ELECTRIC AND MAGNETIC FIELDS FROM OVERHEAD POWER LINES

Final Report

Prepared for

ESKOM HOLDINGS LTD

empetus cc
ELECTROMAGNETIC TECHNOLOGY TRANSFER

18 April 2006

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Prepared for

ESKOM HOLDINGS LTD

by

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Executive Summary

The planning and siting of new power lines involve public participation. In many cases during public meetings and negotiations, the topic of the possible health effects of power frequency electric and magnetic fields surfaces. This report has been prepared to support answers, in a not-too-technical manner and in a way that is easy to understand, to some of the questions that may be raised. It covers in particular:

- Specific concepts that need to be addressed in forming an understanding of the topic;
- Examples of typical field levels in various environments, including power line environments;
- An overview of reviews on research findings;
- Findings of studies conducted on farm animals and plants near power lines;
- Exposure limits and
- Opinions and conclusions drawn by international and credible organizations, such as, the World Health Organisation.

The report is based on information obtained from a literature survey as well as calculations of electric and magnetic field levels near 400kV and 765kV lines.

Numerous studies have demonstrated that EMF exposure may induce some *biological* effects in living cells. Because of the lack of a known biophysical mechanism that would explain these effects, many question the existence of *clinical* responses. The *clinical* responses, as a result of power frequency electric and magnetic field exposure to levels typically found in residential and power line environments, if any, appear insignificant. Despite the lack of firm answers on the topic, responsible attempts to manage the issue have lead to strategies that promote:

- Continuous monitoring of developments in international research;
- Exposure assessment guided by internationally accepted field limits;
- Open communication with those concerned;
- Offering of services related to the measurement of field levels and
- Reduction of exposure if required and if it can be achieved at reasonable cost.

Keywords

Electric Field, Magnetic Field, Overhead Line, Health Effects

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1. INTRODUCTION

The planning and siting of new power lines involve public participation. In many cases during public meetings and negotiations, the topic of the possible health effects of power frequency electric and magnetic fields surfaces. This report has been prepared to support answers, in a not-too-technical manner and in a way that is easy to understand, to some of the questions that may be raised. It covers in particular:

- Specific concepts that need to be addressed in forming an understanding of the topic;
- Examples of typical field levels in various environments, including power line environments;
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2. DISCUSSION

2.1 What are Electric and Magnetic Fields?

Electric and magnetic fields (EMF) are always created, in varying levels, with the generation and use of electricity and at the frequency of the electrical power system. In South Africa, as in most European countries, electric power is supplied as an alternating current (AC) at a frequency of 50 Hertz (Hz). This means that the electric current flowing in the system changes direction 50 times per second. The American power system operates at 60 Hz.

Power system frequencies (50 Hz or 60 Hz) are much lower than the frequencies of electromagnetic energy applied, for example, in 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). This is important to note when discussing biological effects. 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.

Any 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.

At the low frequency of 50 Hz or 60 Hz, two fields exist that can be studied separately: electric fields and magnetic fields.

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).

Electric field levels are measured in Volts per metre (V/m). Because of the range of the levels encountered in power system environments, field levels are reported in kilovolt per metre (kV/m). (One thousand V/m = 1 kV/m).

Magnetic fields are produced by the current flowing (movement of electric charge) on a conductor. Electric current is measured in Ampere (A). The current on a system may vary depending on the number of devices (load) supplied by the system. As the load changes, the magnetic field will change. Magnetic fields decrease with an increase in distance from the source (conductor).

Magnetic field levels are measured in Tesla (T). Because of the range of the levels encountered in typical power system environments, field levels are reported in microtesla (μT). (One millionth of a Tesla = 1 μT). Some American literature use the unit of Gauss (G) where 10 milligauss (mG) = 1 μT.

Electric fields at 50 Hz are easily shielded by conducting objects. Reducing magnetic fields (at 50 Hz) requires special engineering techniques or designs and are treated in Section 2.7 of this report.

Electric and magnetic fields may exist alone or in combination. For example, an electric field will be created around the electric lead of a lamp plugged into and switched on at the wall, with the device switched off (light off). Should the lamp be switched on at the wall and at the device (light on), electric current will flow and a magnetic field will co-exist with the electric field in the vicinity of the electric lead. This field effect is the same for power lines.

Table 1 summarises typical electric field levels encountered in various environments and close to household appliances [1].

Table 1: Summary of typical electric field levels encountered in various environments and close to household appliances [1].

Description	**Electric Field (V/m)**
Directly below 400kV power line at ground level.	10,000
25m from centre line of 400kV power line.	1,000
Near typical domestic appliances.	10 - 250
Typical field level in homes.	1 - 10
Outside homes.	Less than 1

On a calm, clear and sunny day, the natural electric field could be a few tens of V/m. This level can increase to several thousand V/m during a thunderstorm.

Table 2 summarises typical electric field levels measured in the vicinity of Eskom power lines [2].

Table 2: Summary of typical electric field levels measured in the vicinity of Eskom power lines [2].

Voltage (kV)	Max Electric Field (V/m)	Electric Field at Servitude Boundary (V/m)	Servitude Width (m) (1)
765	7,000	2,500	40,0
400	4,700	1,500	23,5
275	3,000	500	23,5
132	1,300	500	15,5

(1) Measured from the centre of the line.

From Table 2 it is clear that the electric field falls to lower levels with an increase in distance from the line.

Table 3 summarises typical magnetic field levels encountered in various environments and close to household appliances [1].

Table 3: Summary of typical magnetic field levels encountered in various environments and close to household appliances [1].

Description	Magnetic Field (μT)
Directly below 400kV power line at ground level.	40
25m from centre line of 400kV power line.	8
Directly below 132kV power line at ground level.	7
25m from centre line of 132kV power line.	0,5
Vacuum cleaner, electric drill.	2 - 20
Food mixer.	0,6 - 10
Hair dryer.	0,01 - 7
Dish washer.	0,6 - 3
Washing machine.	0,15 - 3
Fluorescent lamp.	0,15 - 0,5
Ambient field inside homes.	0,01 - 0,2

Note: Levels indicated for household appliances were measured at 30cm from the appliance.

From Table 3 it can be seen that appliances, particularly those with electric motors, may generate magnetic fields with levels similar to power lines. Exposure to fields from household appliances is usually of a short duration.

The natural magnetic field is of the order of 30μT (in Johannesburg) and may vary up to about 70μT at the poles (North or South pole). This field is static and varies very slowly with time.

Table 4 summarises typical magnetic field levels measured in the vicinity of Eskom power lines [2].

Table 4: Summary of typical magnetic field levels measured in the vicinity of Eskom power lines [2].

