tap lines carry electricity to and from the new substation on double-circuit lattice steel towers. The two circuits together will produce an electric-field level beneath the line of 7.68 kV/m and a magnetic-field level beneath the line of 13.9 µT. At 50 m to the east of the centreline of these double-circuit structures, the electric and magnetic fields are projected to be 1.68 kV/m and 7.1 µT, respectively. At 75 m, these values will drop to 0.36 kV/m and 1.6 µT. On the western side of the section near the existing 110 kV line, the addition of the 400 kV lines will have only a very small effect on the existing field levels.

International guidelines for both public and occupational exposure to extremely low frequency (ELF) EMF were issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1998 and updated in 2010 (ICNIRP 1998, 2010) and by the International Committee on Electromagnetic Safety (ICES) in 2002. In Ireland, the Communications Regulator and the Commission for Energy Regulation have adopted the 1998 ICNIRP guidelines (DCMNR, 2007). **The EMF produced by transmission lines in this project are all below the limits, i.e., theBasic Restriction Levels, recommended by these international organisations.**

Introduction

Electric power in Ireland is transmitted throughout the country over an extensive electrical network that includes over 6,500 kilometres (km) of high-voltage transmission lines from generation facilities. The Laois-Kilkenny Reinforcement project planned by EirGrid consists of two new substations—one in the townland of Coolnabacky near the town Timahoe in County Laois and one in the townland of Moatpark near the town of Ballyragget in County Kilkenny. A new double-circuit loop connection of the 400 kV Dunstown-Moneypoint transmission line will connect to the proposed Coolnabacky 400/110 kV Substation and a new 110 kV transmission line will connect to Coolnabacky Substation. The existing Athy- Portlaoise 110 kV line (which crosses the Coolnabacky site) will also connect to the Coolnabacky 400/110 kV Substation. In addition, the existing 110 kV line from Ballyragget-Kilkenny, which is currently operating at 38 kV, will be rebuilt as a 110 kV transmission line. This chapter provides background information on electric and magnetic fields (EMF), discusses known effects from short-term exposure and the guidelines established to mitigate such effects, and summarizes reviews that evaluate the weight-of-evidence, derived from studies of longer-term exposure and health by international and governmental agencies. The EMF calculations for the various aspects of this project are provided in Appendix A.

Overview of Electric and Magnetic Fields

Electromagnetic Spectrum

EMF are a type of electromagnetic energy, which are characterized on the electromagnetic spectrum by their frequency, i.e., number of times these fields change direction and amplitude per second. On the electromagnetic spectrum, EMF falls into the extremely low frequency (ELF) range of 30-300 Hertz (Hz). A related characteristic of electromagnetic energy is its wavelength. 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 the interaction with objects and living things. The coupling of fields to objects is greatest when the wavelength of the field is similar to the size of the object. Electricity is transmitted in the power system in

Ireland as alternating current (AC) at a frequency of 50-Hz; therefore, because of their long wavelength of approximately 6,000 km, the fields do not couple well to organisms. A radiofrequency field at 800 megahertz, on the other hand, has a wavelength on the order of 37 centimeters (cm), more similar to the diameter of the human body, which allows for more efficient coupling. At sufficiently high intensities, radiofrequency energy in the very high frequency range can heat tissue, and ultraviolet light and higher frequency energy can damage cells directly.[1] Thus, ELF EMF, with low frequency and long wavelength, need to be considered separately from energy at these other frequencies to evaluate potential health effect of interactions in the ELF range with living things.

Electric and Magnetic Fields in our Everyday Environment

All components of the transmission system that generate or transmit electricity, such as generating stations, substations, transmission lines, and distribution lines produce ELF EMF. In addition, anything that uses electricity in our homes, schools, and workplaces is a source of ELF EMF. These fields describe the way electrical charges interact around a source.

Electric fields occur as the result of voltage applied to electrical conductors and equipment. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per metre (kV/m); 1 kV/m is equal to 1,000 V/m. The voltage of the transmission system will determine the electric field level produced—the higher the voltage, the higher the electric field level. Since the voltage of electrical equipment is quite constant, the electric field it produces is also constant.

Magnetic fields are produced by the flow of electric current. The magnetic field is expressed as magnetic flux density in units of microtesla (μT). In a transmission system, magnetic field levels depend on the arrangement of electrical conductors. In addition, like electric field levels that vary with voltage, magnetic field levels depend on the amount of current applied, so the higher the current, the higher the magnetic field generated. Unlike electric fields, however, magnetic fields are only present when electrical equipment is turned on (i.e., current is flowing).

1 Note, these forms of electromagnetic energy are not produced by ELF sources to any significant extent.

Several other characteristics of ELF EMF are relevant. Electric fields are commonly blocked by conducting objects—trees, shrubbery, fences, building, and even the human body—while magnetic fields are not effectively blocked by conducting objects. So contributions to a person's electric field exposure are more common from indoor sources, while magnetic field exposure levels are determined from multiple sources—both indoors and outdoors.

A common factor is that both electric and magnetic field levels diminish quickly with distance from the source. Magnetic fields, rather than electric fields, have been the focus of most research on ELF EMF exposure over the past 30 years for two main reasons—electric fields are effectively blocked by most objects and early research did not reveal an association between long-term electric field exposure and any health effects.

ELF EMF sources and exposure considerations

Over the past 100 years, the increasing reliance worldwide on electricity in all facets of daily life has made exposure to ELF EMF from power sources ever-present. 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.

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.

Background levels

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 0.01 µT and 0.2 µT.[2] 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 0.038 µT in homes (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.

Exposure from appliances

The strongest sources of magnetic fields encountered indoors are electrical appliances and equipment. While these fields may diminish with distance from the source more rapidly than fields from power 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 50 cm using a procedure that best characterized normal use (Table 1).

Table 1. Average magnetic field level from appliances measured at 50 cm.

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

Transmission and distribution lines

In outdoor environments, the most common sources of magnetic fields are distribution and transmission lines. Since the intensity of magnetic fields diminishes quickly with distance from

[2] http://www.hpa.org.uk/Topics/Radiation/UnderstandingRadiation/UnderstandingRadiationTopics/ElectromagneticFields/ElectricAndMagneticFields/SourcesAndExposureToElectricAndMagneticFields/#exposure

the source, however, the contribution to indoor magnetic field levels from transmission lines is usually not extensive. 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 as 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).

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[3] in 2004 of representative local substations in the United Kingdom supports this conclusion. Magnetic field levels at enclosure boundaries overall were 1.1 µT, while at distances of 5 m to 10 m outside the substation fence, the magnetic field was not detectable above between 0.02 µT and 0.05 µT. Consistent with the IEEE's finding, along the path of cables entering the substation, the magnetic field was measured at 1 µT. The National Grid conducted a similar survey of suburban substations. Magnetic field levels of 1.9 µT diminished by more than half at 1.3 m. In the vicinity of nearby housing at about 5 m, the fields could not be distinguished from other background sources (HPA, 2004).

Personal exposure

Every person's average exposure to magnetic fields is determined by the environments where one spends time, the sources encountered in those locations, and the duration of exposure. If someone worked as a welder or lived in a home with faulty wiring, for example, his or her average exposure may be elevated during those periods.

---

3 The National Radiological Protection Board was merged into the Health Protection Agency of Great Britain in 2005.

Numerous exposure assessment methods have been developed to estimate personal exposure to magnetic fields. These methods include calculated historical fields; personal exposure meters; spot measurements; wire code categories; distance; 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 effects 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.

Monitoring a person's personal exposure levels with a recording magnetic field meter is preferred, but this type of measurement is often utilized 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 long-term variations a person experiences from year to year, so may not fully represent past exposure (WHO, 2007).

Brief encounters with high magnetic field levels, such as 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 time-weighted average (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 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 measurements from many sources over time is a common source of confusion when assessing exposure levels (Bailey and Wagner, 2008).

Electric and magnetic fields from existing transmission lines and the proposed Laois-Kilkenny Reinforcement Project

The existing and proposed lines in the vicinity of the Project are shown in Figure 1.

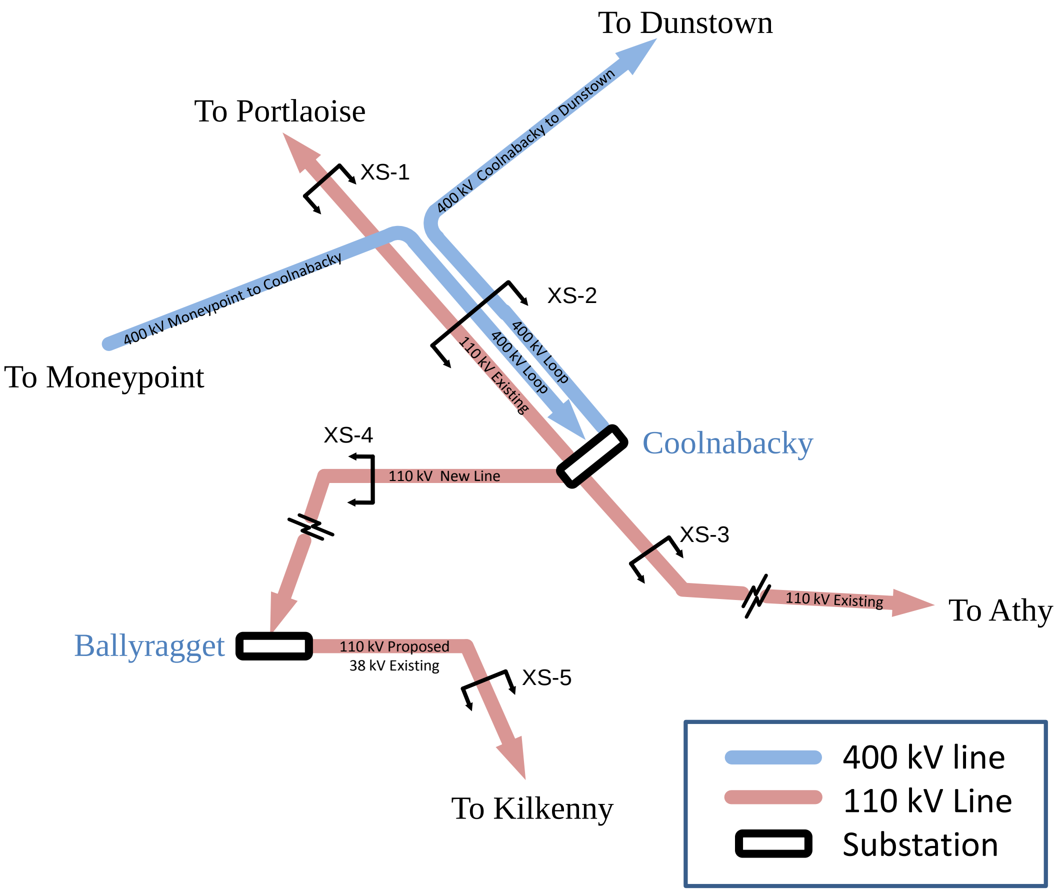

Figure 1. Schematic representation of the routes of existing and proposed transmission lines. The five route sections which were modeled are also marked.

