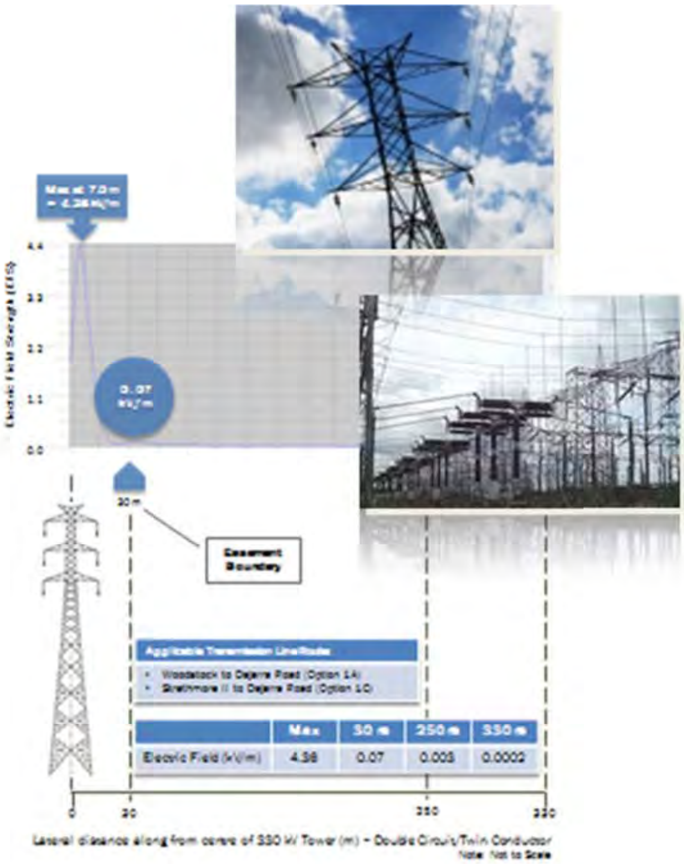
CopperString Project



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Environmental Impact Assessment - EMF Specialist Study

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Prepared for

Resource and Land Management Services (RLMS)

Prepared by

LineTech Consulting

30 Chetwynd Street
PO Box 4444
Loganholme DC
Queensland 4129

+61 7 3801 5521

+61 7 3801 5523

www.linetech.co.nz

tony.auditore@linetech.co.nz

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Prepared by:	Tony Auditoré (Principal Engineer) LineTech Consulting Ltd tony.auditore@linetech.co.nz Phone: + 64 (07) 852 5339 Mobile: + 64 (021) 277 3773
Reviewed:	Editorial review by John Marsden John.marsden@linetech.co.nz Phone: +64 (07) 853 3548 Mobile: +64 (021) 454 8956

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CopperString Base Case Project:
EMF Specialist Study

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ABBREVIATIONS

The following abbreviations have been used in this document:

AC	Alternating Current
AN	Audible Noise
B	Magnetic Flux Density
BPA	Bonneville Power Administration
B_R	Resultant of the Magnetic Field
B_X	Horizontal Component of Magnetic Field "X"
B_Y	Horizontal Component of Magnetic Field "Y"
B_Z	Vertical Component of Magnetic Field "Z"
CNEL	Community Noise Equivalent Level
dB	Decibel
DC	Direct Current
EHF	Extremely High Frequency
EHS	Electrical Hypersensitivity
ELF	Extremely Low Frequency (30 – 300 Hz)
EM	Electromagnetic
EMF	Electric and Magnetic Fields, or electromagnetic field
EMI	Electromagnetic Interference
G	Gauss (unit of magnetic flux density)
GHz	Gigahertz (10^9 Hertz)
HPLC	High Performance Liquid Chromatography
HV	High Voltage
Hz	Hertz (cycles per second)
IARC	International Agency for Research on Cancer
ICNIRP	International Commission for Non-Ionizing Radiation Protection
kHz	Kilohertz (10^3 Hertz)
kV	kilovolt (10^3 Volt)
LF	Low Frequency
MF	Medium Frequency
mG	milliGauss (10^{-3} Gauss)
MHz	Megahertz (10^6 Hertz)
NAS	National Academy of Science
NIEHS	National Institute of Environmental Health Sciences
NRPB	National Radiological Protection Board
OHEW	Overhead Earth Wire
OPGW	Optical Ground Wire
RAPID	Research and Public Information Dissemination
RI	Radio Interference
RN	Radio Noise
SHF	Super High Frequency
SNR	Signal to Noise Ratio
TVI	Television Interference
USEPA	United States Environmental Protection Agency
UHF	Ultra High Frequency
VHF	Very High Frequency
VLC	Visible Light Communications
VLF	Very Low Frequency
V/m	Volts per meter
WHO	World Health Organisation

GLOSSARY

Amperes	Unit used to measure current (the flow of electrons past a point per unit of time). Often abbreviated as "amps." Typical sources are power lines, power supply cables, heating equipment and power transformers.
Ampacity	Current that will meet the design, security, and safety criteria of a particular line on which the conductor is used.
Alternating current	An electric current that reverses direction at regular recurring intervals of times (as opposed to direct current (DC), which flows only in one direction).
Attribute	Physical properties, or characteristics, of electric and magnetic fields. Some such attributes are frequency, intensity, and transients.
Alternative hypothesis	A hypothesis different from the “null hypothesis”. In the report case, the null hypothesis is that EMF has no effect on health and the alternative hypothesis is that they are harmful.
Association	A statistical dependence between two or more events or variables.
Background levels	The amounts of EMF found (that are not due to an obviously specific source) in a typical environment of an industrialized society.
Bias	Prejudice. Something that may skew the results; having the results appear greater or less than that which is real.
Biological effect	An effect that occurs naturally in the human body. An example: the pupils of the eye will change according to the difference in lighting.
Bundled Conductor	An assembly of two or more conductors used as a single conductor and employing spacers to maintain a predetermined configuration. The individual conductors within a bindle are called subconductors.
Calculated fields	Indirect estimate of magnetic fields using current load and voltage data and distance to power lines, and in this study by SESEnviroPlus software program.
Carcinogen	A cancer-causing substance.
Causal relationship	A causal relationship whether there is a causal relationship between EMF and cancer - study to see if EMF causes, or affects the progress of, cancer.
Chance	When an event occurs without the systematic influence of identified factors it has occurred by chance.
Conductor	Material within which charge is free to move. Metals and electrolytes are conductors; the flow of charge within a metal or electrolyte is governed by Ohm’s law at a point.

Conductor Surface Gradient	The electric field at the surface of the conductor. The unit is volt per meter (V/m), although for transmission line conductors, the commonly used unit is kV/cm. For calculating the conductor surface gradient, conductor stranding is generally neglected.
Conductor Surface Irregularity factor	The ratio between the measured corona onset gradient of a practical transmission-line conductor and the corona onset gradient calculated for an ideal smooth cylindrical conductor of the same diameter.
Consistency	Close similarity between findings in different samples or populations, or in studies conducted by different methods or investigators.
Corona	Electrical discharge due to ionization of the air surrounding an electrode caused by a voltage gradient exceeding a certain critical value. The source may be from conductors, hardware, accessories, or insulators.
Corona Pulse	A voltage or current pulse that occurs at some designated location in a circuit as a result of corona discharge.
Corridor	The abstract pathway beneath and alongside an overhead powerline or high voltage equipment installation within which the reception of broadcast and radio communication services is not protected from radio disturbance generated by the line or high voltage equipment.
Current	The flow of electrons charges through a conductor. Currents produce magnetic fields.
Double-Circuit Lines	Two separate overhead three-phase power lines using the same conductor support structures along some of their length.
Easement	The pathway beneath and alongside an overhead powerline over which the owner or operator of the overhead line has legal entitlement, e.g. ownership, access to or control of land usage.
Electromagnetic spectrum	Electromagnetic Spectrum: The complete range of electromagnetic frequencies is comprised in the electromagnetic spectrum. Electric power frequencies are found in the ELF (extremely low frequency) band at one end of the spectrum, whereas high-frequency waves (ultraviolet light, X-rays and gamma rays) can be found at the other end. Visible light, including sunlight, occupies the middle region.
Epidemiology	The study of the distribution of health related effects in a specified population.
Extremely low frequency	Extremely low frequency fields are at the end of the electromagnetic spectrum. They range between 3 to 3,000 Hz. Power frequency (50 Hz) magnetic fields are of extremely low frequency.
Electric field strength (EFS)	Also referred to as E-field in ICNIRP Guidelines and measured in kV/m.
Electromagnetic spectrum	The full range of frequencies of electromagnetic fields. The spectrum is broken down into the following categories: extremely low frequency (ELF), very low frequency (VLF), radio frequency (RF), microwave, visible

	light, and ionizing radiation (x-rays and gamma rays).
Fair-Weather Audible Noise	In the context of audible noise, radio noise, and corona loss from overhead transmission lines, this term refers to the levels of those phenomena in dry conditions and excludes rain, fog, mist, snow, sleet, and conductor icing, but not conditions of high relative and absolute humidity, and extremes of ambient temperature.
Fault current	An abnormal current flow resulting from a Fault.
Frequency	The rate at which a periodic waveform repeats itself in time at one position in space. Frequency is measured in cycles-per-second or Hertz (Hz). The electric power frequency in Australia is 50 Hertz.
Gauss (G)	A unit for expressing the strength of a magnetic field.
Generated Corona Loss	A quantity related to the corona loss of a conductor that is a function only of the conductor radius and the electric field distribution near its surface and not on the overall conductor configuration. It is expressed in units of W/m.
Hertz (Hz)	The unit of frequency for the alternating currents and their resulting magnetic fields corresponding to one cycle per second. In Australia, the electric power frequency is 50 Hz.
Ionizing radiation	Electromagnetic radiation for which the frequency is high enough so that there is sufficient energy to break the internal bonds in atoms and molecules. Such frequencies typically are in the optical range or higher, more than a trillion times larger than power-line frequencies.
L_{50} Noise Level	Level exceeding 50% of the time.
Lateral profile	A graphical representation of the varying strength of the magnetic field and the distance from a power line.
Magnetic field	Referred to as B-field in ICNIRP guidelines and measured in microTesla (µT).
Magnetic field strength (MFS)	Also referred to as B-field strength in ICNIRP guidelines and measured in A/m.
milliGauss (mG)	Gauss is a unit used for measuring magnetic fields. A milliGauss is one thousandth of one Gauss. One milliGauss is equal to 10 micro Teslas (µT), which is another magnetic field strength unit often used for the measuring of magnetic fields.
Morbidity	Rate of disease.
Mortality	Rate of death.
National Institute of Environmental	The National Institute of Environmental Health Sciences. This agency managed the federal government's EMF research program, known as

Sciences	the EMF RAPID Program (for Research And Public Information Dissemination).
Non-Ionizing radiation	Electromagnetic radiation for which the frequency is not high enough so that the bonds in atoms and molecules may be broken. Power-line frequencies, radio waves, microwaves and other forms at the lower end of the spectrum cannot alter the bonds of molecules or atoms. These forms of electromagnetic energy cannot create ions and thus are known as Non-Ionizing.
NRPB	The National Radiological Protection Board of the United Kingdom. NRPB is an independent body that has responsibility for advising UK government departments and others on standards of protection for exposure to ionising and non-ionising radiation, which includes electric and magnetic fields.
Optical ground wire (OPGW)	Conductor used to shield transmission lines from lightning with its metallic cores replaced with optical fibres.
Overhead earth wire (OHEW)	Connecting an object that conducts electricity, such as a wire or the metal frame of an appliance, to an object with zero potential to conduct electricity (such as the earth).
Phase	The phase or phase conductor is any conductor other than the overhead earth wire on the transmission line energised at the nominal system voltage. In a three-phase power system, there are three phases consisting of one or more conductors per phase.
Phasing of conductors	The order in which different phase conductors of three phase lines are placed.
Population attributable risk	The proportion of cases of a particular disease in the entire population that is attributable to those who are exposed to a risk factor in that population.
Power grid	The power grid encompasses a network of long distance, high-voltage transmission lines, substations, and distribution lines carrying electricity that will eventually be distributed to customers of local utilities.
Probability	The estimate of the frequency of an event.
Prudent avoidance	Is a precautionary principle in risk management that states reasonable efforts must be made to minimise potential risks when the actual magnitude of the risks is unknown.
Radio Interference (RI)	Degradation of the reception of a wanted signal caused by radio frequency (RF) disturbance.
Risk	The probability that an unwanted event will occur.
RAPID	The US federal government's EMF research program (for Research And Public Information Dissemination) more generally known as the EMF RAPID Program, managed by NIEHS (the National Institute of