Voltage (kV)	Current (A)	Max Magnetic Field (μT)	Magnetic Field at Servitude Boundary (μT)	Servitude Width (m) (1)
765	560	6,0	1,5	40,0
400	650	10,5	2,5	23,5
275	350	6,0	1,0	23,5
132	150	4,0	1,0	15,5

(1) Measured from the centre of the line.

It is clear from Table 4 that the magnetic field falls to lower levels with an increase in distance from the line.

2.2 Modern Power Line Structures and Associated Electric and Magnetic Fields

In discussing electric and magnetic fields from overhead power lines it is useful to refer to the maximum field level below the line as well as the field level at the servitude boundary. Maximum field levels are found at the midspan position (the position midway between two adjacent towers), where the conductors are closest to the ground.

Electric fields created in the vicinity of overhead power lines depend on the voltage on the line, the tower configuration and the conductor height above ground.

Magnetic fields created in the vicinity of overhead power lines depend on the current flowing on the line, the tower configuration and the conductor height above ground.

Table 5 illustrates some of the existing and newer line designs used by Eskom at 400 kV and 765 kV. Typical electric and magnetic field profiles associated with these designs are indicated in Figures 1 to 4. For the field calculations, the lowest conductor was kept at the same height for all three configurations considered: 17 m above ground for 765 kV and 13 m above ground for 400 kV. Refer to Appendix A for more detail on the line configurations used in the field calculations.

The magnetic field profiles in all cases were calculated for a line current of 1,000 A. Because the magnetic field is directly proportional to the line current, the field value can easily be scaled up or down for different loads on the line.

The zero metre mark ó0 mô in Figures 1 to 4 indicates the centre of the line.

It is clear from the field profiles in Figures 1 to 4 that different tower configurations present different field profiles. Power line design engineers use this as a technique in the design of overhead power lines to arrive at the lowest and desired field levels in the vicinity of a power line. It should be noted that electric and magnetic field levels are not the main consideration in the design of an overhead power line, but that other parameters related to the geometry (conductor type, placement of shield wires and phase spacing, for example) play a significant part in the design of the line in order to optimize its electrical performance and to minimise cost.

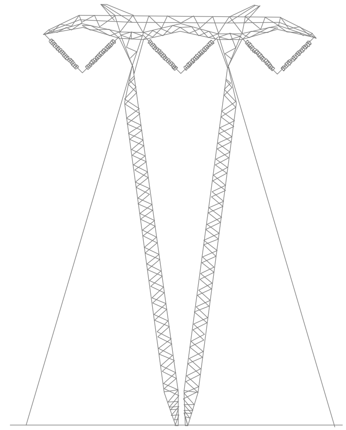
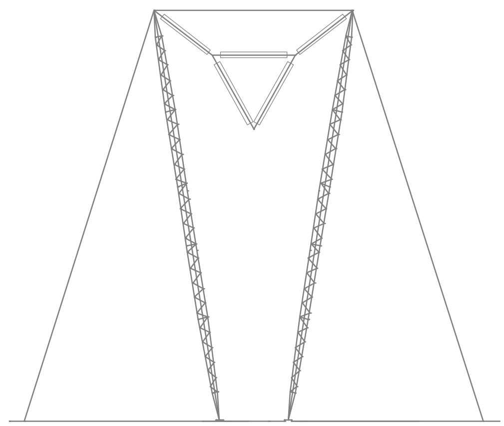
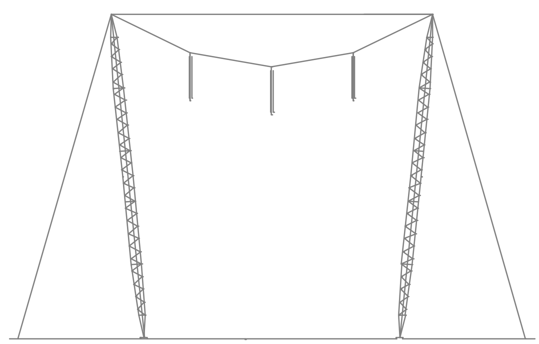
In some instances, power lines may be constructed to run parallel to each other. Electric and magnetic field profiles of an example of two 765 kV lines running parallel to each other (60 m centre to centre spacing) are respectively indicated in Figure 5 and Figure 6. In this case the centres of the towers are located at -30 m and 30 m in Figures 5 and 6.

From Figure 2 it can be observed that the maximum magnetic field level for the 400 kV designs, is higher than the maximum magnetic field level for the 765 kV designs. This is because the height of the conductors, in the case of the 400 kV designs, is lower than that for the 765 kV designs. In both cases the line current was 1,000 A.

The profiles indicated in Figures 1 to 6 show how the field levels fall to lower values with increasing distance from the line. Maximum allowable field levels used in the design of overhead power lines are covered in Section 2.6.

Although specific tower designs can be selected to reduce maximum field levels, if required, field reduction is not the main consideration in the selection of a specific tower type. Techniques, other than tower configuration, to reduce field levels are covered in Section 2.7.

Table 5: Some of the existing and newer 400kV and 765kV line designs of Eskom.

	 (A) ï Horizontal / Flat Configuration
	 (B) ï Delta Configuration
	 (C) ï Cross Rope Configuration

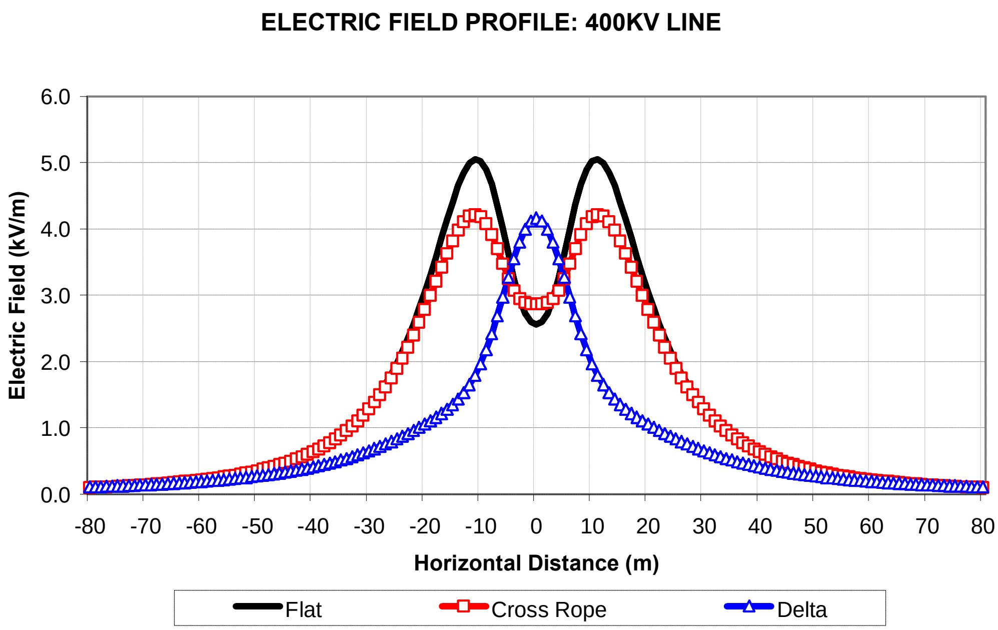


Figure 1: Typical electric field profiles for a 400kV line associated with the tower designs indicated in Table 5 (Tower geometry as per Appendix A).