For the first 2.3 km of the line in route section XS-3 and all of route section XS-5, the conductors of existing lines will be reconductored to accommodate higher line loads; a new line will be added on the XS-4 route, and the voltage of XS-5 conductors will be upgraded from 38 kV to 110 kV operation. At 110 kV the electric fields under these lines are all about 1.7 kV/m and at 50 m from the centreline of the structures the electric field will be over 80 times lower, 0.02 kV/m or less. The magnetic fields from the lines in the XS-4 and XS-5 route sections will increase under the conductors after construction to 10.6 µT but will drop more than 50-fold to 0.2 µT at a distance of 50 m from the centreline. The project would not appreciably change the levels of electric or magnetic fields after construction from existing levels on route section XS-1 or XS-3. In these sections, the magnetic field levels today or in the future will all be very low, 0.1 µT, at a distance of 50 m.

The only line section of the project for which electric and magnetic field levels will increase above those just described above is XS-2 where the new 400 kV tap lines carrying electricity to and from the substation will be mounted on double-circuit lattice steel towers. One tap line will be mounted on one side of the towers; the other tap line on the opposite side. The two together will produce an electric-field level under the line of 7.68 kV/m and a magnetic-field-level under the line of 13.9 µT. At 50 m to the east of the centreline of these structures the electric and magnetic fields are projected to be 1.68 kV/m and 7.1 µT, respectively. At 75 m, these values will drop to 0.36 kV/m and 1.6 µT. On the western side of the section near the existing 110 kV Portalaoise-Coolnabacky line, the addition of the 400 kV lines and the choice of phasing will have only a very small effect on the existing field levels.

Exposure guidelines from international organisations

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 European Union used the 1998 guideline as the basis for guidelines on human exposure to EMF from power sources that they incorporated into their recommendation that they be applied to location 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).

In determining their guidelines, the ICNIRP conducted a weight-of-evidence review of the cumulative research at the time (in both 1998 and 2010) and concluded that the epidemiologic data was not sufficient to establish any guidelines as the evidence did not 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, and the stimulation of nerves and muscles. These responses to exposure are transitory and non-life threatening.

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 judged 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 50 Hz fields for the general public are presented in Table 2.

Table 2. General public reference levels (ICNIRP) and maximum permissible exposures (ICES) and exposure levels estimated to produce internal current densities and electric fields equal to Basic Restrictions

Agency	Magnetic Field (μT)	Electric fields (kV/m)
ICNIRP (1998)		
Reference Level	100	5
Basic Restriction[a] exposure	364	9.22
ICNIRP (2010)		
Reference Level	200	5
Basic Restriction[b] exposure	200[c]/ 474[d]	9.9[d]
ICES		
Maximum Permissible Exposure	904 μT	5 or 10[e]
Exposure = Basic Restriction[f]	361 μT[g]	10.7[g]

[a] Basic Restriction is 2 mA/m^2 in the head. Calculated field levels from Dimbylow (2005).
[b] Basic Restriction is 20 mV/m in CNS of head.
[c] Magnetic field level of 200 μT described in ICNIRP (2010).
[d] Calculated magnetic and electric field value from Dimbylow (2005).
[e] ICES determined an exception of 10 kV/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).
[f] Basic Restriction is 5.89 mV/m in the brain.
[g] Field levels calculated from Kavet et al (2012).

Both organizations set limits on internal doses (current density or electric field) termed Basic Restrictions that are not to be exceeded. ICNIRP has published Reference Levels that set forth levels of environmental exposures that if not exceeded, would guarantee that the Basic Restrictions are met. These are listed in Table 2. For comparison, the Maximum Permissible Exposures (MPE) recommended by ICES and exposures required to produce the Basic Restriction on internal electric fields are also included in Table 2.

If environmental exposures exceed the Reference Levels or MPE values that does not mean that the Basic Restrictions are exceeded; rather additional dosimetric research is needed. Both organizations incorporate large safety factors, i.e., the guidelines are at a level greatly below that which effects are known to occur in order to account for any unknown variability or greater likelihood for effects on susceptible populations.

ELF EMF Research

Research on ELF EMF and health has been conducted for several decades. While early research at the beginning of the twentieth century focused on the basic nature of ELF EMF and its interaction with the human body, it was not until the late 1970s that the first community epidemiology study was published. This study by Wertheimer and Leeper (1979), which suggested that children with cancer were more likely to live near electric distribution lines that had characteristics predictive of higher ELF EMF levels, was the impetus for the large body of peer-reviewed, scientific studies that has been published over the past 30 years. These include experimental studies on animals (*in vivo*) and cells (*in vitro*) on exposure to ELF EMF and epidemiology studies of various health outcomes (including cancer in adults and children, neurodegenerative disease, and reproductive and developmental effects).

Over the past twenty years, numerous multi-disciplinary national and international scientific and governmental organizations have performed periodic weight-of-evidence reviews of the EMF research literature. It is these types of evaluations that guide future scientific research priorities, lead scientific organizations to recommend standards and guidelines, and assist governmental organizations to establish regulations to reduce or limit potentially risky exposures, if needed.

Weight of evidence review process

A weight-of-evidence review begins with a systematic review of published, peer-reviewed epidemiology and experimental research. The weight that individual studies provide to the overall conclusions is not equal—studies vary widely in terms of the sophistication and validity of their methods. Therefore, each study from each discipline must be evaluated critically and a final conclusion is then reached by considering the cumulative body of research, giving more weight to studies of higher quality. Scientific and health agencies put together panels of scientists to conduct these weight-of-evidence reviews. These panels consist of experts from around the world in the areas of interest (e.g., epidemiology, neurophysiology, toxicology) and they follow standard scientific methods for arriving at conclusions about possible health risks.

The picture that is formed from a weight-of-evidence review can take on different forms. In some cases (e.g., smoking and lung cancer), a clear picture of an adverse health effect is presented by the research within a relatively short timeframe. In most cases, however, the picture is initially unclear and more questions are raised than answered. It is impossible to prove the negative in science—i.e., to say that any exposure is completely safe—therefore, research studies can only reduce the uncertainty that there is a health effect through continued research. The only way to reduce this uncertainty is to conduct high quality studies with meaningful results that are replicated across study populations (in the case of epidemiology studies) and by different laboratories (in the case of experimental research). Thus, in most areas of research, unless the data clearly indicate an increased risk at defined exposure levels, scientific panels will conclude that the research is inadequate or limited in some way and requires further study until the uncertainty has been reduced below an acceptable level. While the public may interpret this conclusion as indicating concern, it is natural for scientists to recommend future research to reduce uncertainty even around a largely negative body of research by determining whether some findings that appear positive can be confirmed. The importance of this process cannot be underestimated as scientists are well aware that establishing the validity of research findings can be difficult because most findings from either epidemiology or experimental laboratory studies cannot be replicated (Begley and Ellis, 2011; Ioannidis et al., 2011).

Weight of evidence assessment of cancer research

IARC is a division of the World Health Organization (WHO). The objective of the IARC is to promote international collaboration in cancer research. The Agency is inter-disciplinary, bringing together skills in epidemiology, laboratory sciences and biostatistics to identify the causes of cancer. The IARC conducts weight-of-evidence reviews as part of its standard process for identifying carcinogens and has adopted standard language to describe the research findings. Other scientific agencies, including the WHO, have adopted this language and classification scheme. These classifications are described here because the general public's interpretation of the IARC terms can be very different from the true meaning of these terms.

First, each research type (epidemiology, *in vivo*, and *in vitro*) is evaluated to determine the strength of evidence in support of carcinogenicity. Epidemiology studies are characterized as having *sufficient evidence* for carcinogenicity if an association is found and chance, bias, and confounding[4] can be ruled out with "reasonable confidence." *Limited evidence* describes a body of epidemiology studies where the findings are inconsistent or if an association is observed, there are outstanding questions about study design or other methodological weaknesses that preclude making strong conclusions. *Inadequate evidence* is assigned if there is a lack of data or there are major quantitative or qualitative issues with the body of studies. The same overall categories apply for *in vivo* research. *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.

Agents are then classified into five overall categories using the combined categories from epidemiology, *in vivo*, and *in vitro* research (listed from highest to lowest risk): (1) known carcinogen, (2) probable carcinogen, (3) possible carcinogen, (4) non-classifiable, and (5) probably not a carcinogen. The category possible carcinogen 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.

---

[4] Chance refers to a random event; an association may be observed that is simply the result of a chance occurrence. Bias refers to any error in the design, conduct, or analysis of a study that result in a distorted estimate of an exposure's effect on the risk of disease. Confounding is a situation in which an association is distorted because the exposure being studied is associated with other risk factors for the disease.

The IARC has reviewed over 900 substances and exposure circumstances to evaluate their potential carcinogenicity. Over 80% of exposures fall in the categories possible carcinogen (28%) or non-classifiable (53%). 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 a carcinogen, which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

In 2002, a Working Group of scientists convened by IARC classified ELF magnetic fields as a possible carcinogen, this classification, however, does not provide any context for understanding how likely it is that magnetic fields are carcinogenic. This perspective is provided by subsequent reviews by health and scientific agencies summarized below. While the possibility of a relationship between magnetic fields and cancer cannot be ruled out yet because researchers cannot explain a statistical association that was found in some epidemiology studies, the full body of evidence is weak and a cause-and-effect relationship is unlikely. Other exposures that have been classified as possible carcinogens, for example, include familiar exposures such as coffee, diesel fuel, pickled vegetables, and engine exhaust.

ELF EMF and health studies – weight of evidence reviews

As indicated above, there are three types of research that scientists use to evaluate the relationship between any environmental exposure and an adverse health effect—epidemiology studies of humans, experimental studies in animals (*in vivo*), and experimental studies in cells and tissues (*in vitro*). To evaluate potential risks of any exposure, health agencies 'weigh' the evidence obtained from these three types of research. A weight-of-evidence review is based on a comprehensive review of all three types of research together, since each type of study has inherent strengths and weaknesses. The overall pattern of results of epidemiology and experimental studies must be considered together because epidemiology studies address the limitations of experimental studies and *vice versa*.