	Environmental Health Sciences).
Scientific reviews	Multi-disciplinary panels of scientists review all of the research on EMF, in aggregate, to draw conclusions about the significance of the research findings.
Short circuit	Occurs when a current bypasses the load by traveling on a path with little or no resistance which causes heat and possible fire hazard.
Signal to Noise Ratio (SNR)	Ratio of the value of the signal to that of the noise.
Spot measurements	One-time field measurement of magnetic fields, a so-called "snapshot" or point-in-time measurement.
Study	An examination or analysis of a subject in a particular situation or environment.
Surface Gradient	Magnitude of the electric field at the surface of an overhead conductor. Its magnitude varies according to the system voltage and the dimensions of the conductor.
System voltage	Nominal phase-to-phase r.m.s. voltage of the power system.
Transients	Sudden changes in magnetic fields.
Tesla (T)	A unit for the measurement of magnetic flux density (MFD) equal to one weber per square meter. Due to the magnitude of the measurement it is more convenient to record MFD in micro-Teslas (µT) compared to T. 1µT represents one millionth of a Tesla.
Television interference (TVI)	Radio interference occurring in the frequency range of television signals.
Transmission lines	Power lines supported by metal lattice towers that carry high-voltage electricity between geographic areas, between a power generation facility to a substation in a community.
Transformer	A device used to convert electrical currents of one voltage into currents of a different voltage.
Voltage	Electric potential or potential difference (the difference in "electrical pressure" between two different points of an electrical circuit). The electric force that causes current in a conductor.
Wet conductor	A condition in which the conductors are saturated with water drops.
WHO	The World Health Organization based in Geneva, Switzerland, operates the International EMF Project, with its objective to assess health and environmental effects of exposure to static and time-varying electric and magnetic fields in the frequency range 0 - 300 GHz.

CopperString Base Case Project: EMF Specialist Study

1. INTRODUCTION

The purpose of this document is to undertake desktop electromagnetic field (EMF) studies for the CopperString Base Case Project in order that the land management and environmental assessment teams can complete the land acquisition and environmental approvals. EMF studies are necessary to determine the magnitude of electromagnetic fields generated from the proposed transmission lines and substations, and to identify whether long-term exposure at the predicted magnitude would be expected to result in adverse health effects in exposed populations. In addition the study considers the effects of electromagnetic fields on fauna and flora.

The details of this project, including the proponent and project components are provided in the Project Description Chapter of the EIS. Of particular importance to this study are Table 2.1[1], Table 2.7[2] and Table 2.9[3]. A geographical overview of the proposed line route is illustrated in *Appendix A: CopperString Transmission Link*.

In general terms, EMF studies will consist of the calculation of electrical field strength (EFS), magnetic field strength (MFS) and magnetic field density (MFD) components.

These EMF studies are based on the notional transfer capacity of 400–500 MW and the main operating voltages of 220 kV and 330 kV. Additionally, 275 kV system voltages are also considered for the incoming supply at Woodstock Substation and 132 kV at Mount Isa Substation. Transmission towers are double and single circuit galvanised steel lattice construction with conductor arrangements of single and twin conductor. These towers will be approximately 32 to 75 metres high and spaced between 300 and 500 metres based on the topography. Details of these towers are illustrated in *Appendix B: Typical Tower Types & Dimensions.*

Calculations are based on typical 330 kV and 275 kV towers that are commonly used in the Queensland area. Although the 220 kV system voltage is lower than the typical 275 kV tower, use of this structure has benefits from a standardisation and availability point of view.

Final calculation results for this study of EFS, MFS and MFD are illustrated in Appendix C[4], D[5] and E[6]. A summary of the residential and services locations are illustrated in *Appendix F: Residential & Services Locations*. All of the calculations contained in this report have been based on a conceptual design with typical towers, conductor type (Sulphur) and clearances. These calculations will be reviewed and if necessary modified during the final design stage of the transmission line.

[1] Transmission line sections
[2] Transmission line easement description
[3] Technical description of substations
[4] Transmission Line Electric Field Strength (EFS) Calculation Results
[5] Transmission Line Magnetic Field (MFS & MFD) Calculation Results
[6] Substation EMF Calculation Results

2. CONCEPTS OF EMF

2.1 Background

Large electrical power systems rely on the supply of power from the generation (or source) to the consumer along overhead transmission lines. In Australia this is an alternating current (AC) supplied at a frequency of 50 Hertz (Hz). This means that the electric current flowing in the system changes direction 50 times per second. Power system frequencies (50 Hz) are much lower than the frequencies of radio broadcasting (typically 88 to 108 MHz (1 MHz = 1 million Hertz)) or microwave systems operating at 2.4 GHz (1 GHz = 1 billion Hertz).

Energised overhead transmission lines "radiate" invisible electromagnetic fields (EMF) from their conductors. EMF are composite fields made up of electric fields and magnetic fields. Electric fields (measured in kV/m) are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. Magnetic fields (measured in μT) are created when electric current flows – the greater the current, the stronger the magnetic field. It is important for landowners in the proximity of transmission lines and substations to be aware of the expected magnitude and statutory limitations of these EMFs. These fields are largely dependent on the magnitude of applied voltage and the current conveyed along the line. Secondary influences are the phase configuration (positioning of conductors), size, number and spacing of conductors, number of circuits per tower and the minimum height above ground. Typical MFD values for common electrical house appliances and power lines are illustrated in Table 1: Typical Magnetic Field Measurements and Ranges.

Table 2-1: Typical Magnetic Field Measurements and Ranges[7]

	Typical Measurement (μT)	Range of Measurements (μT)
Stove	0.6	0.2 – 3
PC	0.5	0.2 – 2
TV	0.1	0.02 – 0.2
Electric Blanket	2.0	0.5 – 3
Hair dryer	2.5	1 – 7
Refrigerator	0.2	0.2 – 0.5
Toaster	0.3	0.2 – 1
Kettle	0.3	0.2 – 1
Fan	0.1	0.02 – 0.2
Distribution line (under the line)	1.0	0.2 – 2
Transmission line under line edge of easement	 2 1	 1 – 20 0.2 – 5

[7] Sourced from http://www.ena.asn.au/udocs/2009/08/Electric-and-Magnetic-Fields-What-we-know.pdf

The report reviews the calculated EMF values of the proposed transmission lines for their various operating voltages and energy transfer. The calculated values contained in Section are within the Australian statutory guidelines. When compared against Table 1 it is evident that the levels of expected magnetic fields at the closest habitable property (250 m away) is well below than a typical measurement for house appliances.

Health concerns stem from the theory that any biological effects that may occur from exposure to microwave frequencies will be as a result of heating of biological tissue. Safety precautions, for this frequency range, are thus based on limiting field levels that may cause a rise in tissue temperature.

Biological effects associated with exposure to power frequency EMF, occur as a result of electric current induced in the subject by the EMF. Safety precautions, for these frequencies are thus based on limiting field levels that may induce electric current in the subject that are considered harmful.

There are other health related issues specific to short term safety regarding transmission lines. The above comments are directed towards normal power network operation, also known as steady state conditions. In the rare event of a fault occurring on the transmission line, an abnormally high current flows which magnifies the magnetic field in short time duration. This time duration is dependent on the power network being able to isolate the fault and is typically no more than 0.40 seconds. As this is an extremely rare event, and the fact that the probability of exposing the public to such an event is extremely rare; this report does not consider the study of fault current duration relevant. However, this report does review all likely underground and above ground services that may be affected by such an event.

At the low frequency of 50 Hz, two fields exist that can be studied separately: electric fields and magnetic fields. Magnetic fields are produced by the current flowing (movement of electric charge) along a conductor. Electric current is measured in Ampere (A) and its magnitude varies depending on the power network delivery capability and number of customers (load) supplied by the system. As the load changes, the magnetic field will change. Magnetic fields are measured by both magnetic field strength (MFS) and magnetic field density (MFD). Reducing 50 Hz magnetic fields requires special engineering techniques or designs.

Electric fields may exist without the presence of magnetic fields. This occurs when a transmission line is energised without load – it has an applied voltage but is not conveying current.

Both electric and magnetic fields decrease rapidly with an increase in distance from the source. In the case of a transmission line these decrease laterally from the overhead line conductor.

2.2 Magnetic Coupling Mechanism

In addition to health related effects of EMF, this study also considers the effect that EMF has on underground and above ground services such as digital communication cables, water and gas pipelines along the CopperString transmission line route. From this point of view there are three magnetic field coupling mechanisms between the transmission line and the services. These include inductive, conductive and capacitive coupling as described below.

2.2.1 Inductive coupling

An above ground, as well as an underground cable or pipeline located in the vicinity of an overhead line will be subject to voltages induced by magnetic coupling as illustrated in *Figure 1: Inductive Coupling Mechanism*. Smaller induced voltages are induced during steady state conditions and maximum induced voltages are reached when electrical faults occur. The magnitude of induced voltage will depend on the fault current, on the length of parallelism and on the distance between the pipeline and the overhead line.

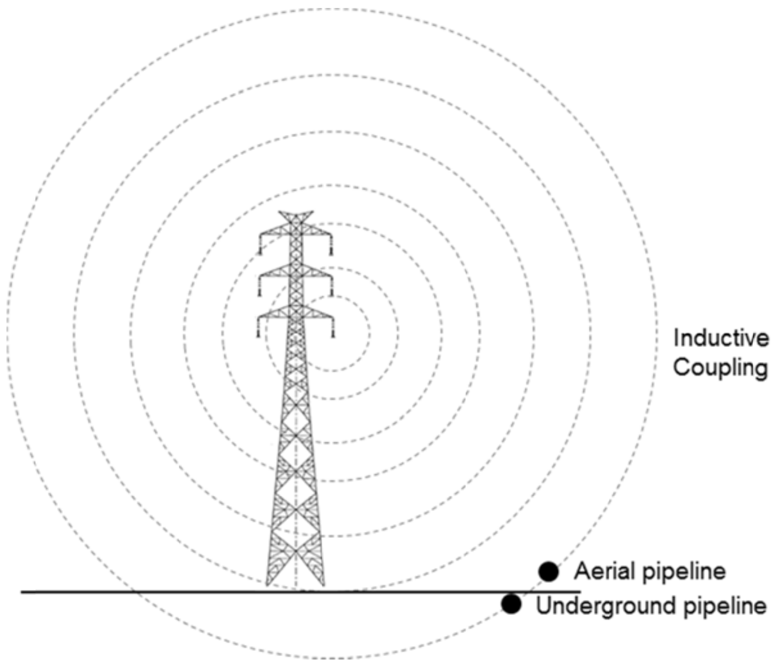

Figure 1: Inductive Coupling Mechanism

2.2.2 Capacitive Coupling

Only aerial or above ground pipelines are subjected to capacitive coupling as illustrated in *Figure 2: Capacitive Coupling Mechanism.* The influence of capacitive coupling occurs in both normal operation and fault conditions. Their magnitudes depend mainly on the system voltage and the distance between the overhead line and pipeline.