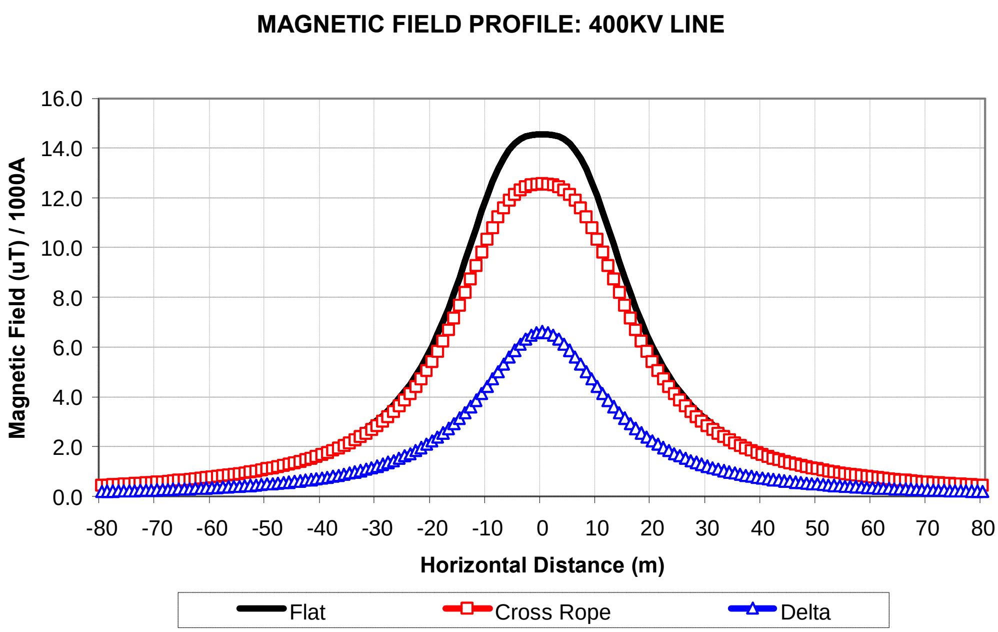


Figure 2: Typical magnetic field profiles for a 400kV line associated with the tower designs indicated in Table 5 (Tower geometry as per Appendix A).

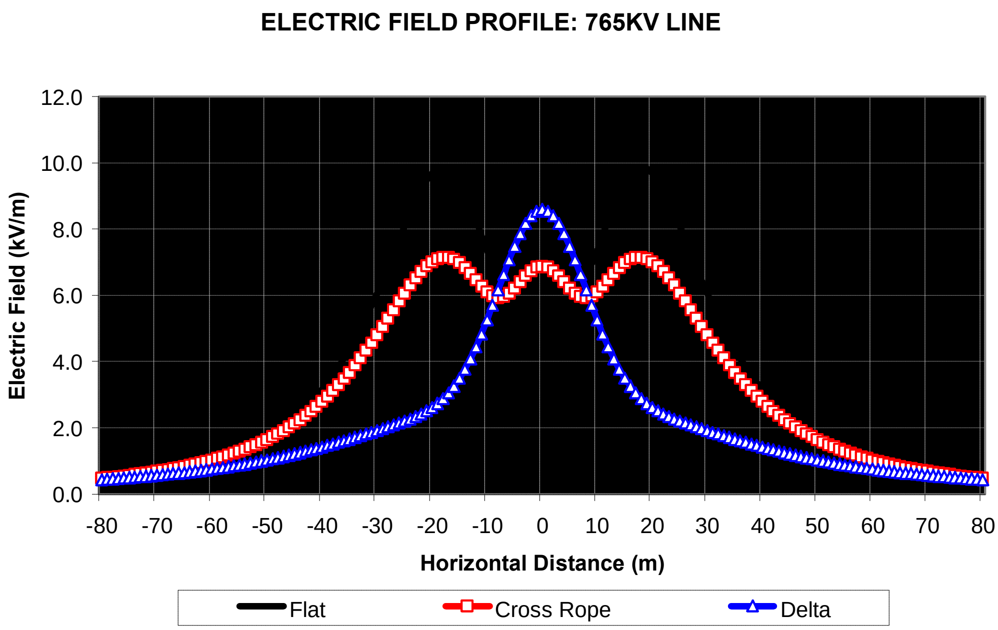


Figure 3: Typical electric field profiles for a 765kV line associated with the tower designs indicated in Table 5 (Tower geometry as per Appendix A).

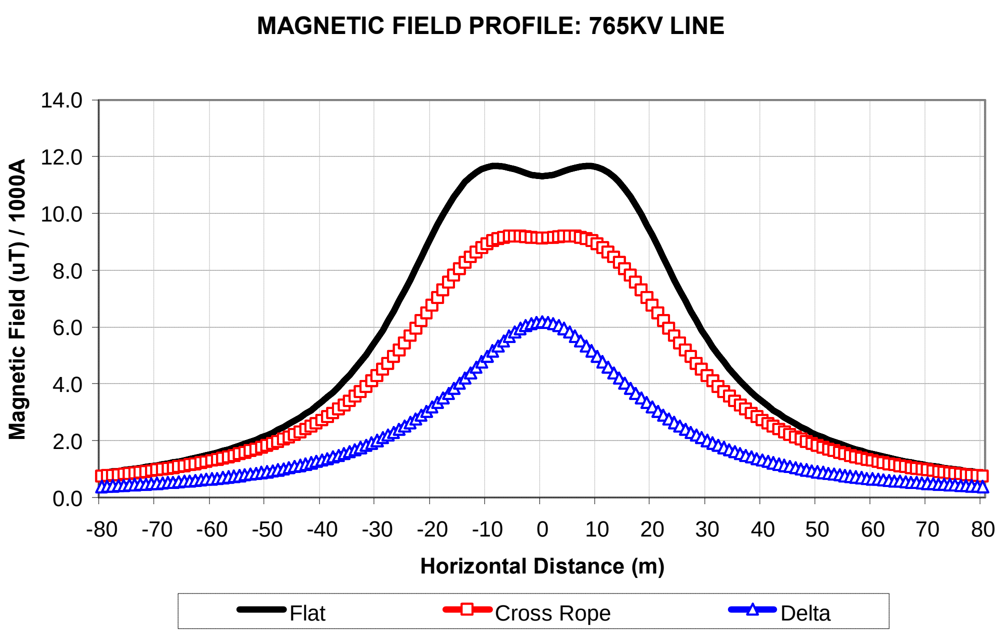


Figure 4: Typical magnetic field profiles for a 765kV line associated with the tower designs indicated in Table 5 (Tower geometry as per Appendix A).