In contrast to epidemiology studies that observe humans in their everyday environment over which researchers have no control, experimental studies are conducted under controlled laboratory conditions designed to test specific hypotheses. For example, *in vivo* studies can strictly control the exposure level in the exposed group as well as factors such as food, housing, and temperature so these variables are precisely measured in both the exposed and unexposed groups. Generally, experimental studies in animals are required to establish cause-and-effect relationships, but the results of experimental studies by themselves may not always be directly extrapolated to predict effects in human populations. Therefore, it is both necessary and desirable that biological responses to agents that could present a potential health threat be explored by epidemiologic methods in human populations, as well as by experimental studies in the research laboratory.

Conclusions of international review bodies

The organizations that have conducted recent weight-of-evidence reviews of the research literature on ELF EMF and possible adverse health effects include the European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN), the Health Council of the Netherlands (HCN), the HPA of Great Britain, the International Agency for Research on Cancer (IARC), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the Swedish Radiation Protection Authority (SSM), and the World Health Organization (WHO).

Although the nature of scientific investigation dictates that the risk of an effect from exposure to any substance, including ELF EMF, cannot be entirely ruled out, the amount and quality of research that has been conducted to date, has led these scientific organizations to consistently conclude that the evidence is insufficient to support the conclusion that there is a causal relationship between long-term exposure to ELF EMF and any disease. The extensive timeframe in which scientific investigations into the effects of ELF EMF on human health have been conducted and the consistency of results adds to the evidence that there is not an adverse effect, or that if there is a risk associated with exposure it is small.

Overall, the published conclusions of these scientific review panels over the past 30 years have been consistent. The WHO review, which is the most comprehensive weight of evidence evaluation to date, concluded:

> New human, animal, and *in vitro* studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen" (WHO, 2007, p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted" (WHO, 2007, p. 355).

Likewise, none of the other review panels concluded that magnetic fields are a known or likely cause of any adverse health effect at the long-term, low exposure levels found in the everyday environment. As a result, no standards or guidelines have been recommended by health agencies to prevent exposures at these levels. As discussed, guidelines from ICNIRP and ICES have recommended limits on exposure of the general public and workers to very high EMF levels to prevent the induction of voltages in the body that could stimulate nerves and tissue.

ELF EMF and childhood leukemia

Most of the uncertainty and controversy surrounding magnetic-field exposure is related to the research on childhood leukemia. Some epidemiology studies reported that children with leukemia were more likely to live closer to power lines, or have higher estimates of magnetic-field exposure, compared to children without leukemia; other epidemiology studies did not report this statistical association. 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 leukemia and the proportion of matched healthy controls that had average magnetic-field exposure greater than 3-4 mG suggested a possible relationship or association (Ahlbom et al., 2000; Greenland et al., 2000). These pooled analyses provide some evidence for an association between magnetic fields and childhood leukemia; 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; chance, bias, and confounding could not be ruled out with reasonable confidence. Further, *in vivo* studies 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 found a cellular mechanism by which magnetic fields could induce carcinogenesis.

Considering all the evidence together, the WHO, as well as other scientific panels, classified magnetic fields as a *possible* cause of childhood leukemia (IARC, 2002; ICNIRP, 2003; HCN, 2004; WHO, 2007). The term "*possible*" denotes an exposure for which epidemiologic evidence points to a statistical association, but other explanations cannot be ruled out as the cause of that statistical association (e.g., chance, bias, and confounding) and experimental evidence does not support a cause-and-effect relationship.

Despite additional research conducted since 2007, scientific organizations have not recommended that the classification of "possible carcinogen" be changed to any other IARC category such as "probable" or "known human carcinogen" (SCENIHR, 2009; EFHRAN, 2010; ICNIRP, 2010; SSM, 2010). ICNIRP, which conducted one of the most recent evaluations of the evidence when it revised it guidelines in 2010 concluded:

> It is the view of ICNIRP that the currently existing scientific evidence that prolonged exposure to low frequency magnetic fields is causally related to an increased risk of childhood leukemia is too weak to form the basis for exposure guidelines. In particular, if the relationship is not causal, then no benefit to health will accrue from reducing exposure (ICNIRP, 2010, p. 829).

The WHO and these more recent reviews have stressed the importance of innovative research to explain the discrepancy between the results of some epidemiology studies of childhood leukemia and the lack of evidence from experimental studies. Researchers believe that the development of childhood leukemia, like any other cancer, is influenced by a multitude of different factors, e.g., genetics, environmental exposures, and infectious agents (Buffler et al., 2005; McNally et al., 2006).

ELF EMF and other health outcomes

The WHO and other scientific organizations have not found any *consistent* associations with regard to ELF EMF exposure and any other type of cancer or disease, nor have they concluded that there is a cause-and-effect link with any health effect, including childhood leukemia (WHO, 2007; HMG, 2009; SCENIHR, 2009; EFHRAN, 2010; ICNIRP, 2010; SSM, 2010).

Although some research questions remain, the epidemiologic evidence does not support a cause-and-effect relationship between magnetic fields and adult leukemia/lymphoma or brain cancer, with the data being described as inadequate or weak (WHO, 2007; SCENIHR, 2009; EFHRAN, 2010). Scientific organizations have concluded that there is strong evidence in support of ***no*** relationship between magnetic fields and breast cancer or magnetic fields and cardiovascular disease (WHO, 2007; SSI, 2008; ICNIRP, 2010; EFHRAN, 2010; SSM, 2010).

Although two epidemiology studies reported a statistical association between peak magnetic-field exposure and miscarriage (Lee et al., 2002; Li et al., 2002), a serious bias in how these studies were conducted was identified and various scientific panels concluded that these biases preclude making any conclusions about associations between magnetic-field exposure and miscarriage (HCN, 2004; NRPB, 2004; WHO, 2007; ICNIRP, 2010).

While an association between some neurodegenerative diseases (i.e., Alzheimer's disease and amyotrophic lateral sclerosis (also known as Lou Gehrig's disease) and estimates of higher average occupational magnetic-field exposure has been reported, scientific panels have described this research as weak and inadequate and recommended more research in this area (SCENIHR, 2007; WHO, 2007; SCENIHR, 2009; HCN, 2009; ICNIRP, 2010; EFHRAN, 2010; SSM, 2010).

In summary, over the past twenty years, reviews published by scientific organizations using weight-of-evidence methods have concluded that the cumulative body of research to date does not support the hypothesis that ELF EMF causes any long-term adverse health effects at the levels we encounter in our everyday environments.

Conclusions of a review for Ireland

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. This group's conclusions 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)

The report answers many questions commonly raised by the public in relation to EMF and health. The report confirms that the ICNIRP 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" (p. 20). The conclusions of the Expert Group's assessment have been reviewed and updated more recently by Professor Denis O' Sullivan, Dublin Institute for Advanced Studies, as a member of the Panel of Experts convened by the Office of the Chief Scientific Advisor to the government of Ireland (O'Sullivan, 2010).

Precautionary recommendations

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,"[5] some persons may express concern about the perceived risk of exposure from such lines (Repacholi, 2012).

---

[5] http://www.who.int/peh-emf/about/WhatisEMF/en/index3.html

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, 2007, p. 372).

The following specific measures were suggested (adapted from WHO, 2007, 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.

- Government and industry should promote research programs to reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure (adapted from pp. 372-373, WHO 2007).

The Irish government adheres to the precautionary principle as well. In the review conducted by the Department of Communications, Marine and Natural Resources, the specific precautionary recommendation relates 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).

The above precautionary goals have been achieved by reconductoring existing lines, reducing the fields from the adjacent 400-kV lines by recommending a line phasing that reduces the magnetic field away from the lines, and paralleling an existing 110-kV transmission line. 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 incorporated stakeholder input during the consultation process as described in the Planning Report submitted with the application.

EirGrid's EMF policy

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 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 recommendations and guidelines of the various independent international bodies;
- Closely monitor and support engineering and scientific research in this area, and;

- Provide advice and information to the general public and to staff on the issue of EMF.

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.

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 ICNIRP standards provides sufficient public health protection.

Further information

Table 3 indicates the scientific organization that conducted a recent review or update or released a statement along with an online link.

Table 3. Scientific weight-of-evidence reviews on ELF EMF

Organization	Date of Publication	Online Link
The European Health Risk Assessment Network on Electromagnetic Fields Exposure	2010a	http://efhran.polimi.it/docs/EFHRAN_D2_final.pdf
	2010b	http://efhran.polimi.it/docs/IMS-EFHRAN_09072010.pdf
The Health Council of Netherlands	2009a	http://www.gezondheidsraad.nl/en/publications/advisory-letter-power-lines-and-alzheimer-s-disease
	2009b	http://www.gezondheidsraad.nl/sites/default/files/200902.pdf
The International Commission on Non-Ionizing Radiation Protection	2010	http://www.icnirp.de/documents/LFgdl.pdf
The Scientific Committee on Emerging and Newly Identified Health Risks (European Union)	2007	http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_007.pdf
	2009	http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_022.pdf
The Swedish Radiation Protection Authority	2007	http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2009/SSM-Rapport-2009-36.pdf
	2008	http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2010/SSM-Rapport-2010-44.pdf

References

Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, Linet M, Michealis J, Olsen JH, Tynes T, Verkasalo PK. A pooled analysis of magnetic fields and childhood leukemia. Br J Cancer 83:692-8, 2000.

Begley CG and Ellis LM. Raise standards for preclinical cancer research. Nature 483:531-534.

Buffler PA, Kwan ML, Reynolds P, Urayama KY: Environmental and genetic risk factors for childhood leukemia: appraising the evidence. Cancer Invest 23:6, 2005.

Department of Communications, Marine and Natural Resources (DCMNR). Expert Group on Health Effects of Electromagnetic Fields. March 2007. http://www.dcmnr.gov.ie/NR/rdonlyres/9E29937F-1A27-4A16-A8C3-F403A623300C/0/ElectromagneticReport.pdf.

Dimbylow, P. Development of the female voxel phantom, NAOMI, and its application to calculations of induced current densities and electric fields from applied low frequency magnetic and electric fields. Physics Med Biol 50:1047-1070, 2005.

European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN): Risk Analysis of Human Exposure to Electromagnetic Fields. Report D2 of the EFHRAN Project. 2010.

European Union (EU). Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). Off J Eur Comm L199/59, 1999.

European Union (EU) – European Parliament and Council. Directive 2004/40/EC of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic field) entered into force in the European Union. Off J Eur Union L184:1-9, 2004.

Greenland S, Sheppard AR, Kelsh MA, Kaune WT. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Epidemiology. 11:624-634, 2000.

Health Council of the Netherlands (HCN). ELF Electromagnetic Fields Committee. Electromagnetic Fields: Annual Update 2003. The Hague: Health Council of the Netherlands. Publication No. 2004/1, 2004.

Health Council of the Netherlands (HCN). Health Council of the Netherlands; Reports 2008. The Hague: Health Council of the Netherlands. Publication No. A09/02, 2009.