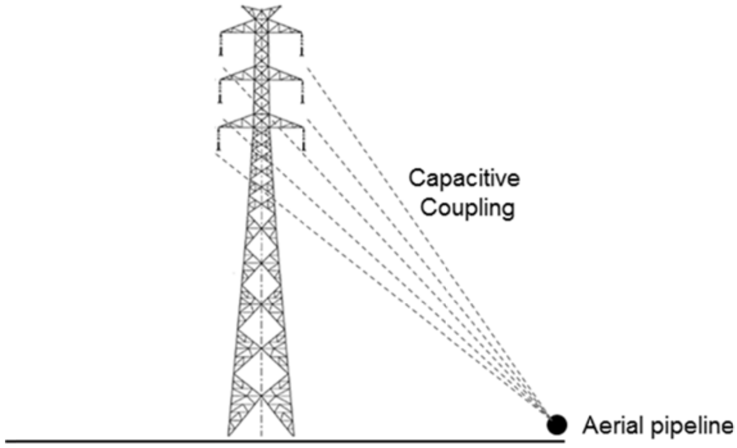

Figure 2: Capacitive Coupling Mechanism

2.2.3 Conductive Coupling

Conductive coupling occurs when fault currents flow through the earthing of an overhead tower or substation which then produces a voltage rise of the earth electrode and of the neighbouring soil with respect to remote earth. The potential of the pipeline would rise to the local earth potential and be transferred over a relatively long distance. The influence of conductive coupling is a function of the pipeline insulation and resistance impedance.

2.3 Electric Field Strength (EFS)

Electric fields are produced by the presence of electric charges and therefore the Voltage (V) applied to a conductor. Generally the voltage on a system is stable and remains the same. Electric fields decrease with an increase in distance from the source (conductor) and increase the closer to the source.

Electric field levels are measured in Volts per metre (V/m). Due to the range of the levels encountered in power system environments, field levels are reported in kilovolt (thousand volts) per metre (kV/m). Electric fields at 50 Hz are successfully shielded by conducting objects. Objects can be effectively shielded from the electric fields by surrounding them with a conductor such as a metal screen.

2.4 Magnetic Field (MFS & MFD)

Magnetic field strength (MFS) is measured in amps per metre (A/m or $A.m^{-1}$).

Magnetic field density (MFD) levels are measured in Tesla (T). Because of the range of the levels encountered in typical power system environments, field levels are recorded in microTesla (μT) – one millionth of a Tesla = 1 μT. An alternative measure of MFD is the unit of Gauss (G) where 10 milliGauss (mG) = 1 μT. This report is consistent with the use of μT.

3. DISCUSSION TOPICS REGARDING EMF

Desktop studies[8] provided by Dr Pieter Pretorius (Eskom Holdings – South Africa) summarise the salient aspects from world-wide research of the effects of EMF on humans, animals and vegetation. Documented below are the main aspects from these studies.

3.1 Effects on Humans

3.1.1 Background[9]

Exposure to electromagnetic fields has been a source of concern for residents throughout the world who are living with the advancements of modern technology. The increased use of mobile and wireless technology, electronics, and household appliances in the past decade have meant that people are exposed to more EMF in day to day environments from a variety of sources. Governments have begun to legislate and stipulate regulatory policies regarding the allowable limits of EMF, but the overwhelming majority of such legislation is concerned only with EMF from higher frequency and radio-frequency sources such as telecommunications and microwave ovens.

However, power transmission lines, and other sources which relate to the transmission and generation of electrical energy emit extremely low frequencies between 0 - 300 Hz. The EMF Research and Public Information Dissemination Program (EMF *RAPID*) of the National Institute for Environmental Health Sciences in the US determined that exposure to extremely low frequency EMF is a “possible” cancer hazard; however, in 2001, the International Agency for Research on Cancer issued a monograph announcing that as a possible carcinogen, extremely low frequency magnetic fields have statistically been linked to childhood Leukaemia. Although not conclusively linked at this time, higher incidents of cancer development have been documented not just among children, but also among adult residents who live or work near high voltage powerlines.

Currently, there is not a great deal of legislation in the international community which pertains specifically to extremely low frequency EMF. Yet, the number of citizens’ groups which have been established around this problem is strong evidence of the concern about power lines endangering the lives of adults and children. Because the overwhelming majority of related legislation pertains to the regulation of higher frequency EMF, compiling a list of legislation and policy specific to low-frequency EMF has been difficult. While a number of jurisdictions and legislative actions have been highlighted here, this is not an exhaustive survey as legislation continues to evolve and develop with regard to EMF. A further guide to standards set by other countries, whether legislated or recommended, may be found on the World Health Organization website. Furthermore, the Union of the Electricity Industry (EURELECTRIC) has produced “EMF Exposure Standards Applicable in Europe and Elsewhere” (Appendix I) which may be helpful.

There are numerous and different types of studies addressing specific aspects of the subject and essential in evaluating potential adverse health effects of electric and magnetic fields. These include laboratory, whole animal and human health studies.

[8] Electric & Magnetic Fields from Overhead Power Lines – A Summary of technical & Biological Aspects; Final Report; Empetus cc; 18 August 2006.
[9] Nadine Wu; Regulating Power Line EMF Exposure: International Precedents; Environmental Law Clinic Faculty of Law, University of Victoria; 22 April 2005.

Laboratory studies are conducted on cells and are intended to reveal fundamental underlying mechanisms involved in linking EMF exposure to biological effects. The focus is on changes, at cellular and molecular level, brought about by exposure to the field. Changes observed may provide clues to how a physical force brings about a biological action in the body. Possible compensation mechanisms may be inhibited during this type of study as the cells are not in their normal living environment. *Whole animal studies* involve live animals, are more closely related to situation in real life and may provide evidence more relevant to establishing safe exposure levels for humans.

Different exposure levels are employed in the study to yield information about dose-response relationships. *Epidemiological studies (human health studies)* provide information on long-term effects of exposure. These studies investigate the occurrence and distribution of diseases, in real life situations, in human populations. Researchers can then establish if there is a statistical association between exposure to EMF and the incidence of a specific disease or adverse health effect. Epidemiological studies involve measurements on very complex human populations. In addition, epidemiological studies are difficult to control to detect small effects and factors, such as, confounding variables, which may play a part in affecting the outcome of the study.

For these reasons, scientists evaluate all relevant evidence from cellular studies, animal studies and epidemiological studies when deciding about potential health hazards from EMF. Of the first reports covering possible effects of electric fields were published in the 1960s[10]. These reports noted Russian substation workers complaining about fatigue and reduced sexual potency and claimed that these effects were to result of exposure to electric fields in the substations.

The debate on possible health effects of exposure to power frequency magnetic fields was stimulated by the first epidemiological study[11], published by Wertheimer and Leeper in 1979, that suggested a possible association between long term exposure to power line magnetic fields and leukaemia in children. Most of the reports suggesting a possible association between some childhood cancers and exposure to EMF are based on epidemiological studies. The findings of the epidemiological studies suggesting such an association have not been confirmed by controlled laboratory studies. The controversy around the topic was stimulated by the latter as well as certain aspects related to epidemiology that included:

- In epidemiology, an agent (for example, EMF) may have an association or correlation with an event (for example, leukaemia) but association does not necessarily indicate a cause-effect relationship.
- The association indicated by some epidemiological studies, if it existed, was small.
- The number of cases in some of these studies was small.

Many studies on the topic of electric and magnetic fields and possible health effects have been reported on over the last two decades.[12, 13 & 14] Some of these studies, from a

[10] Asanova, T P, Rakov, A I, The State of Health of Persons Working in the Electric Field of Outdoor 400 and 500kV Switchyards, Gig Trud Prof Zabol, 10 : 50 – 52, 1966.
[11] Wertheimer, N, Leeper, E, Electrical Wiring Configuration and Childhood Cancer, American Journal of Epidemiology, 109: 273 – 284, 1979.
[12] Carstens, E L, Biological Effects of Transmission Line Fields, Elsevier Science Publishing Co, ISBN 0-444-01018-1, 1987.
[13] Takebe, H, Shiga, T, Kato, M, Masada, E, Biological and Health Effects from Exposure to Power Line Frequency Electromagnetic Fields – Confirmation of Absence of Any Effects at Environmental Field Strength, IOS Press, ISBN 158 603 1058, 2001.
[14] http://www.who.int/peh-emf/en , 18 Aug 2006 & http://www.emfs.info , 18 Aug 2006.

scientific perspective, have been of a higher quality and have been designed and executed in more credible ways than others. In addressing consensus and conclusions drawn from this research, it makes sense to reflect on critical, scientific reviews of published research rather than to address and reflect on individual and isolated studies.

Reviews reported by the following organisations, are noted in order of publication date:

- United States Environmental Protection Agency (USEPA);
- National Radiological Protection Board (NRPB);
- National Academy of Science;
- National Institute for Environmental Health Sciences (NIEHS);
- National Radiological Protection Board (NRPB),
- International Agency for Research on Cancer (IARC),
- International Commission for Non-Ionizing Radiation Protection (ICNIRP),

3.1.2 Environmental Protection Agency (USEPA), 1990 [1].

"In evaluating the potential for carcinogenicity of chemical agents, EPA has developed an approach that attempts to integrate all of the available information into a summary classification of the weight of evidence that the agent is carcinogenic in humans. At this time, such a characterisation regarding the link between cancer and exposure to EMF fields is not appropriate because the basic nature of the interaction between EM fields and biological processes leading to cancer is not understood."

"With our current understanding, we can identify 60 Hz magnetic fields from power lines and perhaps other sources in the home as a possible, but not proven, cause of cancer in people." "The absence of key information summarised above makes it difficult to make quantitative estimates of risk. Such quantitative estimates are necessary before judgments about the degree of safety or hazard of a given exposure can be made. This situation indicates the need to continue to evaluate the information from on-going studies and to further evaluate the mechanisms of carcinogenic action and the characteristics of exposure that lead to these effects."

3.1.3 National Radiological Protection Board (NRPB), 1992 [2].

"In summary, the epidemiological findings that have been reviewed provide no firm evidence of the existence of a carcinogenic hazard from exposure of paternal gonads, the fetus, children, or adults to the extremely low frequency electromagnetic fields that might be associated with residence near major sources of electricity supply, the use of electrical appliances, or work in the electrical, electronic, and telecommunications industries. Much of the evidence that has been cited is inconsistent, or derives from studies that have been inadequately controlled, and some is likely to have been distorted by bias against the reporting or publishing of negative results. The only finding that is at all notable is the consistency with which the least weak evidence relates to a small risk of brain tumours. This consistency is, however, less impressive than might appear as brain tumours in childhood and adult life are different in origin, arising from different types of cell. In the absence of any unambiguous experimental evidence to suggest that exposure to these electromagnetic fields is likely to be carcinogenic, in the broadest sense of the term, the findings to date can be regarded only as sufficient to justify formulating a hypothesis for testing by further investigation."

3.1.4 National Academy of Sciences, 1996 [3].

"Based on a comprehensive evaluation of published studies relating to the effects of power frequency electric and magnetic fields on cells, tissues, and organisms (including humans), the conclusion of the committee is that the current body of evidence does not show that exposure to these fields presents a human-health hazard.

Specifically, no conclusive and consistent evidence shows that exposure to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive and developmental effects."

3.1.5 National Institute of Environmental Health Sciences (NIEHS), 1999 [4, 5, 6].

Table 6 summarises the conclusions drawn by the NIEHS Working group on non-cancer related health effects.

NIEHS concluded the following in terms of cancer:

"The NIEHS believes that the probability that EMF exposure is truly a health hazard is currently small. The weak epidemiological associations and lack of any laboratory support for these associations provide only marginal scientific support that exposure to this agent is causing any degree of harm."

NIEHS noted that the "strongest evidence" for health effects comes from statistical associations observed in human populations with childhood leukaemia. "While the support from individual studies is weak," according to the report, "these epidemiological studies demonstrate, for some methods of measuring exposure, a fairly consistent pattern of a small, increased risk with increasing exposure that is somewhat weaker for chronic lymphocytic leukaemia than for childhood leukaemia."

NIEHS further noted that laboratory studies focusing on basic biological function do not support the findings of the epidemiological associations and "Virtually all of the laboratory evidence in animals and humans and most of the mechanistic studies in cells fail to support a causal [cause and effect] relationship."

