Electric and magnetic fields of power lines

May 2022

1. Introduction to power line electric and magnetic fields

Electric and magnetic fields are phenomena inherent to the generation and consumption of electricity. Electric power is supplied as an alternating current at a frequency of 50 Hertz (Hz or “cycles per second”).

Power system frequency is substantially lower than most other common electromagnetic fields; for example, 5G cellular communication systems operate at 5 GHz (billion Hertz or 1 000 000 000 Hz). Electromagnetic Fields (EMFs) that emanate from power lines are of an Extremely Low Frequency (ELF). The energy associated with the field is proportional to the frequency, and therefore the energy linked to 50 Hz power fields is very low, relative to almost all other EMFs.

Electric and magnetic fields exist in the vicinity of overhead power lines and are related to the voltage and current on the line, respectively.

An electric field is defined as a voltage gradient (measured in Volts per metre or V/m), and electric fields are proportional to the amount of electrical charge on an object, or the voltage potential applied to an object, such as a power line conductor. Electric fields decrease with the square of the increase in distance from the source ($1/r^2$), i.e., at double the distance, the field drops to 25%. Therefore, the field reduces rapidly with increasing distance from the line.

Magnetic fields or ‘magnetic flux density’ are produced by the current flowing (i.e., the movement of electric charge) through a conductor (measured in Tesla, T). The current on an electrical system varies depending on the number and rating of the devices supplied by the system. This is referred to as the ‘load’ on the system. As the load changes, the magnetic fields will change in unison. Magnetic fields also decrease with the square of the increase in distance from the source (e.g., power line conductor).

In the case of power lines, fields at ground level are of interest as this is where there could be human exposure. The fields at ground level are influenced by the conductor configuration on the power line structure and conductor height above ground. As the voltage increases, the structure height tends to increase to maintain safety clearances to objects under the line, and this partially negates the increase in electric field levels at the ground.

All power lines have a certain area of space to either side of the line called the servitude which is allocated for maintenance (Figure 1 and Figure 3). Strictly, this area is not allowed to be developed or inhabited which would interfere with access to the line as well as result in some potential hazards. The levels for public exposure therefore apply to the boundary of the servitude. Workers inside the servitude may be exposed to short-term higher occupational levels.

Interestingly, migratory birds use the earth’s magnetic field to navigate. The earth’s magnetic field is static unlike the field from power lines and varies between 30 µT (micro-Tesla) for most temperate and tropical areas to over 60 µT near to the poles. These birds appear to be completely unperturbed and even

oblivious to the high electric and magnetic field levels encountered when perching directly on conductors or near power lines.

2.1 Electric fields

The overall electric field due to a power line is the resultant of three-phase voltages that vary continuously and are displaced by 120^{o} (i.e., out of “sync:). This means that the fields from the individual phases cancel one another to a large extent. If the three conductors were brought very close together, there would be a zero net field.

The electric field ‘falls off’ to the square of the distance from the line. The partial cancellation, as well as the rapid reduction with distance result in very low field levels - a mere few 10s of metres from the power line (Figure 1). Figure 1 represents the field associated with different 132 kV lines which are the most common high-voltage (HV) lines in South Africa, whilst most visible lines are medium voltage (MV).