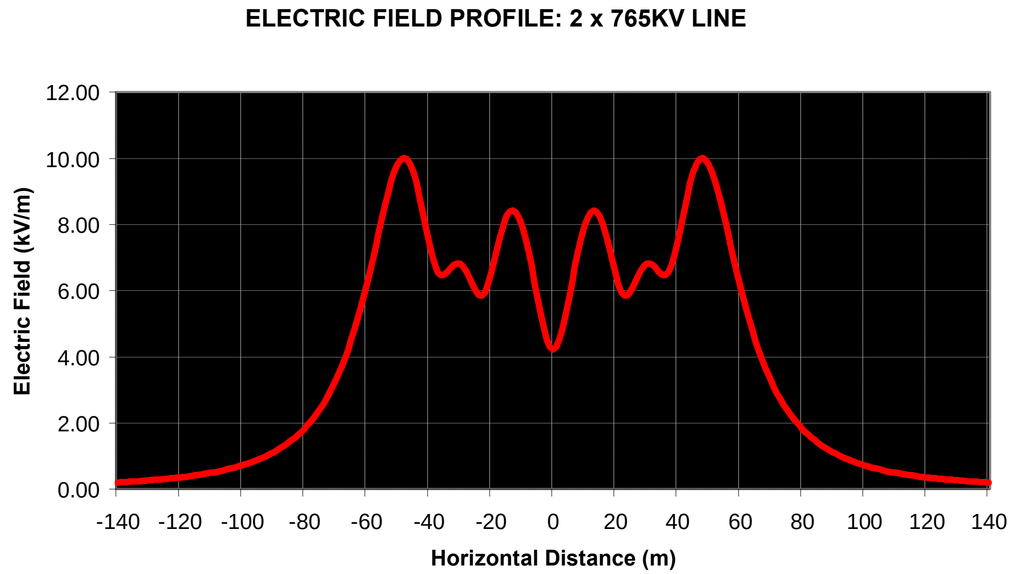


Figure 5: Typical electric field profile for two parallel 765kV lines associated with the Flat configuration indicated in Table 5 (Tower geometry as per Appendix A).

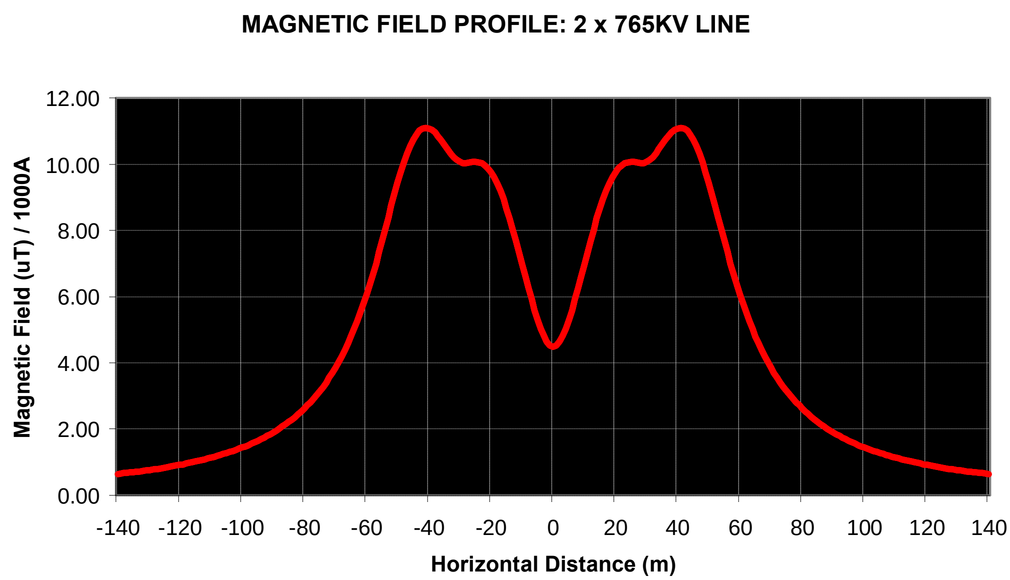


Figure 6: Typical magnetic field profile for two parallel 765kV lines associated with the Flat configuration indicated in Table 5 (Tower geometry as per Appendix A).

2.3 Overview of Research Findings

2.3.1 Background

Of the first reports covering possible effects of electric fields were published in the sixties [3]. These reports noted Russian substation workers complaining about fatigue and reduced sexual potency and claimed these effects to result from 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 [4], published by Wertheimer and Leeper in 1979, that suggested a possible association between long term exposure to power line magnetic fields and leukemia in children.

Epidemiology: The study of the occurrence and spread of diseases in certain populations, relying on statistical techniques.

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, leukemia) 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 [5, 6]. Some of these studies, from a 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 as reported by the following organisations, are covered in the part of the Section to follow:

- Environmental Protection Agency (EPA), 1990 [7];
- National Radiological Protection Board (NRPB), 1992 [8];
- National Academy of Science, 1996 [9];
- National Institute for Environmental Health Sciences (NIEHS), 1999 [10,11,12];
- National Radiological Protection Board (NRPB), 2001 [14];
- International Agency for Research on Cancer (IARC), 2001 [15];

2.3.2 Environmental Protection Agency (EPA), 1990 [7].

ñIn 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 characterization 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.ò

ñWith 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.ò

ñThe absence of key information summarized 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 ongoing studies and to further evaluate the mechanisms of carcinogenic action and the characteristics of exposure that lead to these effects.ò

2.3.3 National Radiological Protection Board (NRPB), 1992 [8].

ñIn 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 that 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.ò

2.3.4 National Academy of Sciences, 1996 [9].

ñBased 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.ò

2.3.5 National Institute of Environmental Health Sciences (NIEHS), 1999 [10,11,12].

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

Table 6. 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**
Adverse birth outcomes from maternal occupational exposure.			X	
Reproductive effects from paternal exposure.			X	
Alzheimerõs disease.			X	
Amyotrophic lateral sclerosis.			X	
Suicide and depression.			X	
Adverse effects on pregnancy outcome or depression.			X	
Effects on immune system in experimental animals.				X
Cardiovascular disease.			X	
Effects on hematological parameters in rodents.				X
Neurobehavioral, neuropharmacological, neurophysiological and neurochemical effects in experimental animals.		X		
Reproductive or developmental effects from exposure to sinusoidal magnetic fields in experimental animals.				X
Affects bone repair and adaptation ï strong evidence for complex clinical exposures to pulsed electromagnetic fields.	X			
Affect nervous system and non-bone connective tissue repair and adaptation in vertebrates ï no conclusion reached.				
Short term exposure and heart rate variability.		X		
Short term exposure and changes in sleep disturbance.		X		
Short term exposure and suppression of melatonin.		X		
Alters the levels of melatonin in rodents.		X		
Alters the levels of melatonin in sheep and baboons.				X
Effects on hematological system in experimental animals.				X
Electric fields can be perceived.	X			

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 leukemia. "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 leukemia than for childhood leukemia."