The panel assisting NIEHS in reaching its conclusions, rejected EMF as a "known" or proven, or even "probable" carcinogen. A majority of the panel said a role in cancer could not be ruled out and EMF should be regarded as "possible" carcinogen. The NIEHS recommended that electric and magnetic fields be treated as a "possible" cancer causing agent, but emphasised the weakness of the data and the low risk that may be involved.

Table 3-1: Conclusions drawn by the NIEHS Working group on non-cancer related health effects

	Biological Parameter / Health Outcome	Evidence Supporting Biological Parameter / Health Outcome			
		Strong	Weak	Inadequate	None
1.	Adverse birth outcomes from material occupational exposure.			X	
2.	Reproductive effects from paternal exposure			X	
3.	Alzheimer's disease.			X	
4.	Amyotrophic lateral sclerosis.			X	
5.	Suicide and depression.			X	
6.	Adverse effects on pregnancy outcome or depression.			X	
7.	Effects on immune system in experimental animals.				X
8.	Cardiovascular disease.			X	
9.	Effects on haematological parameters in rodents.				X
10.	Neurobehavioral, neuropharmacological, neurophysiological and neurochemical effects in experimental animals.		X		
11.	Reproductive or developmental effects from exposure to sinusoidal magnetic fields in experimental animals.				X
12.	Affects bone repair and adaptation – strong evidence for complex clinical exposures to pulsed electromagnetic fields (therapeutically beneficial).	X			
13.	Affect nervous system and non-bone connective tissue repair and adaptation in vertebrates.	No conclusion reached			
14.	Short term exposure and heart rate variability.		X		
15.	Short term exposure and changes in sleep disturbance.		X		
16.	Short term exposure and suppression of melatonin		X		
17.	Alters the levels of melatonin in rodents		X		
18.	Alters the levels of melatonin in sheep and baboons.				X
19.	Effects on haematological system in experimental animals.				X
20.	Electric fields can be perceived.	X			

3.1.6 National Radiological Protection Board (NRPB), 2001 [7].

"Studies reviewed in the earlier report [1992] by the Advisory Group suffered from a lack of measurement-based exposure assessments. Since then, considerable advances have been made in methods for assessing exposure, both in the case of experimental studies and in epidemiological investigations. Instrumentation allowing personal exposure to be measured has become widely available and has been used in many of the more recently published studies. This has provided a substantially improved basis for many of the epidemiological studies reviewed by the Group.

"At the cellular level, there is no clear evidence that exposure to power frequency electromagnetic fields at levels that are likely to be encountered can affect biological processes. Studies are often contradictory and there is a lack of confirmation of positive results from different laboratories using the same experimental conditions. There is no convincing evidence that exposure to such fields is directly genotoxic nor that it can bring about the transformation of cells in culture and it is therefore unlikely to initiate carcinogenesis."

"Those results that are claimed to demonstrate a positive effect of exposure to power frequency magnetic fields tend to show only small changes, the biological consequences of which are not clear."

"Overall, no convincing evidence was seen from a review of a large number of animal studies to support the hypothesis that exposure to power frequency electro-magnetic fields increases the risk of cancer."

"Recent large and well-conducted studies have provided better evidence than was available in the past on the relationship between power frequency magnetic field exposure and the risk of cancer. Taken in conjunction they suggest that relatively heavy average exposures of 0,4 μT or more are associated with a doubling of the risk of leukaemia in children less than 15 years of age. The evidence is, however, not conclusive. In those studies in which measurements were made, the extent to which the more heavily exposed children were representative is in doubt, while in those in Nordic countries in which representativeness is assured, the fields were estimated and the results based on such small numbers that the findings could have been due to chance. In the UK, very few children (perhaps 4 in 1000) are exposed to 0,4 μT or more and a study in the UK, with much the largest number of direct measurements of exposure, found no evidence of risk at lower levels. Nevertheless, the possibility remains that high and prolonged time-weighted average exposure to power frequency magnetic fields can increase the risk of leukaemia in children. Data on brain tumours come from some of the studies also investigating leukaemia and from others concerned exclusively with these tumours. They provide no comparable evidence of an association. There have been many fewer studies in adults. There is no reason to believe that residential exposure to electromagnetic fields is involved in the development of leukaemia or brain tumours in adults." "Laboratory experiments have provided no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children. In practice, such levels of exposure are seldom encountered by the general public in the UK. In the absence of clear evidence of a carcinogenic effect in adults, or of a plausible explanation from experiments on animals or isolated cells, the epidemiological evidence is currently not strong enough to justify a firm conclusion that such fields cause leukaemia in children. Unless, however, further research indicates that the finding is due to chance or some currently unrecognised artefact, the possibility remains that intense and prolonged exposures to magnetic fields can increase the risk of leukaemia in children."[15]

"However, pooled analyses of data from a number of well-conducted studies show a fairly consistent statistical association between a doubling of risk of childhood leukaemia and power-frequency (50 or 60 Hz) residential extremely low frequency (ELF) magnetic field density strengths above 0,4 microTesla. In contrast, no consistent evidence was found that childhood exposures to ELF electric or magnetic fields are associated with brain

[15] International Agency for Research on Cancer (IARC), 2001.

tumours or any other kinds of solid tumours. No consistent evidence was found that residential or occupational exposures of adults to ELF magnetic fields increase risk for any kind of cancer."

"Studies in experimental animals have not shown a consistent carcinogenic or cocarcinogenic effect of exposures to ELF magnetic fields, and no scientific explanation has been established for the observed association of increased childhood leukaemia risk with increasing residential ELF magnetic field exposure."

3.1.7 International Agency for Research on Cancer (IARC), 2001 [8].

"IARC has now concluded that ELF magnetic fields are possibly carcinogenic to humans, based on consistent statistical associations of high level residential magnetic fields with a doubling of risk of childhood leukaemia. Children who are exposed to residential ELF magnetic fields less than 0,4 microTesla have no increased risk for leukaemia."

"However, pooled analyses of data from a number of well-conducted studies show a fairly consistent statistical association between a doubling of risk of childhood leukaemia and power-frequency (50 or 60 Hz) residential ELF magnetic field strengths above 0,4 microTesla. In contrast, no consistent evidence was found that childhood exposures to ELF electric or magnetic fields are associated with brain tumours or any other kinds of solid tumours. No consistent evidence was found that residential or occupational exposures of adults to ELF magnetic fields increase risk for any kind of cancer."

"Studies in experimental animals have not shown a consistent carcinogenic or cocarcinogenic
effects of exposures to ELF magnetic fields, and no scientific explanation has been established for the observed association of increased childhood leukaemia risk with increasing residential ELF magnetic field exposure."

3.1.8 International Commission for Non-Ionizing Radiation Protection (ICNIRP), 2001 [9].

"We reviewed the now voluminous epidemiologic literature on EMF and risks of chronic disease and conclude the following:

a) The quality of epidemiologic studies on this topic has improved over time and several of the recent studies on childhood leukaemia and on cancer associated with occupational exposure are close to the limit of what can realistically be achieved in terms of size of study and methodological rigor.
b) Exposure assessment is a particular difficulty of EMF epidemiology, in several respects:
   - The exposure is imperceptible, ubiquitous, has multiple sources, and can vary greatly over time and short distances.
   - The exposure period of relevance is before the date at which measurements can realistically be obtained and of unknown duration and induction period.
   - The appropriate exposure metric is not known and there are no biological data from which to impute it.
c) In the absence of experimental evidence and given the methodological uncertainties in the epidemiologic literature, there is no chronic disease for which an etiological relation to EMF can be regarded as established.

d) There has been a large body of high quality data for childhood cancer, and also for adult leukaemia and brain tumour in relation to occupational exposure. Among all the outcomes evaluated in epidemiologic studies of EMF, childhood leukaemia in relation to postnatal exposures above 0.4 µT is the one for which there is most evidence of an association. The relative risk has been estimated at 2.0 (95% confidence limit: 1.27–3.13) in a large pooled analysis. This is unlikely to be due to chance but, may be, in part, due to bias. This is difficult to interpret in the absence of a known mechanism or reproducible experimental support. In the large pooled analysis only 0.8% of all children were exposed above 0.4 µT. Further studies need to be designed to test specific hypotheses such as aspects of selection bias or exposure."

3.1.9 Review of Epidemiology and Childhood Leukaemia, 2006 [10].

A review of epidemiology of childhood leukaemia and residential exposure to magnetic fields concluded: "The recent studies, using the exposure methods and the cut-off levels set a priori, each concluded that there was little evidence of any association. The pooled analyses, using different exposure measures and different cut-offs, conclude that an association exists at high exposure levels. It is not clear if the results of the pooled analysis are more valid than those of the recent major studies, although this has been often assumed in influential reviews."

3.1.10 Review of Studies on Breast Cancer, 2006 [11].

"Following a thorough review of the published scientific literature, the report concludes that overall the evidence does not support the hypothesis that exposure to EMF are associated with an increased risk of breast cancer. In addition, EMF do not appear to affect the production or biological action of the hormone melatonin."

3.1.11 Review of Electromagnetic Hypersensitivity, 2005 [12]

Electromagnetic hypersensitivity (EHS) is a term used for symptoms claimed to be related to electric and magnetic field exposure. Symptoms most commonly experienced include redness, tingling and burning sensations of the skin as well as fatigue, tiredness, concentration difficulties, dizziness, nausea, heart palpitation and digestive disturbances.

Based on a Workshop on Electromagnetic Hypersensitivity organised by the World Health Organisation and held in 2004, an international conference on the topic (1998), a European Commission report (1997) and recent reviews of related literature, WHO concluded as follows:

"Electromagnetic Hypersensitivity (EHS) has no clear diagnostic criteria and there is no scientific basis to link EHS symptoms to EMF exposure. Further, EHS is not a medical diagnosis, nor is it clear that it represents a single medical problem."

3.1.12 Pacemakers [13, 14].

Magnetic fields of the order of 100 µT and higher can cause intermittent mode reversion or pacing inhibition in patients with unipolar sensing pacemakers. The overall incidence of this interference is low with more modern pacemakers and depends on the situation of each individual. Electric fields have been shown to affect the older type of pacemakers [19]. Persons wearing pacemakers that may be exposed to power line EMF are advised to consult a physician regarding their individual situations.

3.1.13 ICNIRP 2009 draft guidelines

Extracts from the most recent ICNIRP's 2009 draft guidelines for consultation regarding chronic health effects from EMF are the following:

3.1.13.1 Hypersensitivity

"Some people claim to be hypersensitive to EMFs in general. However, the evidence from double-blind provocation studies suggests that the reported symptoms are unrelated to EMF exposure."

3.1.13.2 Neuroendocrine system

"Overall, these data do not indicate that ELF electric and/or magnetic fields affect the neuroendocrine system in a way that would have an adverse impact on human health."

3.1.13.3 Neurodegenerative disorders

"The studies investigating the association between ELF exposure and Alzheimer's disease are inconsistent. Overall, the evidence for the association between ELF exposure and Alzheimer's disease and Amoyotrophic lateral sclerosis (a motor neurone disease; formerly called ALS) is weak."

3.1.13.4 Cardiovascular disorders

"Overall, the evidence suggests that there is no association between ELF exposure and cardiovascular disease."

3.1.13.5 Reproduction and development

"Overall, the evidence for an association between ELF and developmental and reproductive effects is very weak."

3.1.13.6 Cancer

"A considerable number of epidemiological reports, carried out particularly during the 1980s and 90s indicated that long term exposure to ELF magnetic fields, orders of magnitude below the limits of the current guidelines might be associated with adverse health effects. While the first studies looked at childhood cancer in relation to magnetic fields, later research also investigated different adult cancers. In general, the initially observed associations between ELF magnetic fields and various cancers were not consistently confirmed in studies designed to see whether the initial findings could be replicated. However, for childhood leukemia the situation is different. Research that followed the first study has suggested that there may be an association between residential ELF magnetic fields and childhood leukemia risk, although it cannot be excluded that a combination of selection bias, some degree of confounding and chance could explain the results."