Health Protection Agency (HPA). Electricity Substations and Power Lines, March, 2004. http://www.hpa.org.uk/webw/HPAweb&Page&HPAwebAutoListName/Page/1158934607796?p=1158934607796.

Her Majesty's Government (HMG) - Department of Health, Department for Communities and Local Government & Department of Energy and Climate Change. Government response to the Stakeholder Advisory Group on extremely low frequency electric and magnetic fields (ELF EMFs) (SAGE) recommendations. 16 October 2009. http://webarchive.nationalarchives.gov.uk/+/www.dh.gov.uk/en/Publichealth/Healthprotection/DH_4089500.

International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz C95.6-2002. Piscataway, NJ: IEEE, 2002. Reaffirmed 2007.

Institute of Electrical and Electronics Engineers (IEEE). IEEE guide for the design, construction, and operation of electric power substations for community acceptance and environmental compatibility. IEEE Std. 1127-1998, 2004.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys 74:494-522, 1998.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). Exposure to Static and Low Frequency Electromagnetic Fields, Biological Effects and Health Consequences (0-100 kHz) – Review of the Scientific Evidence on Dosimetry, Biological Effects, Epidemiological Observations, and Health Consequences Concerning Exposure to Static and Low Frequency Electromagnetic Fields (0-100 kHz). *Matthes R, McKinlay AF, Bernhardt JH, Vecchia P, Beyret B (eds.).* International Commission on Non-Ionizing Radiation Protection, *2003.*

International Commission on Non-ionizing Radiation Protection (ICNIRP): Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys 2010, 99(6):818-836.

International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz C95. 6-2002. Piscataway, NJ: IEEE, 2002.

Ioannidis JP, Tarone R, McLaughlin JK. The false-positive to false-negative ratio in epidemiologic studies. Epidemiology 22:450-456, 2011.

Kavet R, Dovan T, Reilly JP. The relationship between anatomically correct electric and magnetic field dosimetry and published electric and magnetic field exposure limits. Radiat Prot Dosimetry 2012 May 22 [epub ahead of print].

Lee GM, Neutra RR, Hristova L, Yost M, Hiatt RA: A nested case-control study of residential and personal magnetic field measures and miscarriages. Epidemiology 13:21-31, 2002.

Li DK, Odouli R, Wi S, Janevic T, Golditch I, Bracken TD, Senior R, Rankin R, Iriye R: A population-based prospective cohort study of personal exposure to magnetic fields during pregnancy and the risk of miscarriage. Epidemiology 13:9-20, 2002.

McNally RJ, Parker L: Environmental factors and childhood acute leukemias and lymphomas. Leuk Lymphoma 47:583, 2006.

National Radiological Protection Board (NRPB). Review of the scientific evidence for limiting exposure to electromagnetic fields (0-300 GHz). National Radiological Protection Board (NRPB). Volume 15, No 3, 2004.

National Institute of Environmental Health (NIEHS). EMF Electric and Magnetic Fields Associated with the use of Electric Power: Questions and Answers. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the U.S. National Institutes of Health, 2002.

O'Sullivan D. A Review of Recent Investigations into the Possible Health Effects of Exposure to Electromagnetic Fields (EMF) from Power Lines. Office of the Chief Science Advisor to the Government of Ireland. 2010. File updated February 11, 2011.

Preece AW, Kaune WT, Grainger P, Golding J. Assessment of human exposure to magnetic fields produced by domestic appliances. Rad Protect Dosimetry. 83:21-28, 1999.

Repacholi M. Concern that "EMF" magnetic field from power lines cause cancer. Sci Total Environ 426: 454-458, 2012.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Possible Effects of Electromagnetic Fields (EMF) on Human Health. European Commission. Directorate C – Public Health and Risk Assessment, 2007.

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) for the Directorate-General for Health & Consumers of the European Commission. Health Effects of Exposure to EMF. January 2009.

Swanson J and Kaune WT. Comparison of residential power-frequency magnetic fields away from appliances in different countries. Bioelectromagnetics 20: 244-254, 1999.

Swedish Radiation Safety Authority (SSM): Recent Research on EMF and Health Risks: Seventh annual report from SSMs independent Expert Group on Electromagnetic Fields 2010. Report Number: 2010:44. SSM, 2010.

Wertheimer N and Leeper E. Electrical wiring configurations and childhood cancer. Am J Epidemiol 109:273-84, 1979.

World Health Organization (WHO). Environmental Health Criteria 238: Extremely Low Frequency (ELF) Fields. Geneva, Switzerland: World Health Organization, 2007.

Appendix A - EMF Associated with the Laois-Kilkenny Reinforcement Project

As part of the Laois-Kilkenny Reinforcement Project, EirGrid plans to construct a new substation in the townland of Coolnabacky near the town of Timahoe in County Laois. A new double-circuit loop connection of the 400-kilovolt (kV) Dunstown-Moneypoint transmission line will connect to the proposed Coolnabacky 400/110 kV Substation, as will a new 110 kV transmission line (approximately 26 kilometres [km]) from the proposed new Ballyragget 110 kV Substation in the townland of Moatpark near the town of Ballyragget in County Kilkenny. The existing Athy-Portlaoise 110 kV line (which crosses the Coolnabacky site) will also connect to the Coolnabacky 400/110 kV substation. In addition to the new 110 kV transmission line and the Athy-Portlaoise 110 kV and 400 kV lines, the existing 110 kV line from Ballyragget-Kilkenny, which is currently operating at 38 kV, will be rebuilt as a 110 kV transmission line.

This report provides calculations of the 50-Hertz (Hz) electric and magnetic fields (EMF), produced by the overhead transmission lines listed above. Higher frequency ELF/VLF signals (i.e., transmission line harmonics) may be present on the distribution system, but they are small and of little concern.[6] The prevalence and magnitude for frequencies above 50 Hz are even lower on transmission lines and other non-utility sources are of greater importance. [7] Calculations are made both under existing and proposed operation along five cross sections perpendicular to the route of the various transmission lines. Existing and proposed conditions on these route segments are compared to assess project-related changes to EMF levels. Electric and magnetic fields were calculated at 1 metre (m) above ground, in accordance with IEC Std. 61786, 1998[8], and are reported as the root-mean-square (RMS) resultant quantities at distances perpendicular to the transmission line. These calculations were performed using computer algorithms that have been shown to accurately predict EMF levels measured near power lines. The inputs to the program are data regarding voltage, current flow, phasing, and conductor configurations.[9] The current and voltage of all transmission lines were assumed to be in phase.

A system diagram of the reinforcement project is shown in Figure A-1, indicating the location and typical direction of current flow for each of the five separate cross sections modeled in this report.

---

[6] Deno DW and Zaffanella LE. Field Effects of Overhead Transmission Lines and Stations. Chap. 8, pp., 329-419. In: Transmission Line Reference Book: 345 KV and Above. Second ed. (Ed: LaForest JJ). Palo Alto, CA: Electric Power Research Institute, 1982.

[7] World Health Organization (WHO). Extremely Low Frequency Fields Environmental Health Criteria Monograph No.238. Geneva: WHO, 2007.

[8] International Standard IEC61786. Measurement of low-frequency magnetic and electric fields with regard to exposure of human beings – Special requirements for instruments and guidance for measurements. CEI/IEC 61786:1998.

[9] Bonneville Power Administration (BPA), an agency of the U.S. Department of Energy (BPA, 1991).

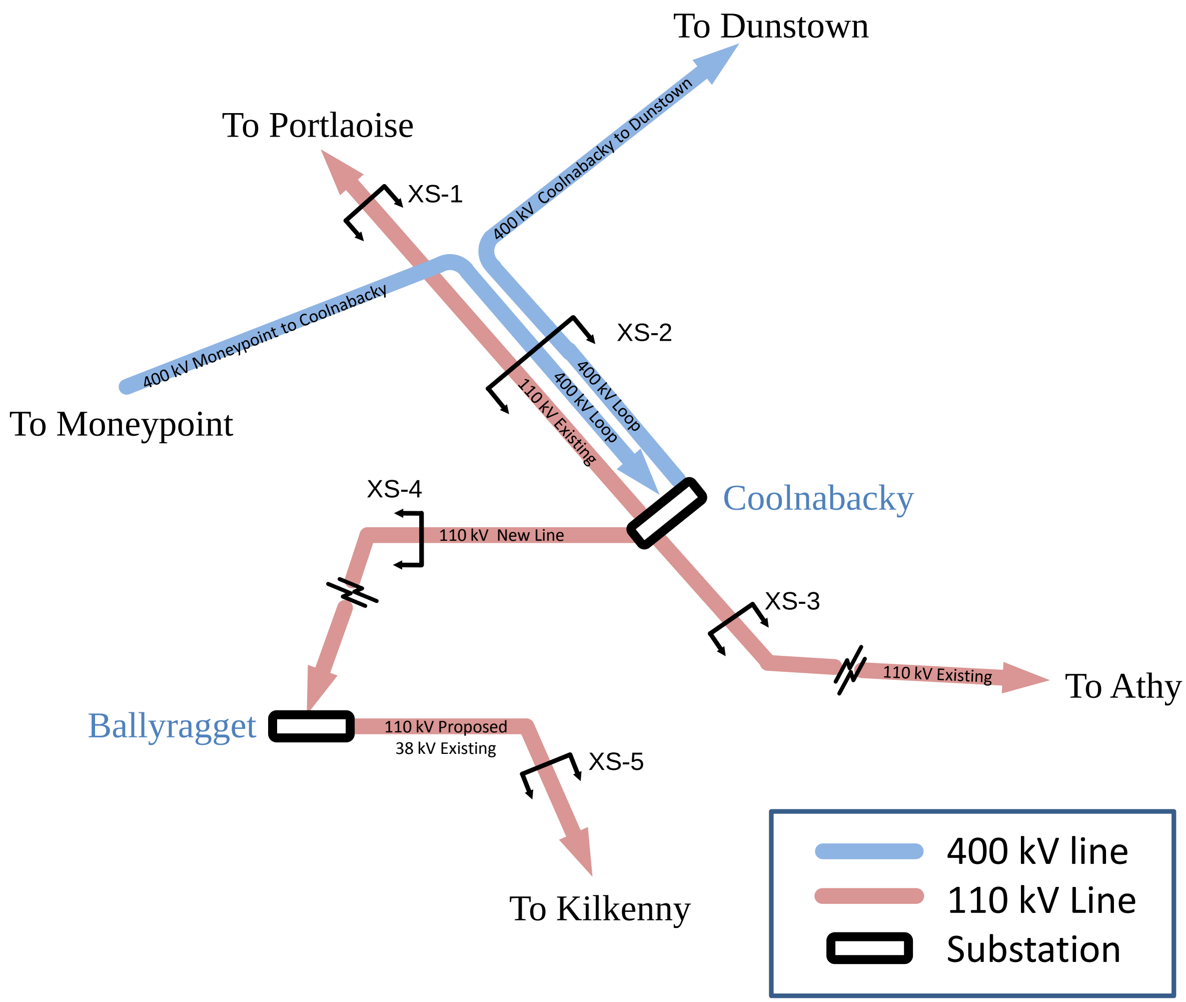

Figure A-1. System diagram of the project showing the locations of EMF modeling cross sections XS-1 through XS-5

The portion of the route between Portlaoise and Athy currently consists of a 110 kV transmission line. After construction of the reinforcement project, this portion of the line will be subdivided into three sections:

1. Cross section XS-1 is representative of approximately 7.5 km of the 110 kV transmission line from Portlaoise to approximately 1.5 km northwest of the proposed Coolnabacky Substation.[10] The existing 110 kV Portlaoise-Athy transmission line is constructed on woodpole portal structures and lattice steel towers where the line changes direction. It is strung with ACSR Wolf (18.13 millimetre [mm] diameter) conductors, no earthwires, a minimum midspan conductor height of 7 m and will not change configuration as part of this project. In the proposed configuration, the Portlaoise-Coolnabacky transmission line will be strung with ACSR Bison (27 mm diameter) conductors with earthwires for the first 1.29 km

[10] The transmission line crosses the 400 kV Moneypoint-Dunstown transmission line approximately 1.5 km northwest of the proposed substation

out of the Coolnabacky Substation; beyond this point the line will not change as part of this development.