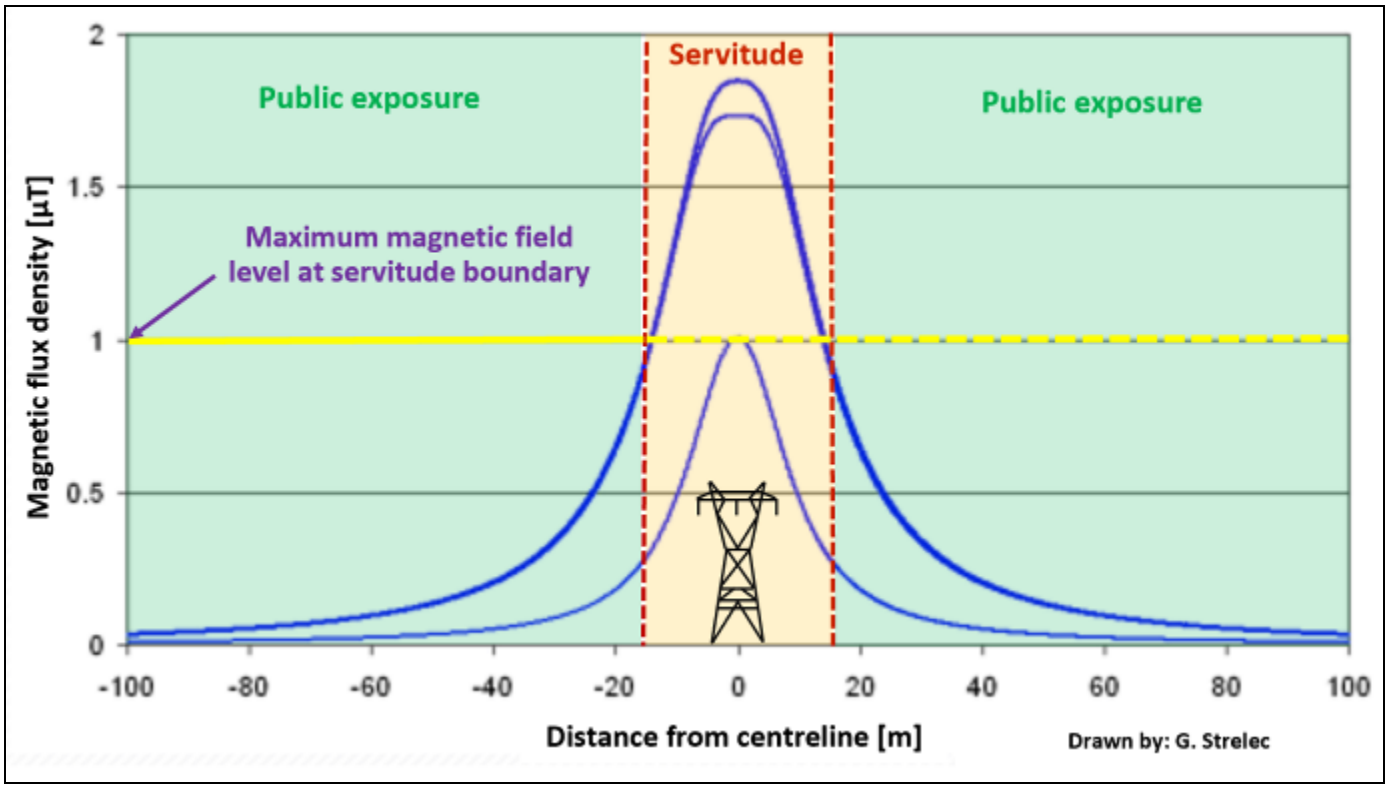

Figure 1: Electric field profile at ground level for typical 132kV line designs

Electric fields are readily attenuated ‘partly shielded) by conductive and even partially conductive ordinary objects or structures e.g., buildings, trees, etc. Figure 2 illustrates the significant electric field attenuation due to normal trees in the path between the source of EMF and measurement position.

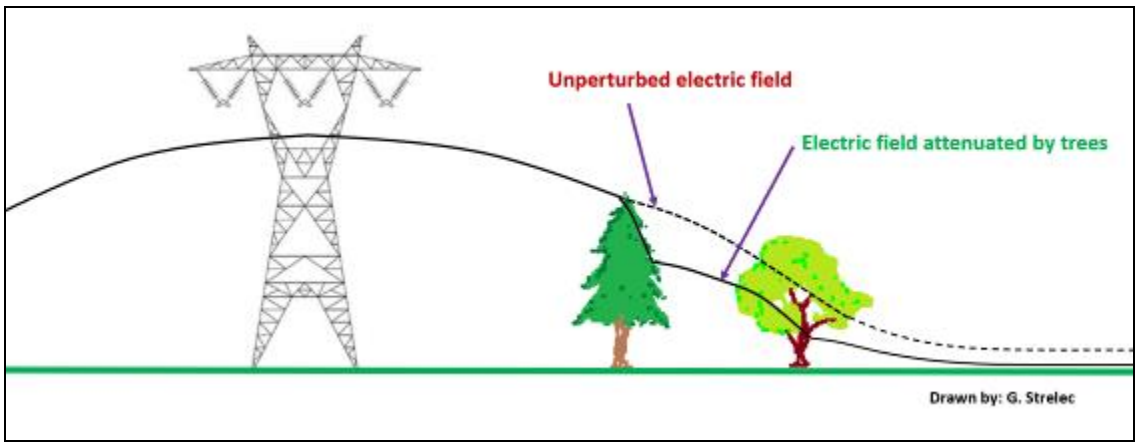

Figure 2. Electric field attenuation due to trees

2.2 Magnetic fields

In South Africa, the most common high-voltage power lines are operated at a nominal voltage of 132 kV and the magnetic fields associated with lines of this voltage level rarely exceed 2 µT. Most overhead lines are medium voltage and are operated at voltages up to 22 kV.