"It is the view of ICNIRP that the currently existing scientific evidence that ELF magnetic fields are causally associated with childhood leukemia is too weak to form the basis for exposure guidelines."

3.1.14 Summary

Despite the fact that scientific data in the area of EMF from low-frequency sources such as powerlines is still unsettled at this point, many jurisdictions have taken the initiative to legislate in this regard. This appears to be in response to the recommendations of the World Health Organization, and in light of a Council Recommendation by the European Commission. In North America, the United States has had varying degrees of success in regard to instituting legislation relating to EMF exposure, but we have yet to see such lawmaking in Canada. While a report by the ELF Working Group of the Federal-Provincial-Territorial Radiation Protection Committee states that at least three provinces in Canada have set voluntary standards with regard to electrical fields, no mandatory standards have been set with regard to magnetic fields.

Furthermore, such standards are set by utilities corporations. Although Canada purports to follow a framework of precaution in its approach to EMF and health, this revolves around education and research rather than extending that precautionary principle to legislation addressing the limits of exposure to low frequency EMF. Although Health Canada is involved with the World Health Organization's International EMF Project, there are currently no guidelines regarding federal standards of exposure of the general public to EMF from electrical installations, much less legislation in this regard. This state of matters was confirmed in a recent press release from Ontario MP Frank Klees, who confirmed in the legislature that there are in fact no federal guidelines regarding EMF. Furthermore, the Minister of Health has refused to develop national standards regarding EMF health concerns.

Most European nations now have implemented standards following the guidelines of the ICNIRP, however excessive they may be; many others have implemented stricter standards, particularly around sensitive zones such as schools, parks and hospitals. Similarly, siting criteria legislation in the United States have provided that power lines must be a stipulated distance away from such areas, in order to minimise the exposure. Where Canada lacks such legislation, it is necessary to consider the precedents of other nations which have made EMF from low frequency sources such as power lines a legislative issue. Other nations have shown a willingness to take the health of their people to task and regulate what is potentially a great harm.

In summary, the following is noted in terms of present knowledge on the possible health effects of EMF:

- The main focus of research has been on a possible association between long term exposure to magnetic fields and childhood leukaemia.
- Based on the epidemiological findings, the risk of EMF being a health hazard is small.
- Based on current understanding of the topic, EMF is regarded as a possible but not proven cause of cancer.

- The suggestion for this health outcome stems mainly from a fairly consistent pattern of the increased but small risk observed from some epidemiological studies. This finding has not been confirmed by (notably all) controlled laboratory studies.
- No evidence of a causal relationship between magnetic field exposure and childhood leukaemia has been found and no dose-response relationship has been shown to exist between EMF exposure and biological effects.
- A possible explanation for the epidemiological findings may be confounding (a factor other than EMF) or bias (subjects studied are not representative of the target population about which conclusions are drawn) which render the data inconclusive and prevent resolution of the inconsistencies in the epidemiologic data.

3.2 Concept of Prudent Avoidance

There is an increasing awareness for electricity suppliers to adopt *precautionary approaches* to manage health risks in the face of scientific uncertainty. This approach in essence refers to taking "prudent action when there is sufficient scientific evidence (but not necessarily absolute proof) that inaction could lead to harm and where action can be justified on reasonable judgments of cost-effectiveness."[16]

There are different precautionary policies promoting caution when addressing concerns about public, occupational and environmental health issues in the face of scientific uncertainty. These policies include (but not limited to) the Precautionary Principle and Prudent Avoidance.

The Precautionary Principle is a risk management policy applied where circumstances present a high degree of scientific uncertainty and reflect the need to take action for a potentially serious risk without awaiting the results of scientific research.

In response to the communities concern regarding low frequency EMFs and possible health effects, a policy of *Prudent Avoidance* has been adopted by the electricity supply industry in Australia. This policy does recognise the present lack of full scientific certainty but recommends that low cost precautions be undertaken where appropriate. As recorded by the ENA[17] *prudent avoidance is* described as … *"doing whatever can be done at modest cost and without undue inconvenience to avoid the possible risk to health"* and includes the following action items:

- *"monitoring and sponsoring research;*
- *continually reviewing policies in the light of the most up to date research findings, especially scientific review panels;*
- *providing awareness training for electricity supply business employees and keeping them informed;*
- *sharing information freely with the community;*
- *measuring fields levels; and*

[16] Quoted at the Treaty of Maastricht by WHO 1999.
[17] ENA Guidance on electrical installation practices to reduce EMF from low voltage wiring – 23 January 2008.

- *practising "prudent avoidance" when designing and siting new transmission and distribution facilities."*

Prudent Avoidance was initially developed during the late 1980's as a risk management strategy for power frequency EMF by Drs. Morgan, Florig and Nair at Carnegie Mellon University. It was defined as "taking steps to keep people out of fields by rerouting facilities and redesigning electrical systems and appliances". Subsequently, Prudent Avoidance has evolved to mean taking simple, easily achievable, low cost measures to reduce EMF exposure, in the absence of a quantifiable risk. In addition to Australia, prudent avoidance has been adopted as policy in parts of the electrical sector in Sweden and a few US states (California, Colorado, Hawaii, New York, Ohio, Texas, and Wisconsin).

The prudent avoidance approach does present difficulties regarding its application to EMF exposure. One difficulty is the lack of clear evidence for health hazards from long-term exposure to EMF which are below the recommended guidelines. Another difficulty is attempting to create cautionary EMF policies that have consistency and equity in a modern day environment of ubiquity exposure at highly variable levels and over wide frequency ranges. One only needs to consider a typical urban environment which contains a multitude of radiofrequency transmitters, ranging from low power communications transmitters to very high power broadcast transmitters.

Additional focus has been placed on routing power lines away from schools, and phasing power line conductors to reduce magnetic fields near their rights of way." The recent case, *Energex Ltd v. Logan City Council et al*[18], the Planning and Environment Court of Queensland held that although there was no absolute proof that exposure to magnetic fields caused an increased risk of childhood leukaemia; the policy of "prudent avoidance" should apply[19]. This resulted in the Australian court imposing a 0.4 μT magnetic field strength exposure limit on substation development. The health issues relating to this case are discussed on pages 13-19 and details of the judgement are given on pages 19-23 of the Planning and Environmental Court of Queensland – Energex Ltd v Logan City Council & Ors citation.

The above case has no influence on the CopperString Project as the nearest resident property is some approximately 250 m from the proposed transmission line. The calculated results indicate the maximum magnetic field strength at this distance is 0.025 μT (16 times smaller than 0.4 μT).

3.3 Effects on Animal Life

Extensive studies have been carried out on the effects of EMF on agricultural holdings. These studies include system operating voltages of up to 1200 kV and electric field strengths up to 12 kV/m. The electric field strength in these studies exceeds the permissible EFS limit by 140%.

Such studies typically involve the comparison of an exposed group versus a control group and the energisation and de-energisation of a line for some period of time. Although not generally

[18] *Energex Ltd v. Logan City Council & Ors*, [2002] QPEC 1

[19] Denis L. Henshaw, "Why we need prudent avoidance of exposure to elevated levels of magnetic fields associated with the electrical supply", online: Human Radiation Effects Group, University of Bristol http://www.electric-fields.bris.ac.uk/MagneticFieldStrength.htm

reported by beekeepers, studies have shown power line electric fields can affect honey bee colonies[20]. The effects are most likely caused by micro-shocks experienced by the bees whilst inside the hive. Magnetic fields appear to have no significant effect on bees. No effects were reported for bees flying in an electric field of 11 kV/m. In preventing the mentioned effect, it is recommended that bee hives be placed outside the servitude. Should bee hives be placed inside the servitude, techniques to shield the bees from the power line electric field should be applied.

In general, studies[21] of animal reproductive performance, behaviour, milk production, meat production, health and navigation have found minimal or no effects of EMF. The literature[22] published to date has shown little evidence of adverse effects of EMF from overhead power lines on farm animals and wildlife. Experience form electric utilities and results from research show in general that electric fields from overhead power lines do not affect behaviour or health of livestock[23]. Livestock of all kinds often rest or feed underneath power lines.

No effects on cattle fertility were noted in pilot studies of 36 herds, during which artificial insemination was applied.[24] A larger study involving 106 farms in Sweden did not show cows to have decreased fertility. On average, they were exposed to the 400 kV lines for more than 15 days per year and to maximum electric fields of 5 kV/m on some of the farms. An experimental study showed the fertility parameters of 58 cows studied, were not affected by exposure to a 400 kV line. Breeding was achieved by artificial insemination and the fertility parameters included: Estrous cycle, number of inseminations per pregnancy and conception rate. The animals were exposed for 120 days to 50 Hz electric fields of 4 kV/m (average) and magnetic fields of 2 μT (average).

No evidence of differences in the measures of immune function was found in the final analysis of the sheep exposed for 27 months to mean electric and magnetic field levels respectively of 5.2 to 5.8 kV/m and 3.5 to 3.8 μT.[25]

Cattle behaviour was studied near a 1,200 kV prototype line during the summers over a 5 year period. A 12 kV/m maximum electric field was created by the line. Animals showed no reluctance to graze or drink underneath the line. Statistical analysis of data from the two first years of the study indicated that the cattle spent somewhat more time near the line when de-energised. This finding could not conclusively be related to the line. Apart from one animal that died of a bacterial infection, the other animals studied during the 5 year period, remained healthy with no abnormal conditions.

[20] Greenberg, B, Bindokas, V P, Gauger, J R, Biological Effects of a 765kV Transmission Line: Exposure and Thresholds in Honeybee Colonies, Bioelectromagnetics 2 (4) : 315 – 328, 1981.
[21] Takebe, H, Shiga, T, Kato, M, Masada, E, Biological and Health Effects from Exposure to Power Line Frequency Electromagnetic Fields – Confirmation of Absence of Any Effects at Environmental Field Strength, IOS Press, ISBN 158 603 1058, 2001.
[22] Carstens, E L, Biological Effects of Transmission Line Fields, Elsevier Science Publishing Co, ISBN 0-444-01018-1, 1987.
[23] US Department of Energy (DOE) and Bonneville Power Administration (BPA), Electrical and Biological Effects of Transmission Lines – A Review, 1989. And Lee, J M, Reiner, G L, Transmission Line Electric Fields and the Possible Effects on Live Stock and Honeybees, Transactions of the American Society of Agricultural Engineers, 26 (1): 279 – 286, 1983.
[24] US Department of Energy (DOE) and Bonneville Power Administration (BPA), Electrical and Biological Effects of Transmission Lines – A Review, 1989.
[25] Hefeneider, S H, McCoy, S L, Hausman, F A, Christensen, H L, Takahashi, D, Perrin, N, Bracken, T D, Shin, K Y, Hall, A S, Long-term Effects of 60-Hz Electric vs Magnetic Fields on IL-1 and IL-2 Activity in Sheep, Bioelectromagnetics, 22 (3): 170 – 177, 2001.

Effects of electric and magnetic fields on wildlife are subtle and difficult to identify. Based on studies with laboratory animals, wildlife may be able to detect electric fields through such means as hair stimulation. Research has not shown these fields to adversely affect wildlife behaviour or health.[26]

3.4 Effect on Vegetation

The effects of electric fields on plants have been a field of interest to scientists since the eighteenth century[27], mainly because of interest in possible use of electricity to increase crop yield. During the mid-1970s, some EMF studies were specifically directed towards investigations on the effects of power frequency *electric* fields on plants. These were later followed by effects of *magnetic* fields on plants.

An object placed in an electric field will enhance the field. If increased sufficiently, corona may occur. Damage of leaf tips occur at fairly high electric field levels at locations very close to the line. Trees growing this close to the power line have to be pruned and trimmed according to the electric utility's requirements for servitude management. At field levels outside the servitude, where tall trees are allowed and more likely to be found, the electric field levels will be low enough not to cause leaf tip damage.