2. Cross section XS-2 covers approximately 1.4 km of the line between the Moneypoint-Dunstown transmission line and the Coolnabacky Substation. On this portion of the route, the rebuilt Portlaoise-Coolnabacky line will be strung with ACSR Bison (27 mm diameter) conductors and will remain on woodpole portal structures and lattice steel towers. From approximately 100 m south of the Moneypoint-Dunstown line to the Coolnabacky Substation, two 7#6 Alumoweld (12.4 mm diameter) earthwires will be added to the woodpole portal structures. Approximately 62.5 m to the east of the Portlaoise-Coolnabacky line, a new 400 kV loop of the Moneypoint-Dunstown line will be constructed on double-circuit lattice towers. The 400-kV lattice towers will be strung with dual ACSR Curlew (31.68 mm diameter) conductors separated by 450 mm, with a minimum midspan conductor height of 9 m and a single ACSR Lion (22.26 mm diameter) earthwire.

3. Cross section XS-3 covers approximately 2.32 km of the 17 km of the line between the Coolnabacky and Athy Substations. This section of the line is similar to cross section XS-1, with the line supported on woodpole portal structures and steel lattice towers. The line will be strung with ACSR Bison (27 mm diameter) conductors and have two 7#6 Alumoweld (12.4 mm diameter) earthwires for the first 2.32 km out of the Coolnabacky Substation; beyond this point the line will not change as part of this development. In addition, the electrical loading of this line will differ from cross section XS-1 after construction.

In addition to changes to the Portlaoise-Athy line, the reinforcement project also includes two 110 kV transmission lines out of the Ballyragget Substation.

1. Cross section XS-4 is a new 110 kV transmission line which runs approximately 26 km between the Coolnabacky and Ballyragget Substations. This is a new transmission line with a proposed configuration identical in configuration and construction to that of XS-3 (including earthwires), but with a different loading than cross section XS-3.

2. In cross section XS-5, a transmission line runs approximately 22 km between the Ballyragget and Kilkenny Substations. Similar to cross sections XS-3 and XS-4, the transmission line is supported on woodpole portal structures and steel lattice towers. In the existing configuration, the line operates at 38 kV and the support structures are strung with ACSR Wolf (18.13 mm diameter) conductors and predominantly no earthwires except for 1.84 km out of the Kilkenny 110 kV Substation. After the reinforcement project is completed, the line will be strung with ACSR Bison (27 mm diameter) conductors and will operate at 110 kV. Earthwires consisting of two 7#6 Alumoweld (12.4 mm diameter) conductors will run on the line from the Ballyragget 110 kV Substation for the first 1.73 km and from the Kilkenny 110 kV Substation for the first 1.84 km.

Circuit loading under average- and peak-load conditions is summarized in Table A-1 for existing and proposed circuits, with the direction of typical current flow also shown in Figure A-

1 for reference. While these current magnitudes and directions are the typical expected operating conditions for the project, it is possible for the magnitude and direction of current flow in all sections to change based upon varying power demand.

Changes in calculated magnetic-field levels before and after the reinforcement project are depicted in Figure A-2 through Figure A-6 for average-load conditions. Table A-2 summarizes calculated magnetic-field levels at various locations relative to the centreline of the circuits,[11] for average-load conditions, and Table A-3 summarizes calculated magnetic-field levels at the same locations for peak-load conditions. For all modeling, minimum ground clearance was assumed for the bottommost phase of each circuit.

Changes in calculated electric-field levels before and after the reinforcement project are depicted in Figure A-7 through Figure A-11 for the same geometry described above, and the results of calculated electric-field levels at various locations relative to the centreline of the circuits are shown in Table A-4. In some cross sections, the transmission lines have portions with earthwire (typically entering or exiting the substation) and some portions without earthwire. In these cross sections, the presented electric-field calculations include the presence and effect of the earthwire.[12]

---

[11] In cross section XS-2, distances are referenced to the midpoint between the centreline of the two transmission line towers shown in Figure 2.

[12] The addition of earthwire to protect the line from lightning strikes has a small effect on the electric-field calculations, but does not affect magnetic-field calculations.

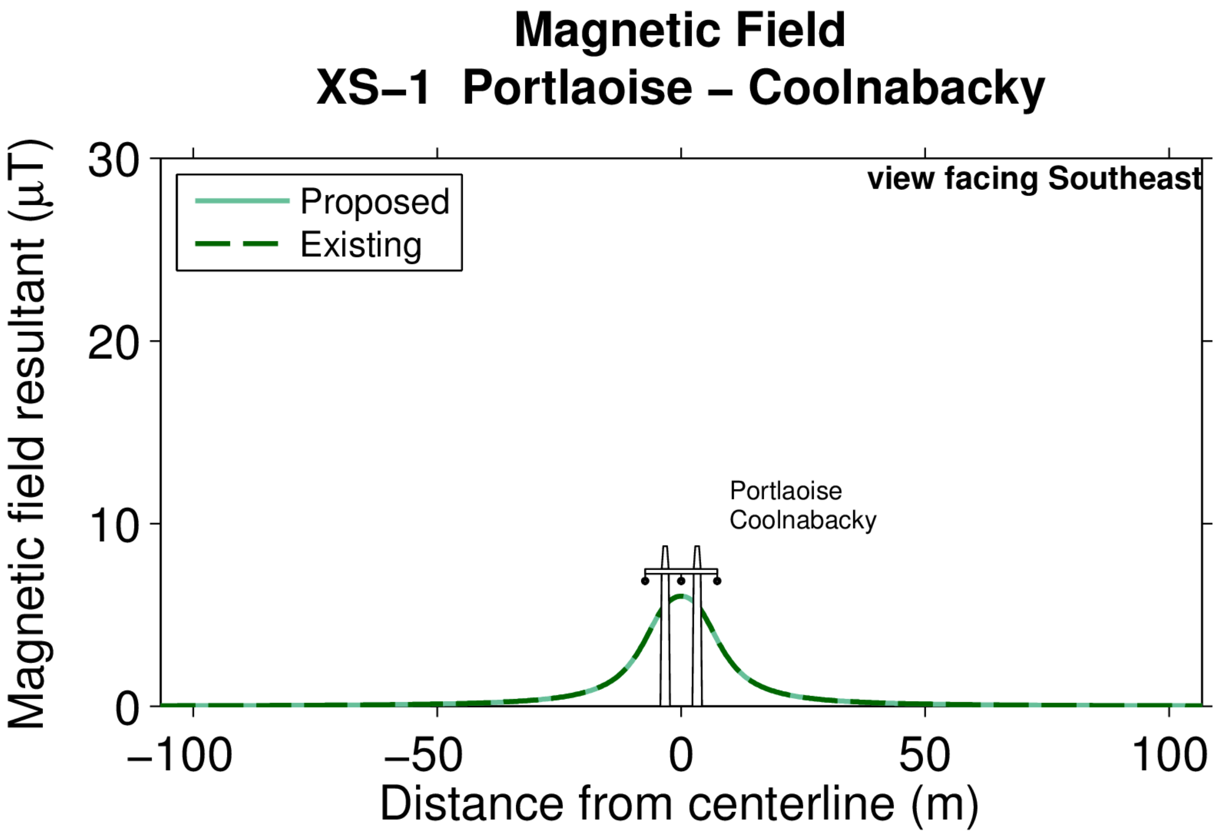

Figure A-2. Calculated magnetic-field profiles in cross section XS-1 under existing and proposed conditions at average load.

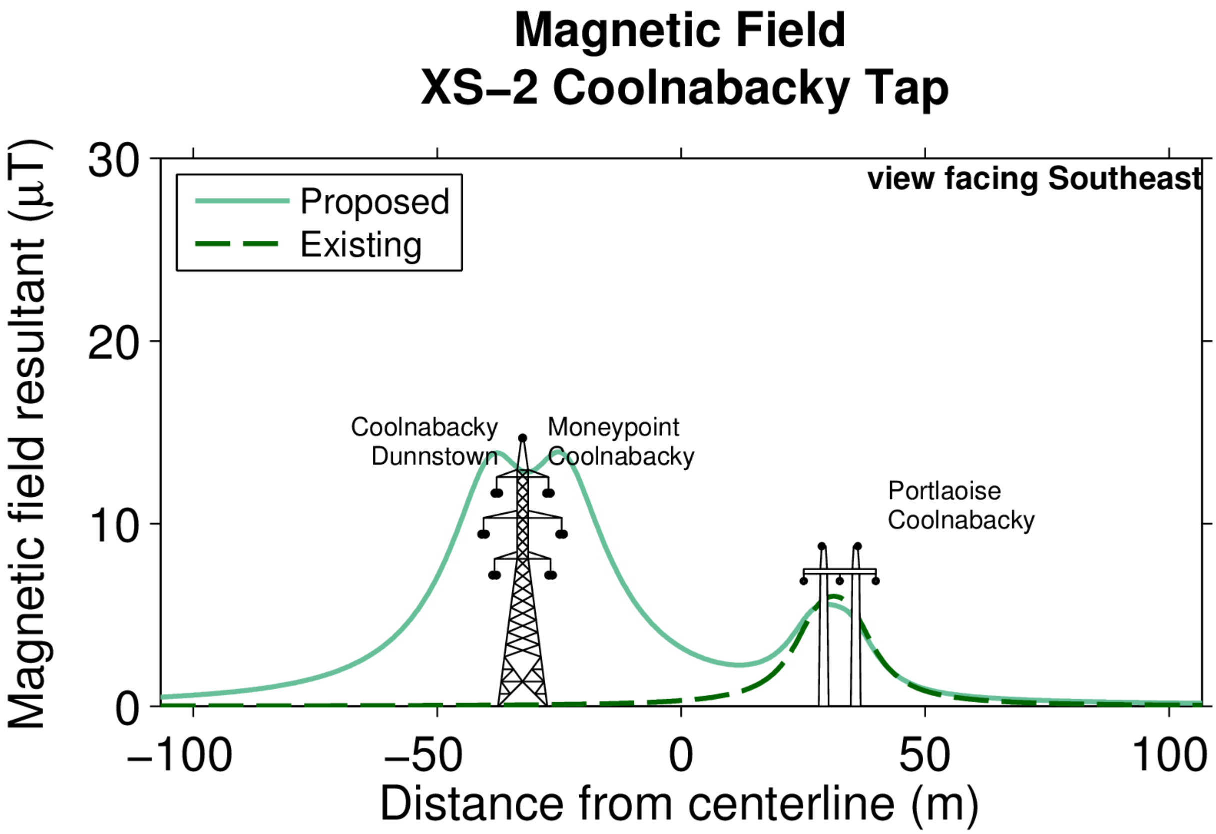

Figure A-3. Calculated magnetic-field profiles in cross section XS-2 under existing and proposed conditions at average load.