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 emphasized the weakness of the data and the low risk that may be involved.

Further discussion on the NIEHS report [13]:

Suggestions to treat EMF as a possible (Group 2B) carcinogen may be alarmist and of concern to the lay person. The Table below indicates examples of several well known agents and the categories they fall in as identified by the International Agency for Research on Cancer (IARC) [13].

Table 7. Examples of agents and their classification according to Groups 1 to 3 [13].

Category	Classification	Examples
Group 1	Carcinogenic	Asbestos, benzene, tobacco smoking
Group 2A	Probable carcinogen	Formaldehyde, ultraviolet radiation
Group 2B	Possible carcinogen	Chloroform, saccharin, coffee, gasoline, welding fumes, EMF
Group 3	Not carcinogenic	Coal dust, selenium, toluene

Being informed that coffee and saccharin, well known consumables by choice, fit the same carcinogenic profile as EMF, may largely alleviate unnecessary alarm or concern. It is therefore imperative that EMF information of this nature, be accurately conveyed and placed in perspective to the person, less versed on the topic.

2.3.6 National Radiological Protection Board (NRPB), 2001 [14].

ñStudies 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. ñ

ñAt 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.ò

ñThose 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.ò

ñOverall, 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.ò

ñRecent 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.ò

ñLaboratory 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.ò

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

ñIARC 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.ò

òHowever, 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.ò

òStudies in experimental animals have not shown a consistent carcinogenic or co-carcinogenic 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.ò

2.3.8 Review of Epidemiology and Childhood Leukemia, 2006 [16].

A review of epidemiology of childhood leukemia 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."

2.3.9 Review of Studies on Breast Cancer, 2006 [17].

ñFollowing 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.ò

2.3.10 Review of Electromagnetic Hypersensitivity, 2005 [18].

Electromagnetic hypersensitivity 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 [18]:

ñElectromagnetic 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.ò

2.3.11 Pacemakers [19, 20]

Magnetic fields of the order of 100µT 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.

2.4 What are the Effects on Animals?

Table 8 summarises the findings of studies done on animals near overhead power lines. Studies typically involve the comparison of an exposed group versus a control group or the energisation and de-energisation of a line for some period of time.

See Notes 2 and 3 at the end of Table 8 for information about fish and bees.

Table 8: Effects of electric and magnetic fields on animals.

No	Study	Finding/s	Reference/s
1.	Livestock near overhead power lines.	Experience from electric utilities and results from research show in general that electric fields from overhead power lines do not affect behaviour or health of livestock. Livestock of all kinds often rest or feed underneath power lines.	[19, 21]
2.	Live stock living near a 765kV line.	A comprehensive study on livestock (beef and dairy cattle, sheep, hogs and horses) living on eleven farms and near a 765kV line showed no evidence that the health, behaviour or performance of the livestock were affected by electric fields. The 765kV line produced electric fields on some of the farms up to 12kV/m.	[19, 22]

No	Study	Finding/s	Reference/s
3.	Milk production on of dairy cattle near 765kV lines.	From a 6 year long study on 55 dairy farms located near 765kV lines, no indication was found that the presence of the power lines developed any long-term effects on milk production.	[19, 23]
4.	Fertility of cattle near 400kV lines.	No effects on cattle fertility were noted in pilot studies of 36 herds, during which artificial insemination was applied, near 400kV lines. A larger study involving 106 farms in Sweden did not show cows to have decreased fertility. On average, they were exposed to the 400kV lines for more than 15 days per year and to maximum electric fields of 5kV/m on some of the farms. An experimental study showed the fertility parameters of 58 cows studied, were not affected by exposure to a 400kV 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 50Hz electric fields of 4kV/m (average) and magnetic fields of 2μT (average).	[19, 24, 25, 26]

No	Study	Finding/s	Reference/s
5.	Behaviour, performance and reproduction of swine raised beneath a 345kV line.	Swine raised on purpose beneath a 345kV power line were exposed to a maximum electric field of 4,2kV/m. A study of their behaviour and performance showed no effects related to field exposure on their body weight, carcass quality, behaviour or feed intake. Findings on reproduction, the second phase of the study, showed no effect of the line on pregnancy rate, frequency of birth defects or weight gain of the young.	[19, 27, 28]
6.	Behaviour of cattle near a 1,200kV line.	Cattle behaviour was studied near a 1,200kV prototype line during the summers over a 5 year period. A 12kV/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 noted.	[19, 29]
7.	Immune function of sheep living near a 500kV line.	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 5,8kV/m and 3,5 to 3,8µT.	[30]

No	Study	Finding/s	Reference/s
8.	Wild animals near overhead power lines.	Research suggests that any 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.	[19, 31, 32]
9.	Wild animals near a 500kV line.	No apparent effects were observed from electric or magnetic fields of a 500kV line on the movement of deer and elk. Some animals were attracted to the cleared servitude for feeding. Game tended to avoid the servitude and similar bush clearings during daytime during the hunting season.	[19, 33]
10.	Small mammals near 500kV lines.	A study on the effect of two 500kV lines passing through a servitude showed small mammals to be more abundant in the cleared servitude in hardwood forests as opposed to pine forests. In both areas, the servitude was used by some species not present in the adjacent forest. The study indicated the use of the various areas by the small mammals to be strongly influenced by vegetation composition and distribution that in turn relate to cover and availability of food.	[19, 34]