Considering the findings of studies on the effects of electric and magnetic fields on plants, it can be concluded that electric and magnetic fields with levels typical of a power line environment, complying with the requirements for proper servitude management as prescribed by the electricity regulator, are unlikely to affect plants in terms of growth, germination and crop production. Applying the above findings to the CopperString Project, it is reasonable to believe that there will be no negative effects on the existing vegetation.

4. GUIDELINES & STANDARDS APPLIED

Various local and international guidelines and standards have been researched for the CopperString Project EMF assessment study. This study has adopted the International Commission on Non-Ionizing Radiation Protection (ICNIRP) limits from the published "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz). The former guideline has been internationally accepted. Of particular relevance from the guideline are Table 6[28] and Table 7[29] within the ICNIRP guideline. Power grid frequency of 50 Hz falls within the 0.025-0.8 kHz frequency range. For occupational exposure a limit of 500/f is specified for the Electric Field Strength (referred to E-field strength) and measured in units of V/m (or kV/m) and the Magnetic Field (B-field) limit is 25/f. For general public exposure a limit of 250/f is specified for the Electric Field Strength (referred to E-field strength) and measured in units of V/m (or kV/m) and the Magnetic Field (B-field) limit is 5,000/f.

[26] Stern, S, Laties, V G, Behavioural Effects of 60Hz Electric Fields: I. Detection of 60Hz Electric Fields by Rats, Project Resumes: Biological Effects from Electric Fields Associated with High Voltage Transmission Lines, US Department of Energy, Washington DC, 1982.
[27] US Department of Energy (DOE) and Bonneville Power Administration (BPA), Electrical and Biological Effects of Transmission Lines – A Review, 1989.
[28] ICNIRP Table 6: Reference Levels for Occupational Exposure to Time-Varying Electric & Magnetic Fields
[29] Table 7: Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values)

ICNIRP Table 6: Reference Levels for Occupational Exposure to Time-Varying Electric & Magnetic Fields

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

[a] Note:
1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

ICNIRP Table 7: Reference Levels for General Public Exposure to Time-Varying Electric & Magnetic Fields

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

[a] Note:
1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

For purposes of this report the rescinded Australian exposure guidelines (described as "interim") set by the National Health and Medical Research Council in 1989 are applicable. This is as the

2006 issued Draft Radiation Protection Standard for Exposure Limits to Electric and Magnetic Fields 0 Hz - 3 kHz has not yet been finalised and invitations for submissions are still on-going. The applied guidelines in this report are similar to many other countries.

5. EMF EFFECTS ON THE RECEPTION OF ELECTRONIC DEVICES

5.1 Background

High voltage transmission lines may generate radio interference (RI) directly under or within the easement area. The level of interference is subject to the operating voltage and the conductor size and configuration. High RI levels may have an effect on the reception quality of electronic devices such satellite phones, cellular networks, UHF radio communication and the internet. Establishing limits for RI is complex as the value is set according to the frequency range for each electronic device.

A summary of frequency spectrum for various communication mediums in relation to know frequency ranges is illustrated in *Table 5.1: Frequency Spectrum Table*.

Table 5.1: Frequency Spectrum Table

Frequency Bandwidth Description	Frequency Range	Typical Application
Extremely Low Frequency (ELF)	0 to 3 kHz[30]	Distress Broadcast
Very Low Frequency (VLF)	3 KHz to 30 KHz	Coastal Radio
Low Frequency (LF)	30 KHz to 300 KHz	Long-wave Broadcast
Medium Frequency (MF)	300 KHz to 3000 KHz	Medium-wave Broadcast
High Frequency (HF)	3 MHz[31] to 30 MHz	Short-wave Broadcast
Very High Frequency (VHF)	30 MHz to 300 MHz	Radio & TV
Super Band	216 MHz to 600 MHz	Cellular, Radio & TV
Ultra-High Frequency (UHF)	300 MHz to 3000 MHz	TV, Cellular & Satellite
Super High Frequency (SHF)	3 GHz[32] to 30 GHz	Radar & Satellite
Extremely High Frequency (EHF)	30 GHz to 300 GHz	Satellite & Microwave
Infrared Radiation	300 GHz to 430 THz[33]	Optical communications
Visible Light	430 THz to 750 THz	VLC[34]
Ultraviolet Radiation	1.62 PHz[35] to 30 PHz	HPLC[36]
X-Rays	30 PHz to 30 EHz[37]	Medical imaging
Gamma Rays	30 EHZ to 3000 EHz	Genetic repair

[30] kHz = 1,000 Hz
[31] MHz = 1,000,000 Hz
[32] GHz = 1,000,000,000 Hz
[33] THz = 1,000,000,000,000 Hz
[34] Visible Light Communication
[35] PHz = 1,000,000,000,000,000 Hz
[36] High Performance Liquid Chromatography
[37] EHz = 1,000,000,000,000,000,000 Hz

The updated Australian radiofrequency spectrum allocations chart is available from the Australian Government (Australian Communications & Media Authority) website as:

http://www.acma.gov.au/webwr/radcomm/frequency_planning/spectrum_plan/arsp-wc.pdf

Figure 2: Typical Emission Limits illustrates typical limits for various frequencies according to relevant international standards. It is evident from the figure that there are numerous standards and permissible emission limits. These limits are continually under review as communities become more reliant on electronic devices in their daily activities and electronic technology developers improve products against the effects of RI.

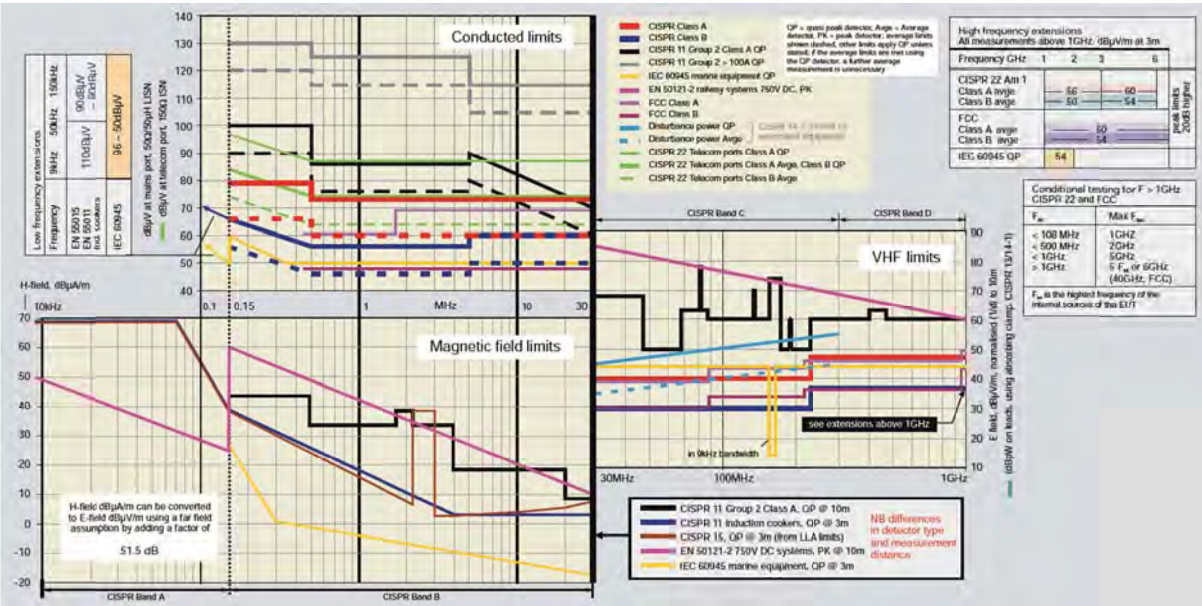

Figure 5.1: Typical Emission Limits[38]

5.2 Cause of Radio Interference

The primary cause of RI generated form overhead lines is corona. Corona is a significant factor in the design of overhead power lines and it influences the selection of the diameter of the phase conductors, the number of conductors in each phase conductor per bundle as well as the conductor clearance to ground. Corona discharge noise consists of broadband noise (hiss, crackle, etc.) and is generally only audible under conditions of high humidity, such as during rain or fog.

An important geographical factor is altitude. A higher altitude causes higher levels of corona than at sea level and importantly applies to the limitation of audible noise (AN) in dry conditions at high altitudes. Despite the long length of the proposed CopperString transmission line, the effect of altitude is not an important consideration as the proposed line spans across altitudes which vary between 100 m and 450 m – a relatively small variation.

[38] Source: Teseq AG

Corona on line conductors and hardware fittings (such as insulators, clamps, spacer-dampers) is usually evident as radio interference, audible noise, visible discharges. Corona is a phenomenon caused by the partial electrical breakdown or ionisation of the air surrounding a conductor or fitting when energised at a high voltage. It is evident when the electric field or voltage gradient on the surface of the conductor or fitting exceeds a critical value which is usually at 30 kV/cm (peak), or about 21 kV rms/cm in standard atmospheric conditions[39].
Figure 5.2: Area of Not Warranted Good Reception illustrates that good reception cannot be warranted directly below and within the transmission line easement. Transmission line design measures ensure that these services are provided at an acceptable quality outside of the easement area.

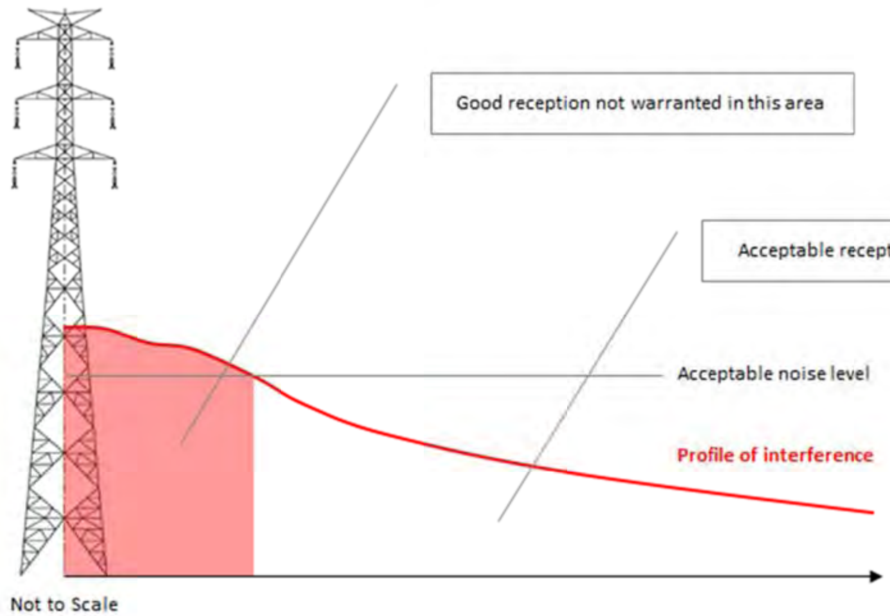

Figure 5.2: Area of Not Warranted Good Reception

5.3 Calculation methods

The four available methods for determining noise on A.C. transmission lines were reviewed for these studies calculations. These include the following:

- IREQ[40]: IREQ integration method will be evaluated (Canada)
- BPA[41]: BPA method will be evaluated (USA)
- EdF[42]: EdF method will be evaluated (France)
- EPRI[43]: EPRI/GE method will be evaluated (USA)

This study's calculations are based on the internationally recognised IREQ (Integration) method and noise measurements been taken along a profile at a height of 1.5 m above

[39] Temperature of 0 °C and absolute pressure of 100 kPa (International Union of Pure and Applied Chemistry (IUPAC).
[40] Hydro-Québec's Research Institute.
[41] Bonneville Power Administration.
[42] Electricitiet de France.
[43] Electric Power Research Institute.

ground. The measurement profile's origin is at the centre of the tower and extends laterally to a distance of up to 100 m. For all types of towers this is well beyond the easement boundary. Atmospheric conditions are considered constant at an altitude of 450 m (maximum altitude) and an average temperature of 30°C. Temperatures were sourced from the Australian Government Bureau of Meteorology. Due to the length of transmission line and the variation along the route, an average temperature has been assumed and exact data for each geographical location will not cause a large variation in the calculated results.