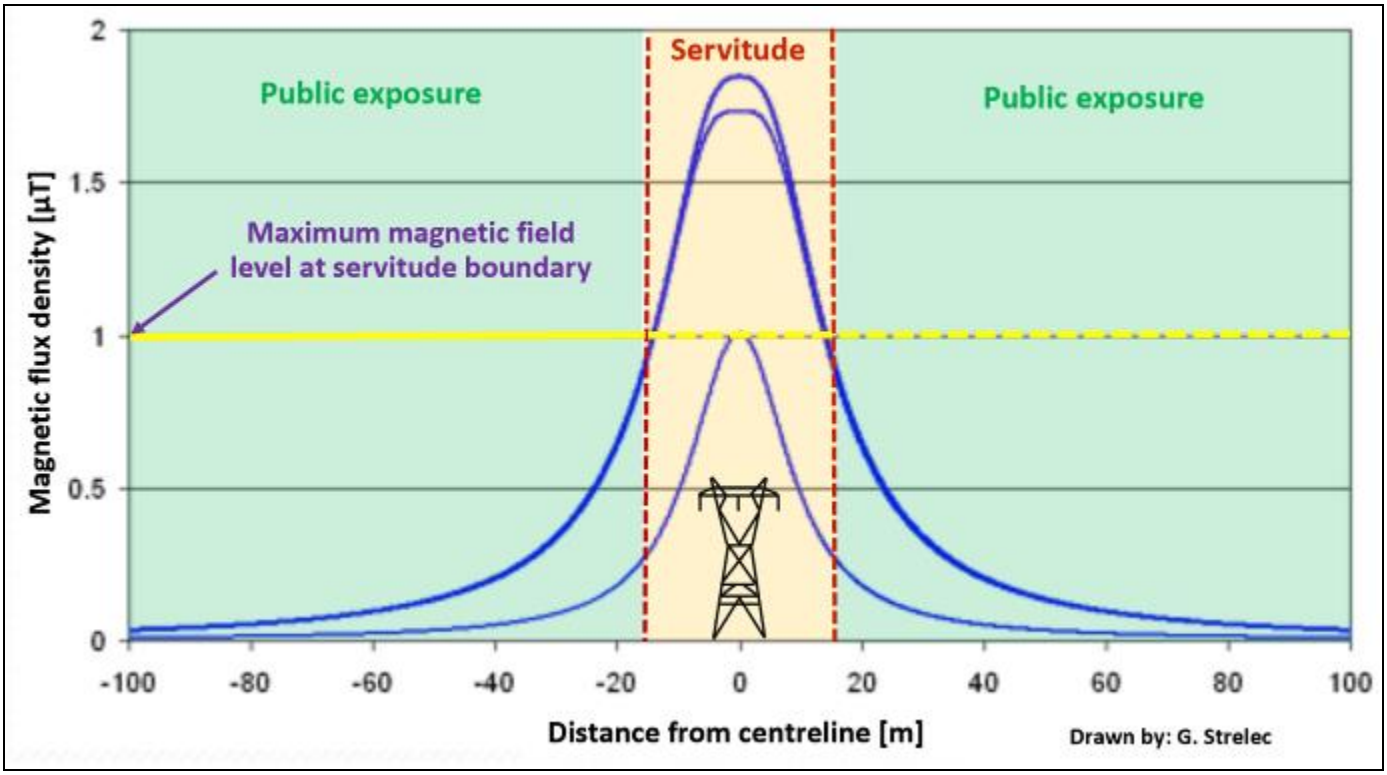

Figure 3. Magnetic field profile at ground level for typical 132kV line designs

Unlike electric fields that are readily attenuated by ordinary materials, magnetic field shielding requires 'ferro-magnetic' metals that have high magnetic permeability, typically iron (steel), and alloys of iron with cobalt or nickel.