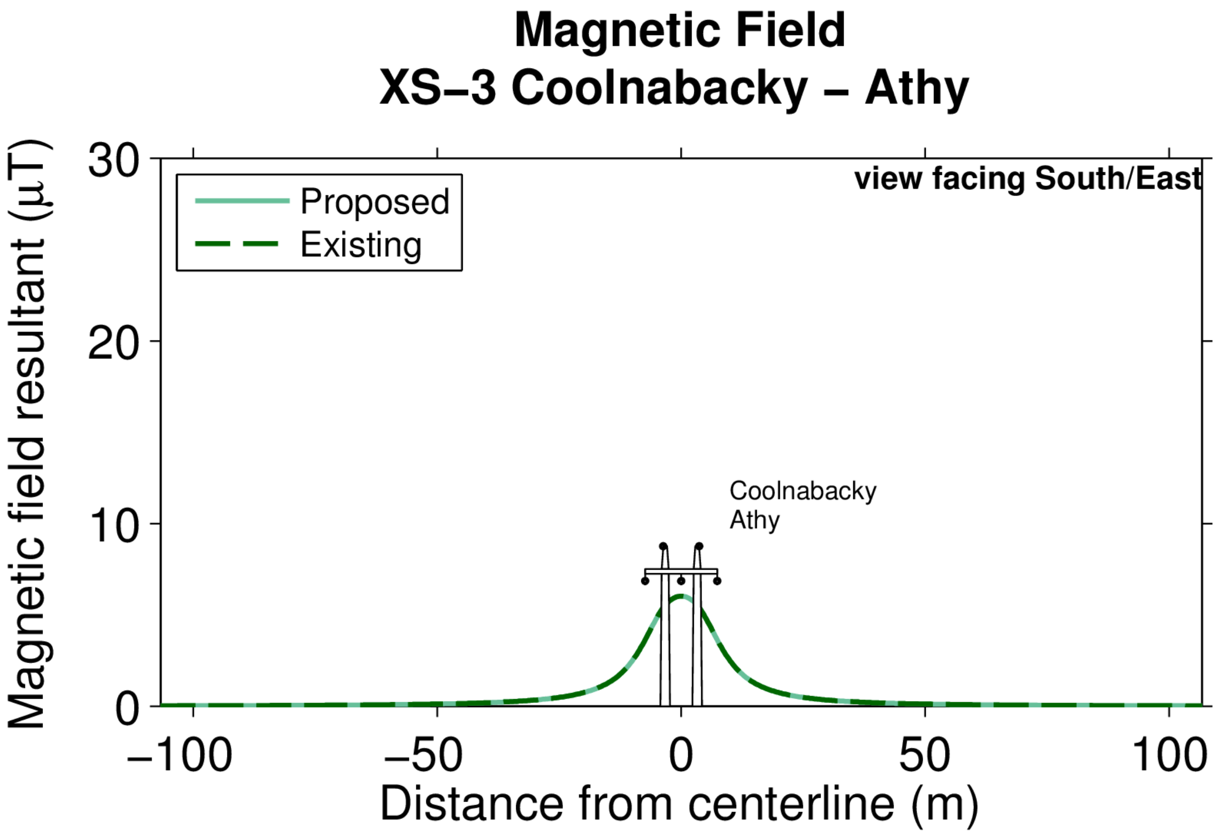

Figure A-4. Calculated magnetic-field profiles in cross section XS-3 under existing and proposed conditions at average-load.

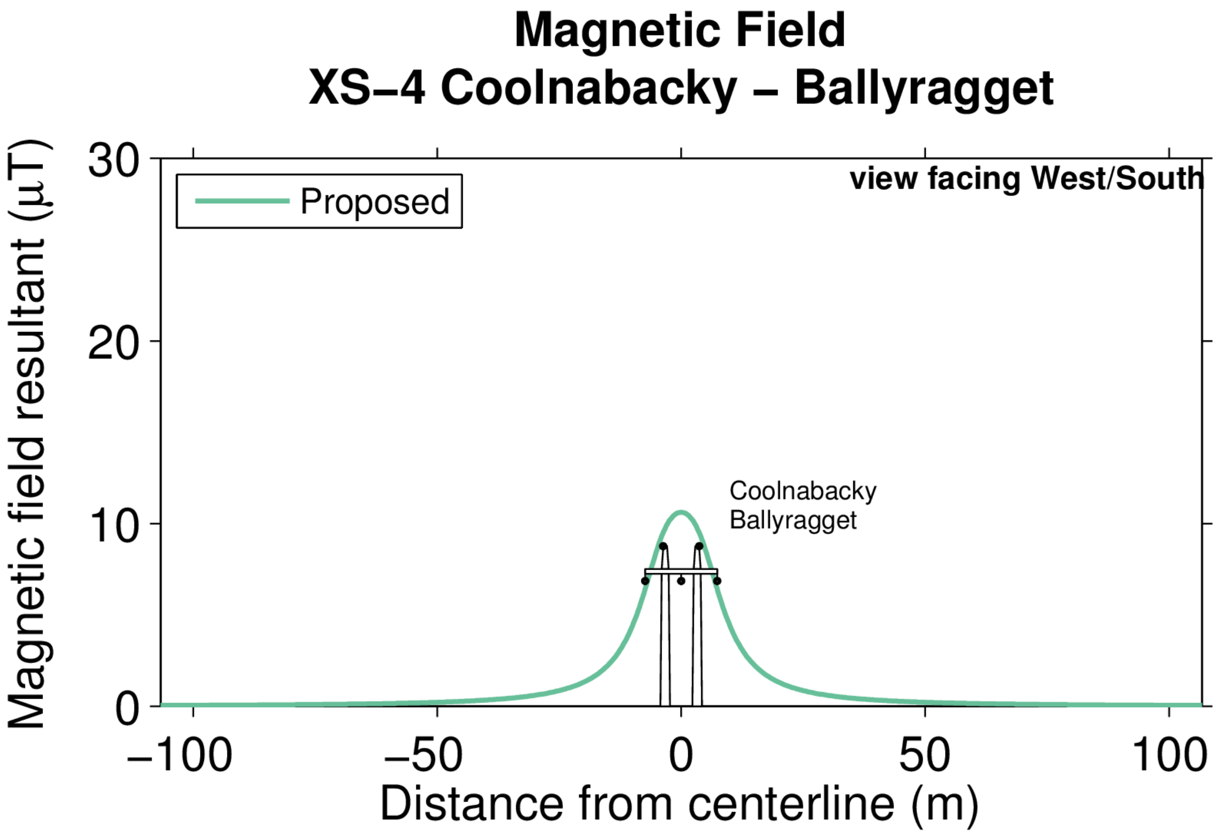

Figure A-5. Calculated magnetic-field profiles in cross section XS-4 under proposed conditions at average load.

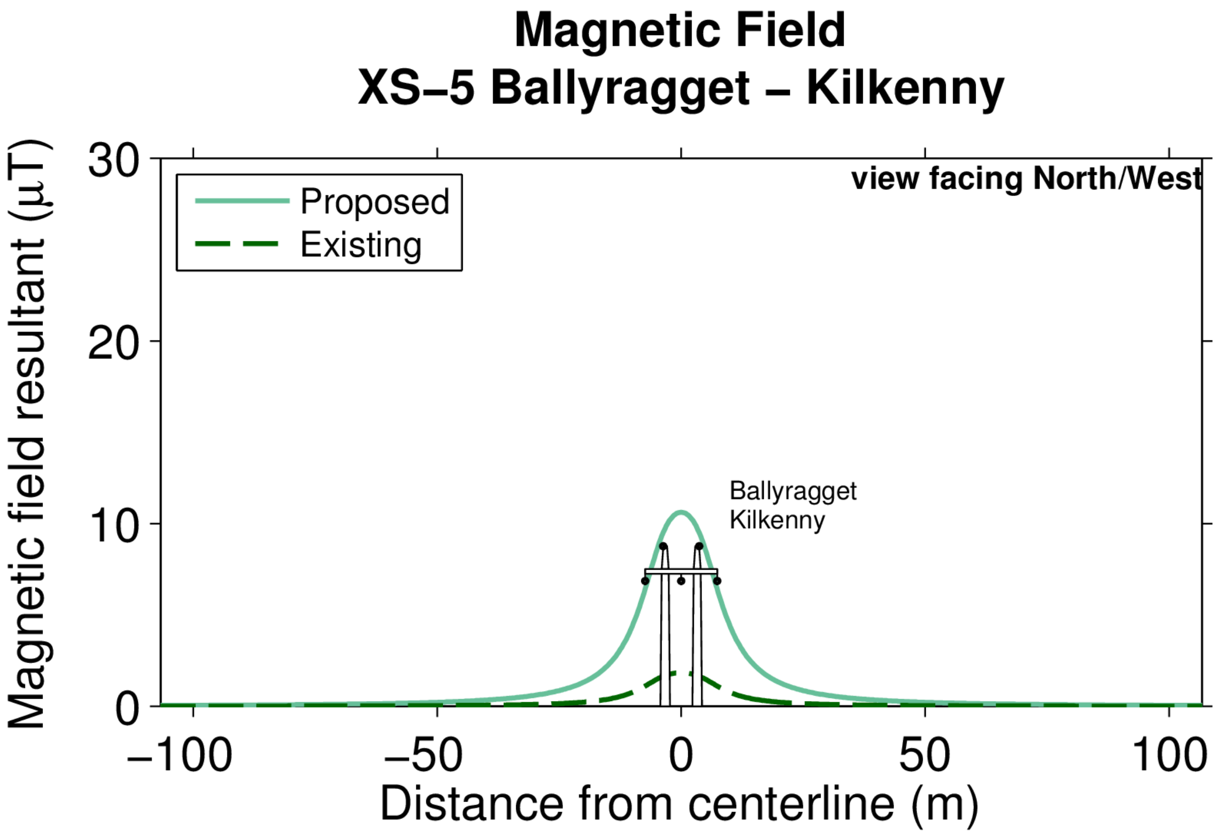

Figure A-6. Calculated magnetic-field profiles in cross section XS-5 under existing and proposed conditions at average load.