No	Study	Finding/s	Reference/s
11.	Small mammals near a 1,200kV line.	A study over several years did not show any adverse effects on the mammals.	[19, 35, 36]
12.	General farm investigations.	ñSeveral large investigations have been carried out on livestock living under and near high voltage power lines. No significant effects on fertility, growth or milk production have been found.ò	[76]
13.	Birds near power lines. (Considerations other than electric and magnetic fields arise in the context of birds and power lines ï see Note 1 below).	Studies of song birds near overhead power lines indicate that vegetation within the servitude is the primary factor influencing usage and behaviour, rather than electric or magnetic fields. A study on hawks nesting in towers of 500kV and 230kV energized power lines have shown that about the same average number of young were produced as were reported for hawks nesting in trees and cliffs. There is no evidence known of that suggest overhead power lines are disrupting the migratory flight of birds.	[19, 35, 37, 38, 39]
14.	Birds near 765kV line. (Considerations other than electric and magnetic fields arise in the context of birds and power lines ï see Note 1 below).	A laboratory study designed to mimic exposure to the 10kV/m electric field of a 765kV line, has shown a reduction in hatching success and increase in egg size, fledging success, and embryonic development of American kestrels.	[40]

Notes : 1) In open country, some bird species may use the towers for perching and nesting. The Environmental Management Programmes employed by electric utilities make provision for birds and power lines. These include: Marking of power line conductors to make them more visible to birds;

Specially designed and modified power lines and towers to reduce the possibility of bird collision and electrocution.

The details of these fall outside the scope of this report and the reader is referred to the local electric utility for more information on these aspects [2]. Research on bird collisions does not suggest that electric or magnetic fields cause disorientation of flying birds. Electrocution of birds with large wingspans is generally associated with distribution lines with relatively small phase spacing and not with electric or magnetic field exposure.

2) Some fish species are sensitive to very weak, low frequency electric and magnetic fields in water. American eels and Atlantic salmon have been reported to perceive low frequency electric fields of between 7 and 70mV/m (millivolt per meter) [41]. A study on electric fields up to 20mV/m (45Hz to 75Hz), however, showed ñlittle, if any effect on behaviour of bluegill fryò [19, 41, 42].

3) Although not generally reported by beekeepers, studies have shown power line electric fields can affect honey bee colonies [19, 43]. 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 11kV/m. In preventing the mentioned effect, it is recommended that bee hives be placed outside the servitude. Alternatively, should bee hives need to be placed inside the servitude, techniques to shield the bees from the power line electric field should be applied. For example, earthing the metal hive lid or introducing an earthed, wire screen over the hives.

4) For findings of specific <u>laboratory</u> studies on plant and animal cell cultures, the reader is referred to Reference [5] and [6] or some of the relevant Internet sites in Appendix B, notably that listed in 7.8.

2.5 What are the Effects on Plants?

The effects of electric fields on plants have been a field of interest to scientists since the eighteenth century, mainly because of interest in possible use of electricity to increase crop yield [19]. During the mid nineteen seventies, 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. Table 9 summarises the findings of some of these studies.

Table 9: Effects of electric and magnetic fields on plants.

No	Study	Finding/s	Reference/s
1.	Eighty five plants species were studied in a laboratory exposed to electric fields up to 50kV/m. In addition, crops (including corn and wheat) grown in a greenhouse, exposed to a 30kV/m electric field.	Some species with sharp pointed leave tips shown minor tip damage starting to occur at electric field levels of 15 to 20kV/m (Note 1). This effect was not observed on plants with rounded leaf tips, even at 50kV/m. Germination, plant growth and productivity were not affected at these high levels.	[19, 44, 45]

No	Study	Finding/s	Reference/s
2.	Corn and other crops growing near 765kV lines, including a test line, producing electric field levels respectively up to 12kV/m and 16kV/m.	The overall results showed no noticeable influence on crop growth and productivity. Some crops growing in the 16kV/m field of the test line showed some leaf tip damage. Overall plant growth was, however, not impaired.	[19, 46, 47, 48, 49, 50]
3.	Corn grown in electric field beneath a 500kV line.	Corn grown in the electric field up to 8,5kV/m showed a lower yield when compared to corn grown in areas shielded from the electric field. Other crops and trees that included cotton, soybeans, clover, poplar and pine showed no effects. The researchers concluded that ñdata for the corn study was insufficient to reach definite conclusions and that further investigation was warrantedò.	[19, 51]
4.	Crops grown near a 500kV transmission line.	No differences in yields of soybeans and rice were noted between that growing under the line and that growing away from the line. A lower cotton yield (about fifteen percent) was found under the line. ñThe authors could not determine whether the effect was related to electric or magnetic fields or to ineffective aerial application of agricultural chemicals to crops near the line.ò	[19, 52]

No	Study	Finding/s	Reference/s
5.	Plants (trees, shrubs, grasses and crops) growing near a 1,200kV prototype line.	The tips of branches of some trees that were planted below the line and left to grow on purpose (as close as 12m from the line) were damaged by corona (See Note 1). Shrubs growing beneath the line were not affected. Weather and natural variability caused significant differences in crop production over a five year period. During this time, with an electric field ranging between 7 and 12kV/m, no consistent differences were noted to indicate the 1,200kV line affected plant growth. No effects could be related to the line on pea and barley seeds during germination studies. Pasture grass growing beneath the line was not inhibited by electric fields up to 12kV/m.	[19, 29, 35, 36, 53]
6.	Wheat growing in pots below a test line producing a 7,7kV/m electric field.	No effects were observed on wheat growth.	[19, 54]
7.	General farm investigations.	ñVarious field studies have shown that power line fields do not affect the growth of crops and other low-growing vegetation. The tips of tree branches allowed to grow near the conductors can be damaged by the corona discharge induced by strong electric fields, although overall tree growth and survival appeared unaffectedò.	[76]

No	Study	Finding/s	Reference/s
8.	Germination of seeds exposed to 50µT magnetic fields at extremely low frequency.	Some authors reported on the enhancement of seed germination from exposure to 50µT magnetic fields. The mechanism for this effect is not understood and other investigators have been unable to confirm this finding.	[55, 56, 57, 58]
9.	Crop performance of crops grown beneath high voltage power lines in electric fields up to 12,5kV/m.	The studies reported small, if any effects.	[55, 59]
10.	Corn and wheat grown in electric fields up to 3,9kV/m and magnetic fields up to 4,5µT in plots at varying distance near a 380kV line. The study was done over a four year period.	The researchers found ñsome evidence for some physiological reactions in response to the effects of field strength. However, the variations were not statistically significant, showed no apparent relation to the field strength, and were comparable to small-scale effects due to differences in soil texture between the plots. Thus, if the study did uncover effects of environmental electric and magnetic fields at these levels, they were minor in nature.ò	[55, 60]

Notes: 1) Any object placed in an electric field will disturb (enhance) the field. If increased sufficiently, corona (ionization of air molecules) may occur. For example, in the case of an electric field disturbed by a sharp pointed leaf tip.

2) For findings of specific laboratory studies on plant and animal cell cultures, the reader is referred to Reference [5] and [6] or some of the relevant Internet sites in Appendix B, notably that listed in 7.8.