2. Health concerns related to power line EMFs

Concerns originated several decades ago about a possible link between health effects and power lines. Until now (2022), there has been no scientific study to indicate anything other than a weak statistical link. In general, controlled laboratory studies do not support the findings of early controversial research on populations near to power lines. Furthermore, no biological mechanism for any adverse health impact has been identified, which can be attributed to the extremely low frequency electromagnetic field exposure from power lines. EMF certainly does not damage DNA (genome), or disrupt any cellular metabolic processes that could result in adverse health effects.

Referring to EMF as "radiation" can be misleading. Radiation is commonly used to describe the potent energy given off by radioactive materials such as uranium. These materials are unstable and emit nuclear radiation in the form of gamma rays, alpha and beta particles, that have extremely high energies and are acutely hazardous to all life and damaging to most materials. This is contrary to EMF, in general, and especially to extremely low frequency electromagnetic fields. Shielding for nuclear radiation requires thick layers of high-density material like lead.

Occasionally, concerns are expressed about possible health effects related to power lines, particularly Electromagnetic Fields (EMFs). These concerns are unduly potentiated by extensive non-scientific and non-peer-reviewed misinformation published on the internet and in social media.

3. Electric and magnetic fields due to household appliances

Electric and magnetic fields are also generated by ordinary electrical household appliances. Close to these appliances, the fields can be higher than those due to power lines. The relative magnetic field exposure from common kitchen appliances is higher than the field when directly under a power line (Figure 4). Although the voltages and currents of power lines may be much higher, the distances between household sources and exposed people are comparatively tiny.