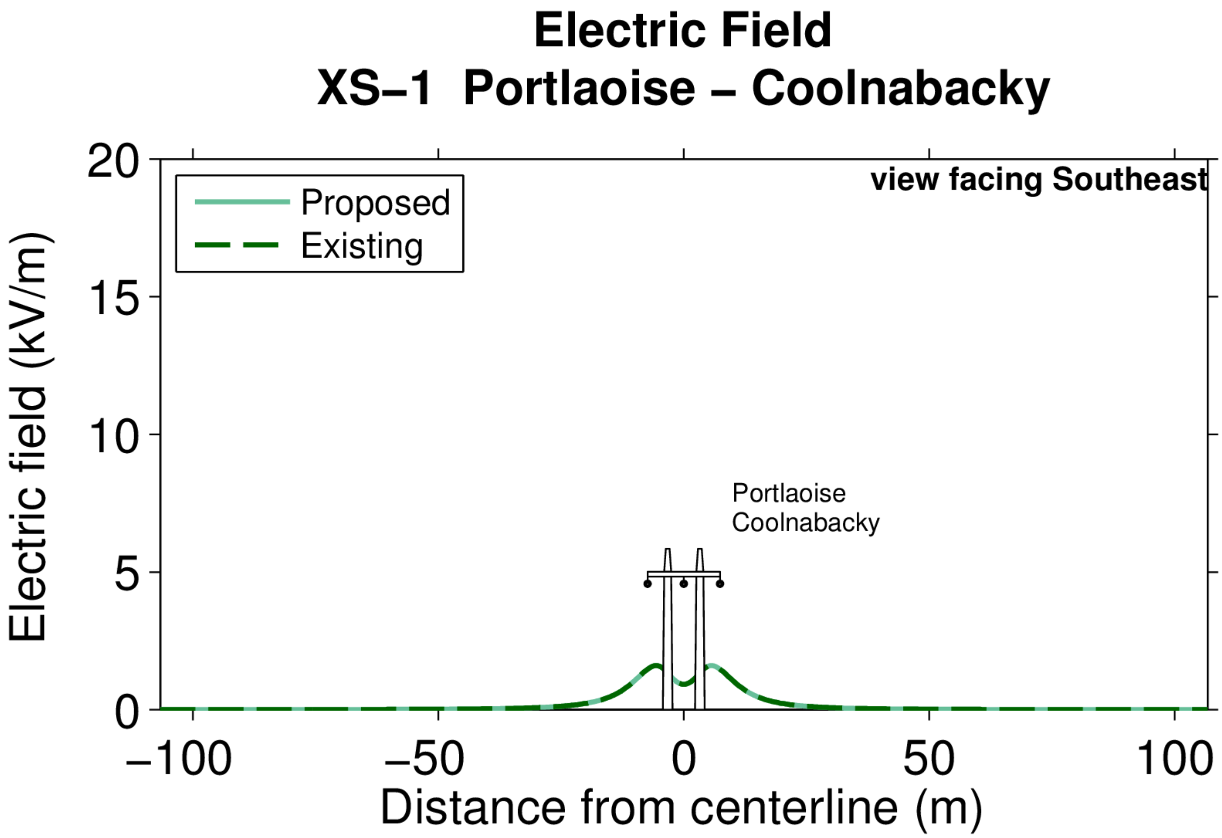

Figure A-7. Calculated electric-field profiles in cross section XS-1 under existing and proposed conditions.

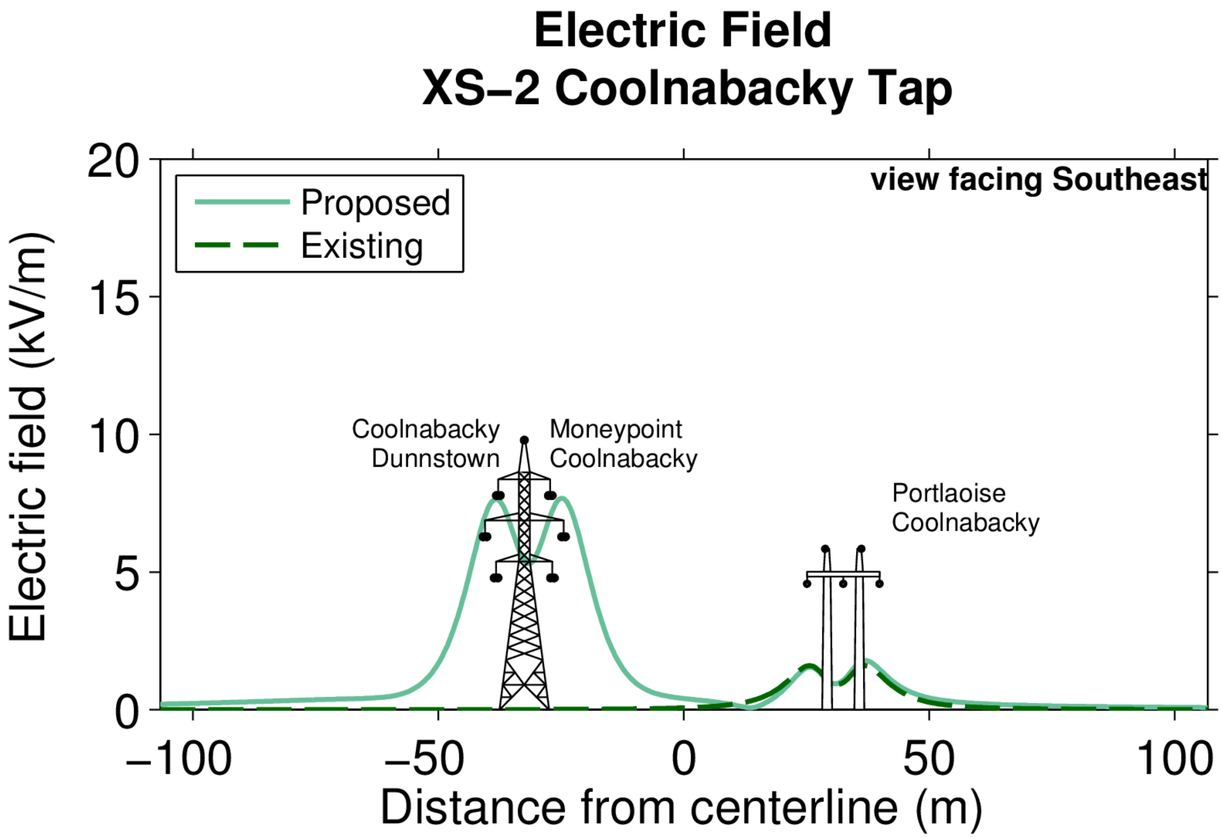

Figure A-8. Calculated electric-field profiles in cross section XS-2 under existing and proposed conditions.

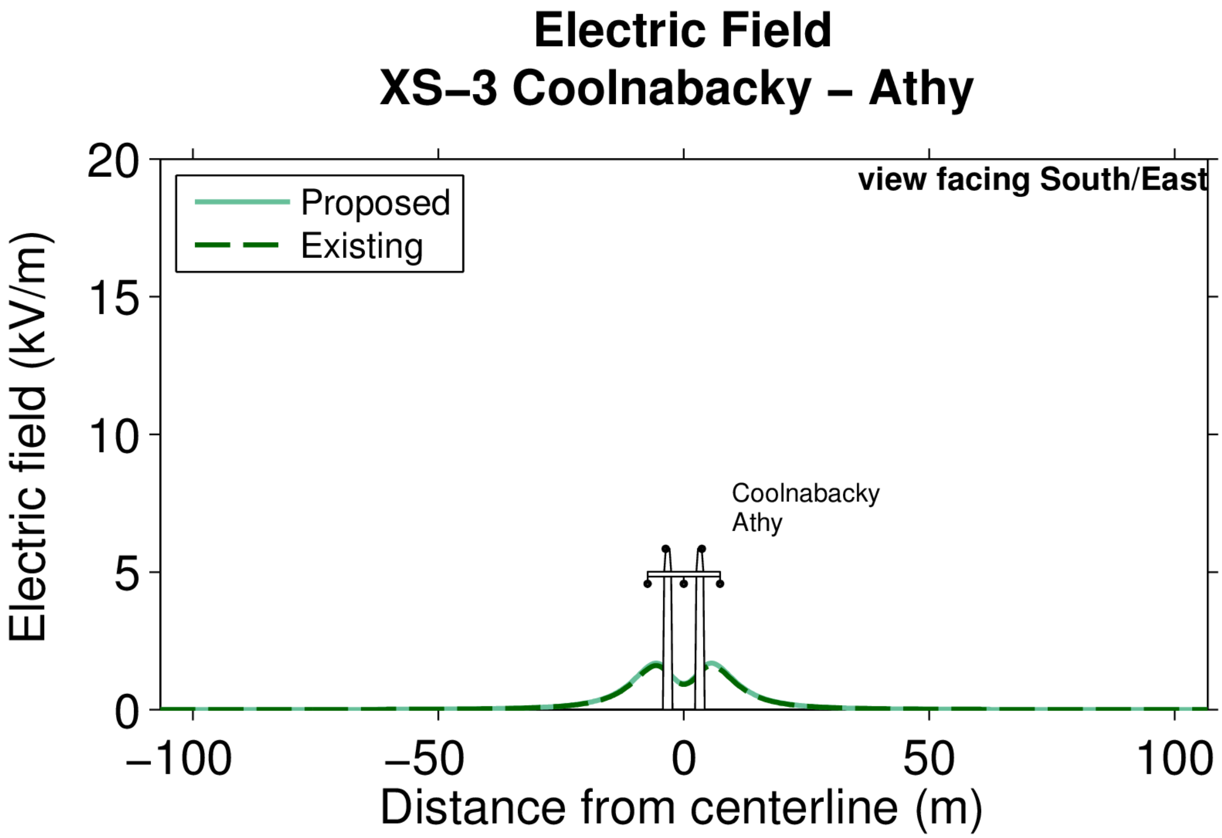

Figure A-9. Calculated electric-field profiles in cross section XS-3 under existing and proposed conditions.