The transmission line is considered as transposed in all calculations and the phasing for double circuit towers are taken as ABC and CBA. For conservative results, only the highest system voltages are considered in the calculations and these are assumed to be at maximum operating voltage (U_m). These are 245 kV (110 % x 220 kV) and 345 kV (105% of 330 kV).

5.4 Calculation Results

The results have been calculated by use of **SES-Enviro Plus** - a Canadian developed program which analyses power line cross sections to determine line parameters, capacitive and magnetic induction, as well as local electrostatic potentials, gradients and corona parameters, for systems of overhead AC/DC transmission line conductors. The program can be used to analyse complex corridors containing any combination of transposed and not transposed transmission lines.

A summary of the calculated RI results for each tower configuration is illustrated in *Table 5.2: Summary of Radio Interference (RI) per Transmission Line Route*. These results are for a lateral distance of 30 m from the centre of the towers which corresponds with the boundary of the easement. The three standard weather scenarios are considered, namely Heavy Rain, L_{50} (Wet Conductors) and Fair (Dry Conditions).

Table 5.2: Summary of Radio Interference (RI) per Transmission Line Route (30 m)

	Radio Interference (dB)		
	Heavy Rain	L_{50} (Wet Conductors)	Fair (Dry Conditions)
330 kV Double Circuit Twin Conductor	66.15	56.51	39.58
220 kV Double Circuit Single Conductor	66.44	56.12	39.26
220 kV Single Circuit Single Conductor	63.89	52.38	35.49

When comparing the above results to international standards, and comparing the proposed line route, the values indicate that the proposed overhead lines do not pose any RI violation issues for any nearby habitant.

As reducing environmental noise is a priority consideration during the planning, design, procurement and operating of the transmission system, it is believed that there will be no residual impacts. Expanding on the former statement; it is believed that no cumulative and interactive impacts will be experienced.

5.5 Discussion of Results

Locating habitable properties (whether residential or industrial) from the provided satellite photographs and comparing to the results; there are no incidents where either the RI values pose any violation risk. The closest property is considered to be the closing span of the 220 kV single circuit single conductor transmission line to Mount Isa Substation. This is approximately 250 m from a residential property. At this distance the expected RI is 15.11 dB for L_{50}. Another property is at Phosphate Hill Substation which is 330 m from a mine. The expected RI is 10.27 dB for L_{50} respectively.

Reviewing the climatic conditions along the proposed transmission line route, it is reasonable to state that the above L_{50} (wet conductor) measurement can be considered a conservative approach in evaluating RI. Fair (dry conditions) would be a more realistic approach. This approach is reasonable as the average annual rainfall and frequency of rainfall along the proposed transmission line is low[44].

RI is a subject that is still under research; particularly in the television reception frequency of 47 MHz to 230 MHz range[45]. For frequencies in the range below 30 MHZ CISPR provides useful guidelines and examples for deriving limits. The principle involves the following four parameters for specifying radio noise limits:

- Minimum wanted radio signal level to be protected
- Minimum accepted signal-to-noise ratio (SNR)
- Reference noise level, represented at 2 m height above ground during prescribed weather conditions (this is assumed to be L_{50} (wet conductor)
- Protected distance.

The maximum accepted noise level is calculated at 54 dB (µV/m). From the results the worst case scenario properties indicate that the RI at these properties is well below the minimum acceptable noise level. The actual calculated RI at 250 m is 15.11 dB which is lower than the maximum acceptable reference noise level of 54 dB (µV/m).

5.6 Satellite Phones, Cellular Networks, UHF Radio and Internet Communication

Television interference due to transmission lines is evident when “snowing” or “lines” appear on the television screen. On radios, mobile and satellite phones a “hiss” or “crackling” sound is evident. The expected RI is a subject that is still under research; particularly in the television reception frequency of 47 MHz to 230 MHz range[46]. For frequencies in the range below 30 MHZ CISPR provides guidelines and examples for deriving limits. The principle involves the following four parameters for specifying radio noise limits:

- Minimum wanted radio signal level to be protected
- Minimum accepted signal-to-noise ratio (SNR)
- Reference noise level during prescribed weather conditions (this is assumed to be L_{50} (wet conductor)
- Protected distance

[44] Australian Government Bureau of Meteorology
[45] See CISPR 18-2 Section 5.5.2 Television reception
[46] See CISPR 18-2 Section 5.5.2 Television reception

Results for worst case scenario properties along the proposed transmission line indicate that the RI at these properties is below the minimum acceptable noise level. The actual calculated RI at 250 m is 15.11 dB (μV/m). This is lower than the acceptable reference noise level of 54 dB (μV/m).

Concerns are often raised over the radio interference generated from high voltage overhead transmission lines on multi-band cellular phone reception. Cellular phones operate at frequency ranges between 800 Megahertz (MHz) and 1.5 Gigahertz (GHz). Existing empirical formulas to calculate the rate of lateral attenuation of radio noise at these frequencies are not accurate and research is on-going to derive these formulas. The IEC document TR CISPR 18-2[47] can however be applied to determine the expected rate of lateral attenuation by comparing the change in attenuation from lower frequencies to higher frequencies. This is carried out for direct distances (*D*) of 20 m and 100 m from the nearest conductor of a line. Available information indicates that the noise level decreases by a factor D^{-x} where x decreases as the frequency increases. Values obtained for x illustrate the expected decay in *Table 5.2: Approximate x Values for Frequency Ranges 0.15 MHz to 300 MHz.*

Table 5.2: Approximate x Values for Frequency Ranges 0.15 MHz to 300 MHz[48]

Frequency Ranges	Factor (x)	Rate of Lateral Attenuation (log D^{-x})	
		20 m	100 m
0.15 MHz to 0.40 MHz	-1.8	0.005	0.0003
0.40 MHz to 1.70 MHz	-1.65	0.007	0.0005
30 MHz to 100 MHz	-1.2	0.028	0.0040
100 MHz to 300 MHz	-1.0	0.050	0.0100
800 MHz to 1.20 GHz	Not Available	>> 0.05[49]	

From the above it becomes evident that the rate of near field lateral attenuation increases as the frequency increases. Therefore the lateral attenuation of high frequencies used in cellular phones, satellite and internet communications can be expected to significantly increase therefore reducing RI over short lateral distances. As high frequency radio interference is extremely directional, calculating the expected radio interference is complex and still under research. Good reception cannot be warranted immediately under transmission lines. Modern mobile technology contains frequency shift digital modulation which has error checks. This technology is less susceptible to high frequency radio interference. There are no expected reception problems beyond the demarcated easement of the proposed overhead line.

[47] Section 5.3.5.1 Attenuation laws.
[48] Approximated for lateral distance of between 20 m and 100 m from the nearest conductor of a line.
[49] Expected attenuation value exceeds above values for frequency ranges 0.15 MHz to 300 GHz.

5.7 Mitigation Measures to Minimise Potential Impacts

The primary mitigation measure against possible environmental “noise” non-compliance is addressed during the design of the transmission line, substation and the specification of high voltage equipment such as transformers and fittings.

Secondary mitigation will take place during the operating of the transmission network. During this period routine inspections and condition based maintenance of high voltage assets will eliminate potential non-compliance. An example would be the routine inspection with portable daylight ultraviolet/corona detection and visualisation instruments for measuring corona discharges.

Radio noise generated by sparking at loose or imperfect, contacts occurs mainly in dry weather since in wet weather the comparatively small gaps involved usually became bridged with moisture. Preventive and remedial measures to minimize radio noise generated by bad contacts and their detection and location are well documented in CISPR/TR 18-3 Ed. 2.0 – Part 3[50]. Such measures include ensuring that all fixing bolts are securely tightened, and bonding of conducting elements, as far as is possible, either to earth or conductor potential.

Inspection of all attributes of equipment designed to limit noise should be performed periodically. This includes both continuous audible sources (connector hardware and busbars) and impulse sources (switchgear).

5.8 Significant Assessment of Residual Impacts

As reducing environmental noise is a priority consideration during the planning, design, procurement and operating of the CopperString Project transmission system, it is evident from the results that there will be no residual impacts.

5.9 Cumulative and Interactive Impacts

As mentioned in the above section, by prioritising the minimisation of environmental noise during the planning, design, procurement and operating of the transmission system, it is believed that there will be no cumulative and interactive impacts.

6. EXPOSURE LIMITS IN AUSTRALIA

The Australian exposure guidelines (described as "interim") were set by the National Health and Medical Research Council in 1989. Subsequently these guidelines have been rescinded and the ARPANSA have issued a Draft Radiation Protection Standard for Exposure Limits to Electric and Magnetic Fields 0 Hz - 3 kHz during 2006. Currently the ARPANSA is inviting submissions on this draft standard. Previous guidelines set by the NHMRC are similar to many other countries. The following limits have been applied to this report:

[50] Section 6: Radio interference characteristics of overhead power lines and high voltage equipment - Part 3: Code of practice for minimizing the generation of radio noise.

General public exposure:

- Electric fields: 5 kV/m for 24 hours a day exposure, 10 kV/m for a few hours per day, can be exceeded for a few minutes per day.
- Magnetic fields: 100 μT for 24 hours a day exposure, 1000 μT for a few hours per day, can be exceeded for a few minutes per day.

Occupational exposure limits:

- Electric fields: 10 kV/m for 24 hours a day exposure
- Magnetic fields: 500 μT for 24 hours a day exposure

The transmission line is considered as transposed in all calculations and the phasing for double circuit towers are taken as ABC and CBA. System voltages are assumed to be at maximum operating voltage (U_m). These are 245 kV (110 % x 220 kV) and 345 kV (105% of 330 kV). Magnetic field calculations are based on 500 MVA per circuit for both 330 kV and 220 kV twin conductor transmission lines. Transferred current is 875 A and 1,315 A respectively. For both single and double circuit 220 kV transmission lines with single conductor, the magnetic field is based on 120 MVA – 315 A.

EMF measurement profiles are set at 1 m height above ground level. These are located perpendicular from the mid-point of the towers (0 m) to a maximum of 330 m as illustrated in *Figure 1: Location of Transmission Line Measurement Profiles*.

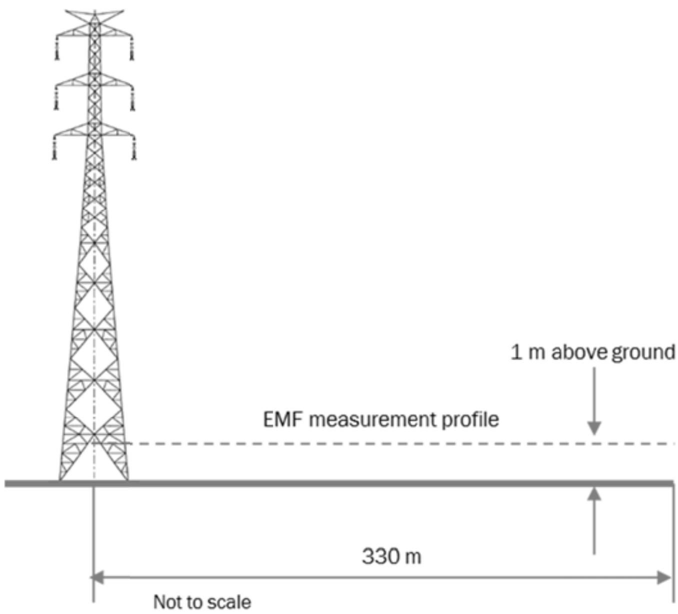

Figure 1: Location of Transmission Line Measurement Profiles

7. CALCULATION RESULTS

Based on the guidelines, standards and study input assumptions, all results for calculations are contained in Appendix C, D and E. These results have been calculated by use of SES-Enviro Plus - a Canadian developed program which analyses power line cross-sections to determine line parameters, capacitive and magnetic induction, as well as local electrostatic potentials, gradients and corona parameters, for systems of overhead AC/DC transmission line conductors. The program can be used to analyse complex corridors containing any combination of transposed and not transposed transmission lines.