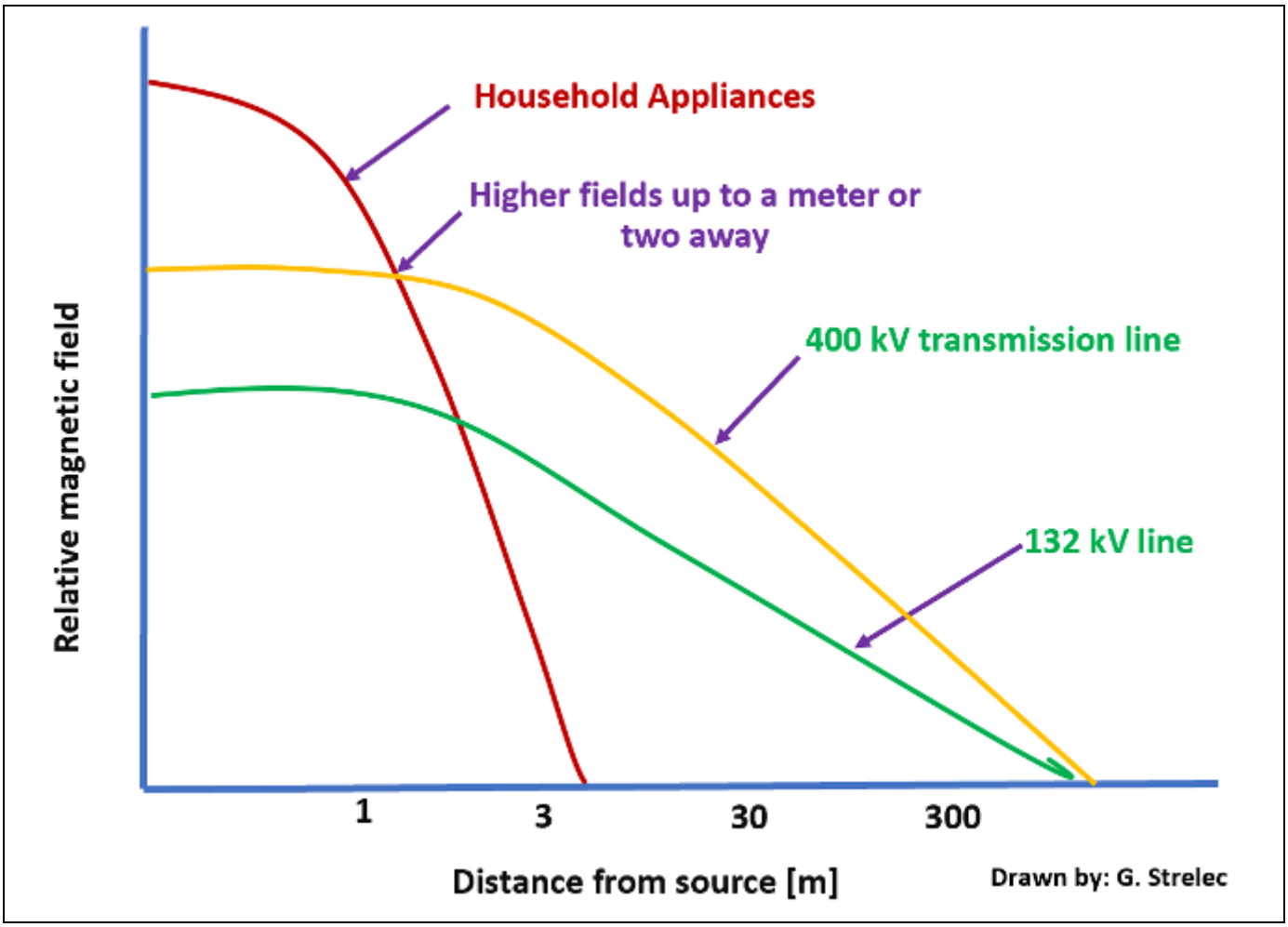

Figure 4: Relative magnetic fields associated with household appliances and overhead lines

EMF exposure in the home is higher in the “near field” (within a metre or two) from ordinary appliances. It is not feasible to design and manufacture specially shielded appliances and household wiring to reduce these fields.

All humans in modern environments are exposed to EMF, as it is an inherent property of electricity. Whilst a shielded connection to the consumer to reduce the electric field is technically possible, the electric field is omni-present due to the presence of voltage in all electrical devices and wiring, even if no power is consumed.

4. Exposure guidelines for EMFs

For more than two decades, the focus of the scientific community has shifted away from Extremely Low Frequency (ELF) Electromagnetic Field (EMF) exposure from power lines as no consistent or compelling evidence could be found. Recent medical research is focussed exclusively on high frequency exposure

from mobile telecommunication systems. There are no recent publications related to the health effects of power frequency EMFs associated with power lines.

Despite the lack of definitive effects or mechanisms, international bodies agreed to take a conservative approach and extensive research was conducted over several decades by experts from various scientific disciplines, including medical and engineering. Ultimately, precautionary guidelines for exposure limits were proposed in the late 1990s by the International Council on Non-Ionising Radiation Protection (ICNIRP). Subsequently, these guidelines were adopted by the World Health Organisation (WHO) and all other health and power utility related international organisations, most of which published these recommendations during the 2000s in their own documentation. The South African Department of Heath endorses the ICNIRP/WHO guidelines. Eskom has also adopted the ICNIRP values and applies these recommendations to all infrastructure, including power lines, underground cables, and substations.

The ICNIRP guidelines and the international consensus (WHO etc.) was reaffirmed in the late 2000s, and the position remains unchanged until the present, in 2022. This information is reviewed, and any potential developments are continuously monitored by Eskom.

It must be emphasised that these guidelines are in the absence of any demonstrable scientific justification. Although some biological effects, such as nerve stimulation, have been demonstrated at levels that are many times higher than these guideline values, no adverse health effects such as changes in living tissue, have been discovered at all. Furthermore, the typical levels from almost all power lines are very low, or even negligible compared to the ICNIRP values.

The human nervous system is electrical in nature. Nerve impulses are transmitted as miniscule electrical pulses. The biological effects related to EMF exposure, such as nerve stimulation, are caused by the currents that are induced inside the body tissues. However, such currents have not been shown to cause any harm to living cells. At extremely high levels, these currents can cause very mild heating effects. As the body is not a very good conductor (resistivity of body tissue ranges between about 10 Ω.m and 50 Ω.m) these effects are mild. In good conductors, such as metals, these ”induction effects” can be pronounced, as these materials are characterised by resistivities that are around 1 billion (1 000 000 000) times lower than body tissue. The induced currents are proportional to the frequency of the EMF, so heating is not considered at 50 and 60 Hz, and only at higher frequencies.