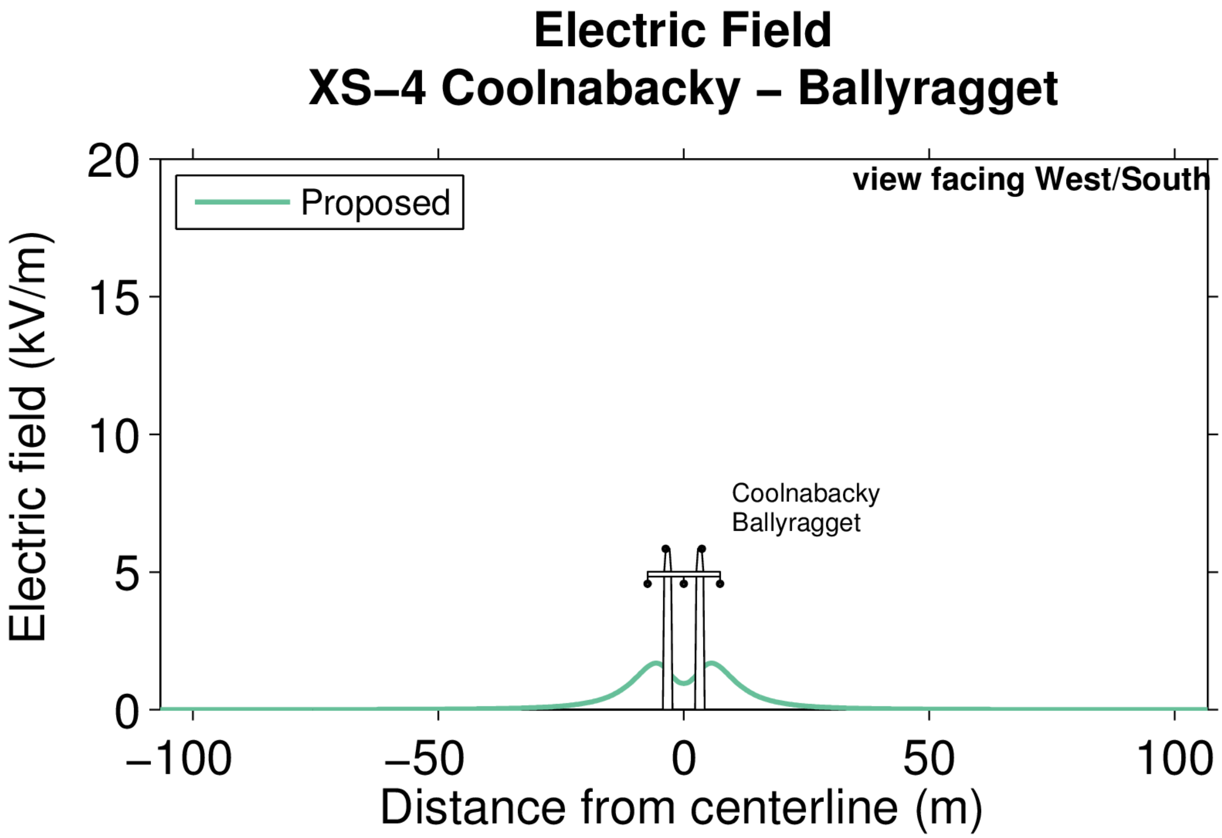

Figure A-10. Calculated electric-field profiles in cross section XS-4 under proposed conditions.

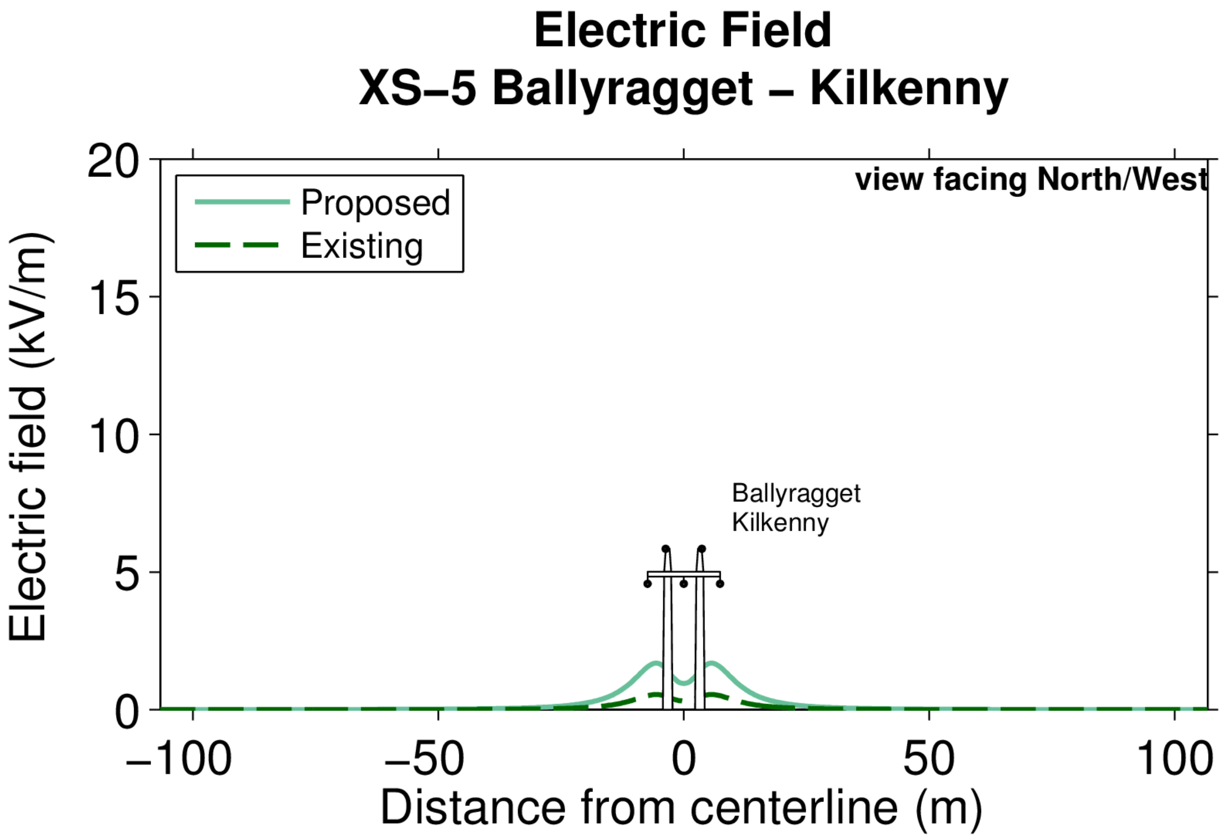

Figure A-11. Calculated electric-field profiles in cross section XS-5 under existing and proposed conditions.

Table A-1. Transmission line loading (MVA) for average- and peak-loading cases.

				Existing		Proposed	
From	**To**	**Cross Section**	**Voltage (kV)**	**Average load (MVA)**	**Peak load (MVA)**	**Average load (MVA)**	**Peak load (MVA)**
Moneypoint	Coolnabacky	XS-2	400	-	-	514	1713
Coolnabacky	Dunnstown	XS-2	400	-	-	514	1713
Coolnabacky	Portlaoise	XS-1, XS-2	110	38	126	38	126
Coolnabacky	Athy	XS-3	110	38	126	38	126
Coolnabacky	Ballyragget	XS-4	110	-	-	67	223
Ballyragget	Kilkenny	XS-5	110[†]	4	18	67	223

[†]Under existing conditions, the Ballyragget-Kilkenny line operates at 38 kV.

Table A-2. Calculated magnetic-field values (µT) for existing and proposed configurations at average load.

		Location				
Route Portion	**Case**	–75 m from centre	–50 m from centre	Maximum	50 m from centre	75 m from centre
Section XS-1	proposed	0.1	0.1	6.0	0.1	0.1
	existing	0.1	0.1	6.0	0.1	0.1
Section XS-2	proposed	1.6	7.1	13.9	1.0	0.3
	existing	0.0	0.0	6.0	0.8	0.2
Section XS-3	proposed	0.1	0.1	6.0	0.1	0.1
	existing	0.1	0.1	6.0	0.1	0.1
Section XS-4	proposed	0.1	0.2	10.6	0.2	0.1
	existing	-	-	-	-	-
Section XS-5	proposed	0.1	0.2	10.6	0.2	0.1
	existing	0.0	0.0	1.8	0.0	0.0

Table A-3. Calculated magnetic-field values (µT) for existing and proposed configurations at peak load.

Route Portion	Case	Location: –75 m from centre	–50 m from centre	Maximum	50 m from centre	75 m from centre
Section XS-1	proposed	0.2	0.4	20.0	0.4	0.2
	existing	0.2	0.4	20.0	0.4	0.2
Section XS-2	proposed	5.2	23.6	46.4	3.2	1.0
	existing	0.1	0.2	20.0	2.8	0.5
Section XS-3	proposed	0.2	0.4	20.0	0.4	0.2
	existing	0.2	0.4	20.0	0.4	0.2
Section XS-4	proposed	0.3	0.7	35.3	0.7	0.3
	existing	-	-	-	-	-
Section XS-5	proposed	0.3	0.7	35.3	0.7	0.3
	existing	0.1	0.2	8.3	0.2	0.1

Table A-4. Calculated electric-field values (kV/m) for existing and proposed conditions.[13]

Route Portion	Case	Location: –75 m from centre	–50 m from centre	Maximum	50 m from centre	75 m from centre
Section XS-1	proposed	0.01	0.02	1.60	0.02	0.01
	existing	0.01	0.02	1.60	0.02	0.01
Section XS-2	proposed	0.36	1.68	7.68	0.43	0.14
	existing	0.00	0.00	1.60	0.27	0.02
Section XS-3	proposed	0.01	0.02	1.69	0.02	0.01
	existing	0.01	0.02	1.60	0.02	0.01
Section XS-4	proposed	0.01	0.02	1.69	0.02	0.01
	existing	-	-	-	-	-
Section XS-5	proposed	0.01	0.02	1.69	0.02	0.01
	existing	0.00	0.01	0.55	0.01	0.00

[13] The electric-field levels are calculated assuming nominal voltages of 110 kV and 400 kV. The maximum operating voltages of these lines is 123 kV and 420 kV, increases of approximately 11% and 5%, respectively. In these cases the electric-field levels described herein would be projected to increase by approximately 11% and 5%, respectively. Note that the electric field calculations are purely a function of circuit voltage and do not rely on current flow (i.e., peak or average loading).