From the table above, it is clear that 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 utilityôs 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, as noted in Table 9 above, 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 electric utility, are unlikely to affect plants in terms of growth, germination, crop production and fertility.

2.6 Exposure Limits

The guidelines for electric and magnetic field exposure set by the International Commission for Non-Ionising Radiation Protection (ICNIRP) [61], an organisation linked to the World Health Organisation (WHO), receives world-wide support [62] and are summarised in Table 10.

Table 10. Electric and magnetic field exposure guidelines set by ICNIRP (1998) [61].

	Electric Field (kV/m)	**Magnetic Field (μT)**
Reference Level		
Occupational	10	500
Public	5	100
	Current Density (mA/m^2)	
Basic Restriction:		
Occupational	10	
Public	2	

The ICNIRP guidelines are based on a Reference Level, a field level easily measured and spatially averaged across the volume taken up by the body of the exposed person, and a Basic Restriction. The Basic Restriction is presented, in this case, as a safe induced current density and is measured in milliampere per square metre (mA/m^2). Should the Reference Level be exceeded, then further evaluation is required to ensure that the Basic Restriction is not exceeded [65].

South Africa: Utilities, in South Africa, involved in the generation and distribution of electrical energy, are bound by the Occupational Health and Safety (OHS) Act [63] to provide such services in a safe manner. There are currently no regulations (under the Hazardous Substances Act) in terms of exposure to power frequency EMF in South Africa and the ICNIRP guidelines are used for assessing human exposure to these fields.

The exposure guidelines set by ICNIRP (1998) [61] are endorsed by the South African Department of Health as well as the South African Forum for Radiation Protection.

North America: No US federal recommendations exist currently for occupational or residential exposure to 60Hz magnetic fields [64]. The safety level set by the Institute for Electrical and Electronics Engineers (IEEE) include [66, 67]:

ñThe maximum permissible exposure level for the general public to electric fields is 5 kV/m, except on transmission line rights-of-way [servitudes], where the limit is 10 kV/mò.

ñThe IEEE Standard explicitly increases the general-public Maximum Permissible Exposure (MPE) level for 60-Hz electric fields from 5 kV/m to 10 kV/m on transmission line rights-of-way. Exposure of the general public would not exceed the MPE of 10 kV/m, except in limited areas under some 765-kV linesò.

Europe: As far as limits for electric and magnetic field exposure applied in Europe are concerned, the European Standard: EN 50392 [68] is strongly based on the ICNIRP guidelines for exposure power frequency to electric and magnetic fields.

From the above, it is noted that utilities are typically guided by a maximum electric field limit of 10kV/m in the design of power lines, particularly 765kV lines. This maximum electric field limit (10kV/m) is based on safety considerations when a large vehicle (truck) parked underneath the line is touched by a well grounded (electrically earthed) person, for example. To meet this design limit, particularly for 765kV lines, the required minimum conductor clearance above ground is adjusted accordingly.

Safety of the public from electric and magnetic field exposure is ensured by application of the ICNIRP guidelines, typically at the servitude boundary as residence within the servitude is generally not allowed. Where exposure to electric and magnetic field levels above the ICNIRP guidelines may take place, special engineering techniques, as outlined in Section 2.7, can be applied to reduce the fields to more acceptable levels.

2.7 Can Fields be Reduced?

As noted earlier, shielding of the electric field can be achieved fairly easily by introducing conductive material into the field. For example, a wire mesh bonded to earth and supported by wooden poles covering the area that needs to be shielded. This technique is effective but may be considered as having significant visual impact. Depending on the desired field level, line compaction (bringing the conductors of the power line closer to each other) may also be applied. The effect of more compact tower designs (Delta configuration as opposed to Flat configuration) on partial field reduction has already been demonstrated in Figures 1 to 4. Field reduction by line compaction is limited because compaction in turn affects other electrical parameters, important to the safe and effective operation of the line.

Although magnetic field reduction, to a certain extent, can be achieved by line compaction (See Figures 1 to 4), special engineering designs are required to reduce magnetic fields significantly. Table 11 summarises some of the methods, including specially engineered techniques, that can be applied to reduce magnetic fields if required. It should be noted that cost and electrical performance of the line strongly dictate the technique to be applied. Magnetic field mitigation is a highly technical subject and, in view of the scope of this report, is only briefly discussed. The reader requiring more technical detail about the techniques mentioned, is referred to References [2, 73, 74, 75]. The application of specific field reduction technique needs to be evaluated on a case by case basis.

Table 11. Summary of engineering techniques that can be applied to reduce power frequency magnetic fields from overhead power lines.

Technique	Brief Description	Field Reduction (1)	Cost (1)	Key Considerations
Line compaction	Reduction in phase spacing.	Marginal	Small	May introduce corona; May limit available techniques for live line maintenance.
Reverse phase	Reversal of phases on double circuit line: RWB ï BWR	Good	Low	Only applicable to double circuit lines.
Delta	Conversion from horizontal flat configuration to delta configuration.	Good	Medium	May introduce corona.
Split phase	Splitting of phases to create additional phases with spatial placement to create significant field reduction.	Exceptional	High	Interphase spacers required; Increase in complexity of line structures; Limit available techniques for live line maintenance; Larger visual impact due to increase in conductors.
Shielding with loops	Conductive loop (passive and compensated) supported by additional poles.	Good	Low	Power dissipated by loop must be considered; Feasible only for local applications; Larger visual impact due to additional conductors.
Shielding with material	Use of high permeability material to shield a small area or product.	Exceptional	Low	Only small areas can be shielded at relatively low cost; Feasible only for local applications.
Underground cabling	Application of underground cabling as opposed to an overhead line.	Good	Very high	Maintenance more complex than lines;

Note: 1) Field reduction and cost are compared to a flat, horizontal configuration.

2.8 International Opinion and Consensus

The following citations summarise international opinion and consensus on the topic:

International Council on Large Electric Systems (CIGRE), 2000 [69].

ñAs EMF science has improved and evolved, it has become increasingly clear that if exposure to EMF poses any health risk at all, the overall public health impact is small. Recent epidemiological studies, carried out on large populations, have not established a causal link between childhood or adult cancers and magnetic field exposure, although some weak and persistent statistical association remain unexplained. At the same time, laboratory studies on cells, tissues and whole animals have found no consistent or convincing evidence that power-frequency electric or magnetic fields in the workplace or at home produce harmful biological effects - nor has any credible mechanism been proposed by which such effects could occur.ò

ñThe knowledge gained from this research is reassuring and in agreement with the actual position statement of the World Health Organization (WHO) and of the American National Institute of Environmental Health Sciences (NIEHS). It is CIGRE's view that there is no scientific justification for measures to reduce exposure to EMF through changes in the technology and management of existing high-voltage power systems. Nevertheless, considering the existence of public concern and some scientific uncertainties, CIGRE will continue to monitor the issue and to update its view in the light of any new developments.ò

World Health Organisation (WHO), 2001 [70].