Consequently, the basic restriction set by ICNIRP is based on induced fields in human body tissues for power frequencies and for higher frequencies, on induced currents that may result in heating. There are two categories:

- Occupational - levels for people who may be temporarily exposed to slightly higher levels than the public due to the nature of their work;
- Public – levels for members of the public who may be continuously exposed due to the proximity of electrical infrastructure.

The Basic Restriction, based on current density, is 10 mA/m^2 (milli-Amperes per area) for occupational exposure and 2 mA/m^2 for continuous public exposure. This body current is impractical to measure, leading to guidelines being based instead on induced field levels in typical human body tissue. The electric and magnetic field exposure guidelines set by the ICNIRP are shown in Table 1.

Table 1. Power frequency (in SA, 50 Hz) electric and magnetic field exposure guidelines (ICNIRP)

Exposure classification	**Electric Field** [kV/m]	**Magnetic Field** [μT)]
Occupational	10	500
Public	5	100

It is emphasised that the ICNIRP values are guidelines and are merely precautionary levels recommended in the absence of conclusive scientific evidence. The ICNIRP values are not South African engineering standards and much less enforced by law (statutory).

The International Council on Large Electric Systems (CIGRE) is the organisation that regulates the international standards for power plant infrastructure, including power lines. CIGRE makes the following statement regarding EMF exposure: “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.”

Despite this, Eskom strives to meet these guidelines for all existing and new infrastructure.

Table 2 provides typical electric field values associated with overhead power lines. This is characteristic of Eskom lines as well as any typical power lines from other international utilities that design to similar overall principles and the same international standards. These values have also been confirmed by numerous site measurements conducted on Eskom lines over several decades and concur with values readily available from other transmission and distribution companies from, amongst others, the USA, Europe, and UK National Grid.

Table 2: Representative electric field levels from power lines for different voltage levels

Nominal Voltage [kV]	**Max. E-Field (kV/m)**	**E-Field at Servitude Boundary [kV/m]** **Guideline: 5 kV/m**	**Servitude Width [m]**
765	7	**2.5** (50%)	40.0
400	4.7	**1.5** (30%)	23.5
275	3	**0.5** (10%)	23.5
132	1.3	**0.5** (10%)	15.5
88	0.8	**0.3** (6%)	15.5

The levels at the servitude boundary are considerably lower than the maximum ICNIRP guideline of 5kV/m for continuous public exposure. The percentage of the guideline value for various power line voltages are in brackets after the typical electric field value.

Eskom operates a few 765kV transmission lines, which is one of the highest voltages in the world. The 765kV voltage level represents a miniscule proportion of the Eskom overhead lines. The field levels at the servitude boundary are only half of the guideline value. Moreover, the 765kV lines only exist in rural countryside and human exposure is extremely limited and will only be transient in nature.

It is far more likely that a small percentage of the population may be exposed to high-voltage power lines energised at 132 kV. The 132kV lines are associated with electric field levels between about 5% and 10% (Figure 1) of the ICNIRP value. Although these are representative levels, in many cases, the fields on power lines are even lower than these values, especially for newer lines which have more compact designs that result in increased mutual cancellation of the fields between the conductors. It is worth to note that the field levels are still below the guideline, even directly below any transmission line (except perhaps for some 765kV designs), whilst the guidelines categorically apply to the servitude boundary.
Table 3 provides representative magnetic field values associated with overhead power lines. Since the magnetic field is related to current, the field levels are not related to the voltage of the line (Table 3), and 765kV lines, for example, usually have lower magnetic field levels than 400kV lines.

Table 3. Representative magnetic fields due to power lines of different voltages

Nominal Voltage [kV]	Current [A]	Maximum magnetic field [µT]	Magnetic field at servitude boundary [µT] Guideline: 100 µT	Servitude width [m]
765	560	6.0	**1.5** (1.5%)	40.0
400	650	10.5	**2.5** (2.5%)	23.5
275	350	6.0	**1.0** (1.0%)	23.5
132	150	4.0	**1.0** (1.0%)	15.5
88	60	1.4	**0.2** (0.2%)	15.5

The ICNIRP guideline level for continuous public exposure is 100 µT. Normal 132kV designs seldom exceed 1 µT (Figure 2) at the servitude boundary, which is only 1% of the guideline value.