For the proposed transmission line, a summary of the electric field strength (EFS), magnetic field strength (MFS) and magnetic field density (MFD) results are illustrated in the tables below. Tables 7-1 and 7-2 in Section 10.1.1 below illustrate the results for both circuits (in the case of double circuit towers) operated at the maximum MVA (500 MVA and 250 MVA). And, Tables 7-3; 7-4 and 7-5in Section 10.1.2 below illustrate the results for a single circuit operating at the maximum MVA (500 MVA and 250 MVA). These results are for a lateral distance of 0 m, 30 m, 250 m and 330 m from the centre of the towers. The distances from the centre of the tower are chosen to correspond with the boundary of the easement and the proximity of the closest habited properties.

Results for the substations are illustrated in tables 7-6 to 7-10 of Section 10.1.3 below. The results indicate that there is a significant reduction in the EMF the further away from the centre of the transmission line and substation conductors. This phenomena is more clearly illustrated in Appendix C: Transmission Line Electric Field Strength (EFS) Calculation Results and Appendix D: Transmission Line Magnetic Field Density (MFD) Calculation Result.

The coupling effect of the proposed transmission line on railway lines and distribution lines have been considered. As these services are routed laterally across a transmission line there is no electromagnetic coupling.

7.1 Transmission Lines

7.1.1 Double Circuit Operation

The calculated results in this section illustrate the EMF in normal operation when both circuits are energised and transferring load. EMF values differ when a single circuit is operated on a double circuit tower configuration. When both circuits are operating there is EMF cancellation of the EMF. The results for single circuit operation on both a double circuit configuration and single circuit configuration are illustrated in section 7.1.2 below.

Table 7.1: 330 kV Double Circuit Twin Conductor – EMF Results

330 kV Double Circuit Twin Conductor System			
Transmission Route:	Woodstock to Dajarra Road		
Distance from tower centre - m	Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) – μT
Minimum[51]	4.350	4.741	5.957
30	0.052	0.613	0.770
250	0.003	<0.001	<0.001
330	0.001	<0.001	<0.001

Table 7.2: 220 kV Double Circuit Single Conductor – EMF Results

220 kV Double Circuit Single Conductor System			
Transmission Route:	Dajarra Road to Mount Isa & Dajarra Road to the Common South Point (CSP)		
Distance from tower centre - m	Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) – μT
Minimum	3.174	4.932	6.197
30	0.047	0.500	0.629
250	0.001	<0.001	<0.001
330	<0.001	<0.001	<0.001

[51] Minimum location refers to the lateral distance at which the EFS, MFS & MF are the maximum values. This distance varies – for EFS the location is at 0 m (centre of tower) & for both MFS & MF it is offset from 0 m.

7.1.2 Single Circuit Operation

Table 7.3: 330 kV Double Circuit Double Conductor – EMF Results

330 kV Double Circuit Twin Conductor System			
Transmission Route:	Woodstock to Dajarra Road		
Distance from tower centre - m	Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) – μT
Minimum	4.959	8.097	10.175
30	0.072	2.102	2.641
250	0.008	0.005	0.006
330	0.004	0.002	0.002

Table 7.4: 220 kV Double Circuit Single Conductor – EMF Results

220 kV Double Circuit Single Conductor System			
Transmission Route:	Dajarra Road to Mount Isa & Dajarra Road to the Common South Point (CSP)		
Distance from tower centre - m	Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) – μT
Minimum[52]	3.05	7.00	8.80
30	0.036	0.91	1.14
250	0.002	0.0009	0.0011
330	0.001	0.0003	0.0004

[52] Minimum location refers to the lateral distance at which the EFS, MFS & MF are the maximum values. This distance varies – for EFS the location is at 0 m (centre of tower) & for both MFS & MF it is offset from 0 m.

Table 7.5: 220 kV Single Circuit Single Conductor – EMF Results

220 kV Single Circuit Single Conductor System			
Transmission Route:	CSP to Cannington & CSP to Phosphate Hill		
Distance from tower centre - m	Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) – µT
Minimum	3.621	10.014	12.583
30	0.339	1.740	2.187
250	0.004	0.020	0.025
330	0.002	0.010	0.013

7.1.3 Substations

Table 7.6: Woodstock Substation – EMF Results

		Woodstock Substation – 500 MVA		
		Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) - µT
330 kV System[53]				
Maximum		9.186	23.195	29.150
Boundary Fence	28 m	0.257	1.323	1.663
275 kV System[54]				
Maximum		8.038	27.676	34.778
Boundary Fence	23 m	0.441	2.479	3.115

[53] 500 MVA at 880 A
[54] 500 MVA at 1050 A

Table 7.7: Hughenden Switching Substation – EMF Results

		Hughenden Switching Station – 500 MVA		
		Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) - µT
330 kV System[55]				
Maximum		9.186	23.195	29.147
Boundary Fence	20 m	0.784	2.801	3.520

Table 7.8: Dajarra Road Substation – EMF Results

		Dajarra Road Substation – 500 MVA		
		Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) - µT
330 kV System[56]				
Maximum		9.186	23.195	29.147
Boundary Fence	32 m	0.161	0.961	1.207
220 kV System[57]				
Maximum		9.154	48.372	62.042
Boundary Fence	18 m	0.637	5.005	6.290

[55] 500 MVA at 880 A
[56] 500 MVA at 880 A
[57] 500 MVA at 1315 A

Table 7.9: Mount Isa Substation – EMF Results

		Mount Isa Substation – 350 MVA		
		Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) - µT
220 kV System[58]				
Maximum		9.154	34.470	43.312
Boundary Fence	17 m	0.765	3.925	4.933
132 kV System[59]				
Maximum		5.212	55.014	69.133
Boundary Fence	27 m	0.067	1.568	1.971

Table 7.10: Cannington & Phosphate Substation – EMF Results

		Cannington & Phosphate Substations – 60 MVA		
		Electric Field Strength (EFS) – kV/m	Magnetic Field Strength (MFS) – A/m	Magnetic Field Density (MFD) - µT
220 kV System[60]				
Maximum		9.154	5.932	7.456
Boundary Fence	14 m	1.375	0.986	1.239

[58] 500 MVA at 918 A
[59] 500 MVA at 1531 A
[60] 60 MVA at 158 A

7.2 Magnetic Coupling Effect

The coupling effect of the proposed transmission line on existing gas pipelines, railway lines and distribution lines has been considered. As the services identified in Appendix F: Residential & Services Location are routed laterally across a transmission line, there is no electromagnetic coupling and therefore no negative effects on these services.

8. MITIGATION MEASURES TO MINIMISE POTENTIAL IMPACTS

The primary mitigation measure against possible environmental “EMF” non-compliance is addressed during the design of the transmission line and substation and in the specification of high voltage equipment such as transformers and fittings.

Depending on the desired field level, line compaction by bringing the conductors of the power line closer to each other may also be applied. Compacting tower designs is limited because compaction affects other electrical parameters, the distance between towers and the safe and effective operation of the line (especially under live-line maintenance).

Regarding the overhead line, magnetic fields can be reduced significantly by means of applying the following design techniques:

- Line compaction by reducing the circuit and phase spacing. This may however introduce higher corona and subsequent radio noise levels.
- Reversal of phases on double circuit transmission line. This technique is applied to the proposed CopperString Project 330 kV and 220 kV double circuit transmission lines.
- Splitting of phases to create additional phases with spatial placement that will create significant field reduction.
- Conversion of a horizontal formation to a delta formation reduces the electromagnetic field. This design technique is already applied in the proposed CopperString Project 220 kV single circuit transmission lines.

Mitigating design techniques are generally restrained in substations. However, compaction of phases is common in substations and additional techniques such as shielding with loops and material is an effective technique. A very effective technique is underground cabling. This is more common at the lower voltage distribution level where it is needed for the higher current transfer. Typical application is the 11 kV supply to the mines at Cannington and Phosphate 220/11 kV substations.

It is emphasised that cost and electrical performance of the line strongly dictate the design of the mitigation measure to be applied and the application of a specific field reduction design technique needs to be evaluated on a case by case basis.

The coupling effect of the proposed transmission line on gas pipelines, railway lines and distribution lines have been considered. When these services are routed laterally across a transmission line there is no electromagnetic coupling. Maximum magnetic coupling occurs when these services are parallel to the transmission line. Fortunately all services identified in Appendix F: Residential & Services Location cross laterally and therefore no mitigation is required for these services. Effective mitigation measures can be applied for any future services installed parallel to the transmission line.

9. SIGNIFICANT ASSESSMENT OF RESIDUAL IMPACTS

As reducing environmental EMF is a priority consideration during the planning, design, procurement and operating of the CopperString Project transmission system, it is evident from the results that there will be no residual impacts.

10.CUMULATIVE AND INTERACTIVE IMPACTS

As mentioned in the above section, by prioritising the minimisation of environmental EMF during the planning, design, procurement and operating of the transmission system, it is believed that there will be no cumulative and interactive impacts.

11.CONCLUSIONS

The purpose of this desktop electromagnetic field (EMF) study is to assist the land management and environmental assessment teams so that can complete the land acquisition and environmental approvals. The magnitude of electromagnetic fields generated from the proposed transmission lines and substations have been calculated and their effects of long-term exposure at the calculated magnitudes on human health, fauna and flora are discussed.

Precautionary approaches to manage health risks in the face of scientific uncertainty are also considered. Of the different precautionary policies promoting caution when addressing concerns about public, occupational and environmental health issuesissue, the Prudent Avoidance principle as applied in Australia and the recent case, *Energex Ltd v. Logan City Council et al*[61] is reviewed. Of significance is that the Planning and Environment Court of Queensland held that although there was no absolute proof that exposure to magnetic fields caused an increased risk of childhood leukemia; the policy of "prudent avoidance" should apply. This resulted in the Australian court imposing a 0.4 μT magnetic field strength exposure limit on substation development.

The above case has no influence on the CopperString Project as the nearest resident property is approximately 250 m from the proposed transmission line. The calculated results indicate the maximum magnetic field strength at this distance is 0.025 μT (16 times smaller than 0.4 μT).

The prudent avoidance approach has been reviewed objectively and difficulties regarding its application to EMF exposure are identified. These difficulties relate to the lack of clear evidence for health hazards from long-term exposure to EMF which are below the recommended guidelines, and attempting to create cautionary EMF policies that have consistency and equity in a modern day environment of ubiquity exposure at highly variable levels and over wide frequency ranges.

Final calculation results for this study of EFS, MFS and MFD are illustrated in Appendix C[62], D[63] and E[64]. A summary of the residential and services locations are illustrated in *Appendix F:*

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[61] *Energex Ltd v. Logan City Council & Ors*, [2002] QPEC 1
[62] Transmission Line Electric Field Strength (EFS) Calculation Results
[63] Transmission Line Magnetic Field (MFS & MFD) Calculation Results

Residential & Services Locations. All of the calculations contained in this report have been based on a conceptual design with typical towers, conductor type (Sulphur) and clearances. These calculations will be reviewed and if necessary modified during the final design stage of the transmission line. The studies conclude that the calculated EMF results will not present any negative health effects on the community along the proposed transmission line or near the proposed substations.

When comparing this report's calculated results of the proposed transmission line to international guidelines, the values indicate that the proposed transmission lines do not pose any EMF violation issues for any of the studied options, transmission line sections and various tower types.

As minimising the effect of EMF is a priority consideration during the planning, design, procurement and operation of the transmission system, no residual impacts are likely to be experienced.

[64] Substation EMF Calculation Results

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12. RELEVANT APPENDICES

Appendix A: CopperString Transmission Link – Route Plan
Appendix B: Typical Tower Types & Dimensions
Appendix C: Transmission Line Electric Field Strength (EFS) Calculation Results
Appendix D: Transmission Line Magnetic Field Density (MFD) Calculation Results
Appendix E: Substation EMF Calculation Results
Appendix F: Residential & Services Location