ñWhile the classification of ELF magnetic fields as possibly carcinogenic to humans has been made, it remains possible that there are other explanations for the observed association between exposure to ELF magnetic fields and childhood leukaemia. In particular, issues of selection bias in the epidemiological studies and exposure to other field types deserve to be rigorously examined and will likely require new studies. WHO therefore recommends a follow-up, focused research programme to provide more definitive information. Some of these studies are currently being undertaken and results are expected over the next few years.ò (The EMF Project currently driven by the WHO is expected to be concluded in 2007).

US National Institute of Environmental Health Sciences (NIEHS) / National Institute of Health, 2002 [64, 71].

ñElectricity is a beneficial part of our daily lives, but whenever electricity is generated, transmitted or used, electric and magnetic fields are created. Over the past 25 years, research has addressed the question of whether exposure to power frequency electric and magnetic fields (EMF) might adversely affect human health. For most health outcomes, there is no evidence that EMF exposures have adverse health effects. There is some evidence from epidemiological studies that exposure to power frequency magnetic field is associated with an increased risk of childhood leukemia. This association is difficult to interpret in the absence of reproducible laboratory evidence or a scientific explanation that links magnetic fields with childhood leukemia. EMF exposures are complex and come from multiple sources in the home and workplace in addition to power lines. Although scientists are debating whether EMF is a hazard to health, the NIEHS recommends continuing education on ways of reducing exposureò.

National Radiological Protection Board (NRPB) (UK), 2004 [72].

ñHaving considered the totality of the scientific evidence in the light of uncertainty and the need for a cautious approach, NRPB recommends that restrictions on exposure to EMF in the UK should be based on the guidelines issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1998.ò

3. CONCLUDING REMARKS

Numerous studies have demonstrated that EMF exposure may induce some *biological* effects in living cells. Because of the lack of a known biophysical mechanism that would explain these effects, many question the existence of *clinical* responses. The *clinical* responses, as a result of power frequency electric and magnetic field exposure to levels typically found in residential and power line environments, if any, appear insignificant. Despite the lack of firm answers on the topic, responsible attempts to manage the issue have lead to strategies that promote:

- Continuous monitoring of developments in international research;
- Exposure assessment guided by internationally accepted field limits;
- Open communication with those concerned;
- Offering of services related to the measurement of field levels and
- Reduction of exposure if required and if it can be achieved at reasonable cost.

4. APPENDIX A – LINE GEOMETRY

The following tower geometries were used in calculating the field profiles indicated in Figures 1 to 6.

765kV Lines

765kV - Flat Configuration

Descriptor	Value / Name	Unit
Servitude width	80	m
Conductor bundle type	Tern	
Bundle diameter	64	cm
No of sub-conductors per bundle	6	
Sub-conductor diameter	27	mm
Phase spacing	15,8	m
Phase A ï height above ground	17	m
Phase B ï height above ground	17	m
Phase C ï height above ground	17	m
Sub-conductor spacing	320	mm

765kV - Compact Cross-rope

Descriptor	Value / Name	Unit
Servitude width	80	m
Conductor bundle type	Tern	
Bundle diameter	64	cm
No of sub-conductors per bundle	6	
Sub-conductor diameter	27	mm
Phase spacing	14	m
Phase A ï height above ground	20	m
Phase B ï height above ground	17	m
Phase C ï height above ground	20	m
Sub-conductor spacing	320	mm

765kV - Delta

Descriptor	Value / Name	Unit
Servitude width	80	m
Conductor bundle type	Tern	
Bundle diameter	64	cm
No of sub-conductors per bundle	6	
Sub-conductor diameter	27	mm
Phase spacing	7	m
Phase A ï height above ground	29	m
Phase B ï height above ground	17	m
Phase C ï height above ground	29	m
Sub-conductor spacing	320	mm

400kV Lines

400kV - Flat Configuration

Descriptor	Value / Name	Unit
Servitude width	47	m
Conductor bundle type	Tern	
Bundle radius	32,9	cm
No of sub-conductors per bundle	3	
Sub-conductor diameter	27	mm
Phase spacing	8,5	m
Phase A ï height above ground	13,1	m
Phase B ï height above ground	13,1	m
Phase C ï height above ground	13,1	m
Sub-conductor spacing	570	mm

400kV - Compact Cross-rope

Descriptor	Value / Name	Unit
Servitude width	47	m
Conductor bundle type	Tern	
Bundle radius	32,9	cm
No of sub-conductors per bundle	3	
Sub-conductor diameter	27	mm
Phase spacing	8,2	m
Phase A ï height above ground	14,3	m
Phase B ï height above ground	13,1	m
Phase C ï height above ground	14,3	m
Sub-conductor spacing	570	mm

400kV - Delta

Descriptor	Value / Name	Unit
Servitude width	47	m
Conductor bundle type	Tern	
Bundle radius	32,9	cm
No of sub-conductors per bundle	3	
Sub-conductor diameter	27	mm
Phase spacing	3,5	m
Phase A ï height above ground	19,3	m
Phase B ï height above ground	13,1	m
Phase C ï height above ground	19,3	m
Sub-conductor spacing	570	mm

5. APPENDIX B – USEFUL INTERNET SITES

The following internet websites (from North America, Europe and South Africa) are listed, with the date the site was confirmed active, and provides additional and useful information to the interested reader:

7.1 World Health Organisation (WHO)

www.who.int/emf , 15 Apr 2006.

7.2 National Institute of Environmental Health Sciences (NIEHS)

http://www.niehs.nih.gov , 15 Apr 2006.

7.3 EMF Portal (Germany)

http://www.emf-portal.org , 15 Apr 2006.

7.4 EMF Net (European Commission)

http://emf-net.isib.cnr.it , 15 Apr 2006.

7.5 International Commission for Non-Ionising Radiation Protection (ICNIRP)

http://www.icnirp.de/pubEMF.htm , 15 Apr 2006.

7.6 National Radiological Protection Board (NRPB)

http://www.hpa.org.uk/radiation/ , 15 Apr 2006.

7.7 Department of Health (South Africa)

http://www.doh.gov.za/search/index.html , 15 Apr 2006.

7.8 John Moulder, Professor of Radiation Oncology, Medical College of Wisconsin, Milwaukee, Wisconsin, USA

www.mcw.edu/gcrc/cop/powerlines-cancer-faq/toc.html , 15 Apr 2006.

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