5. Eskom management of EMF exposure

Eskom has been managing concerns related to EMF since 1988. Furthermore, Eskom established a National Forum in 1990 to report on international research findings and recommend methods on how to deal with the topic of EMF concerns in South Africa.

Policies on EMF have been formulated to practicably cover all the various areas of infrastructure, including power lines and substations. Building of structures beneath powerlines is a major issue in South Africa. This encroaching of servitudes by communities not only impacts utilities who need to maintain the lines, but also increases the risk for the people living under power lines. They are exposed to danger if there is an “earth-fault” (short-circuit) on the line, within the servitudes. Eskom continuously educates communities about the dangers of building structures under powerlines, and also shares the information with municipalities across the country.

Eskom continues to monitor developments in international research and to share information with all stakeholders and the public.

Did you know?

The International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), classifies cancer which is internationally recognised. The four categories and examples are provided in Figure 5 below.

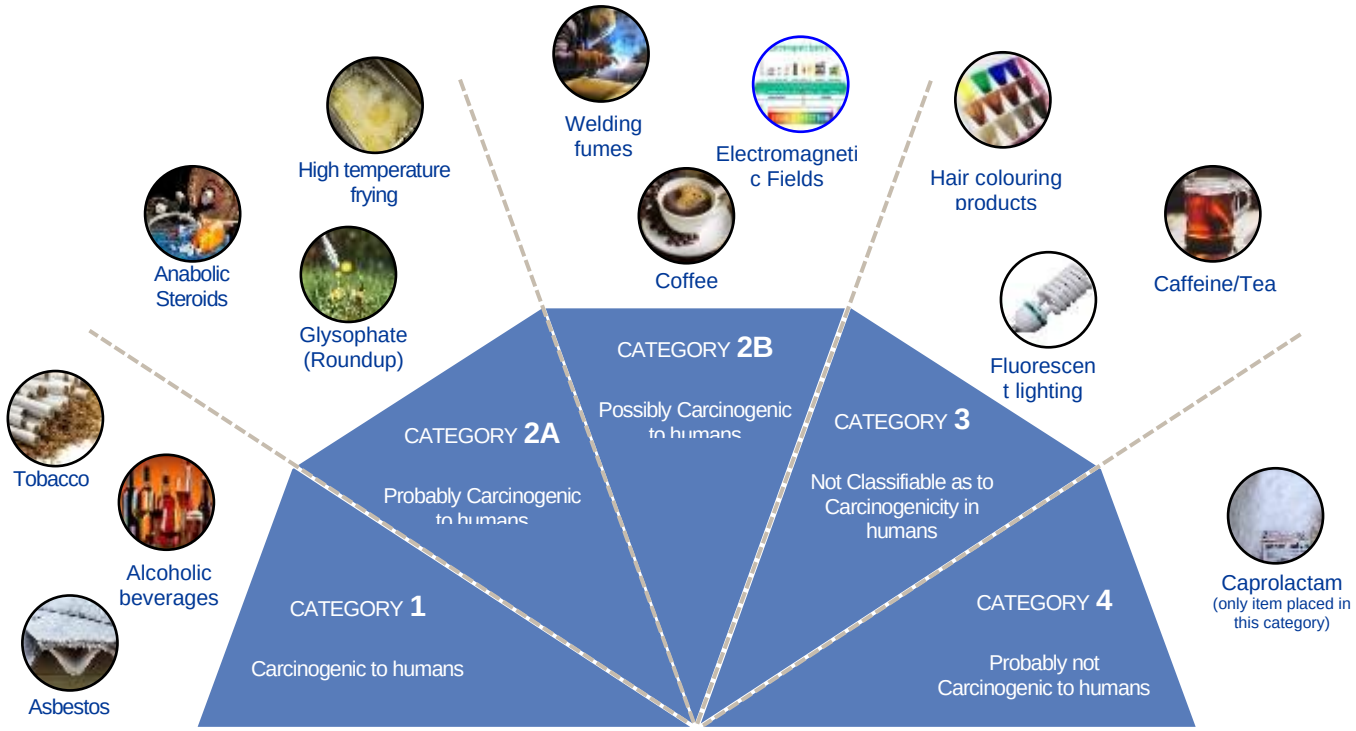

Figure 5: Carcinogenic categories and examples of agent classifications