BEFORE THE BOARD OF INQUIRY

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of applications for resource consent and notices of requirement by Transpower New Zealand Limited for the North Island Grid Upgrade Project

STATEMENT OF EVIDENCE OF ANDREW WILLIAM WOOD FOR TRANSPOWER NEW ZEALAND LIMITED (EMF and human health (biophysics))

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INTRODUCTION

Qualifications

1. **MY** name is Andrew William Wood. I am a biophysicist with a first degree in physics with over 30 years experience in both these areas.

2. **CURRENTLY** I am Professor within the Brain Sciences Institute, Faculty of Life and Social Sciences, Swinburne University of Technology in Melbourne, Australia. I have been full professor for one year and was Associate Professor for the six years prior to that. Until the end of 2002, I was in the School of Biophysical Sciences & Electrical Engineering at Swinburne University of Technology for 23 years, initially as Lecturer and promoted to Senior Lecturer in 1984. Prior to that I was Development Officer for the University of London Board of Studies in Physiology after having completed post-doctoral work within the Department of Medicine at King's College Hospital Medical School, University of London.

3. I have academic qualifications in Physics (BSc Honours, University of Bristol, UK) and Biophysics (MSc, University of East Anglia, UK; PhD, University of London, UK). My Masters and Doctoral theses were both concerned with the transport of mineral salts across biological cell membranes. My research into this topic has continued up to the present, having directed several projects investigating cell calcium dynamics.

4. I am a member of the Australian Institute of Physics, the Institute of Physics (UK), the Bioelectromagnetics Society and a Fellow of the Australasian College of Physical and Engineering Sciences in Medicine. I have been Chairman of the Victorian/Tasmanian branch of the last-named society.

5. **AS** a member of the Bioelectromagnetics Society, I have attended Annual Meetings of the society (and related meetings) for most years since 1991, presenting some of my research work at these meetings.

6. I have been involved in research into possible bio-effects of Electric and Magnetic Fields (**EMF**) for 22 years. In 1985, I spent 5 months in Dr Carl Blackman's laboratory at the US Environmental Protection Agency.

Dr Blackman's name is often associated with the 'Calcium Effect', which is quoted as evidence for low level EMF having biological effects which could possibly be linked to harm.

7. I have been in receipt of funds both from national competitive granting bodies such as the National Health and Medical Research Council (**NHMRC**), the Australian Research Council, and from non-government sources, including a Telstra Research Fellowship. I have received over 12 project grants, the majority to do with possible EMF bio-effects. I am a Research Director with the Australian Centre for Radiofrequency Bioeffects Research (**ACRBR**), which is a NHMRC-funded centre for research excellence.

8. I am involved in several Government committees in radiation and EMF matters, notably the Australian Radiation Protection and Nuclear Safety Agency (**ARPANSA**) Radiation Health Committee (**RHC**) as a non-Ionising Radiation specialist. I am currently the Chair of the Extremely Low Frequency (**ELF**) Standard Working Group, which has been given the task of drafting the new Australian standard relevant to power line EMF exposures, by the RHC.

9. I have undertaken several assignments with the World Health Organisation (**WHO**), including being an invited lecturer at a South American and Caribbean regional meeting on EMF in Lima, Peru, as a short-term consultant within the Ministry of Health, Malaysia, and as a member of the Task Group to finalise the WHO Environmental Health Criteria (**EHC**) monograph on ELF in 2005 [1] (see **Appendix C**, document 1 [1]). The EHC series of monographs, since their inception in 1976, are widely used and recognised as authoritative on a range of chemical and physical agents world-wide. At the week-long meeting of the Task Group, I chaired the 'breakout group' on field exposures, dosimetry and biophysical mechanisms, forming the review group for Chapters 2 – 4 of this monograph.

10. I confirm that I have read and am familiar with the Code of Conduct for Expert Witnesses in the Environment Court Consolidated Practice Note (2006). I have approached the preparation of this evidence in the same way that I would for the Environment Court.

Scope of evidence

11. **IN** this statement of evidence, I address human health issues, from the perspective of a biophysicist. In doing so, I provide the following:

    (a) A discussion of biophysics, and its relevance to human health issues.

    (b) A review of the literature and discussion of the issues in relation to the ELF human exposure guidelines.

    (c) Comment on some of the specific issues raised in submissions relating to biophysics.

OVERVIEW OF BIOPHYSICS

12. **BIOPHYSICS** is the study of biological phenomena in terms of physical principles. By its nature, it is interdisciplinary, and covers a variety of areas of relevance to medicine and biology, in which the methods of physics have been successfully applied. In particular, cellular biophysics covers such areas as bioenergetics (energy transformation at the cellular level), cell signalling (how information is carried within the cell), membrane transport (channels, receptors and transporters involved in cell permeation), and electrophysiology (electricity generated within cells and associated electrical phenomena). (See http://en.wikipedia.org/wiki/Biophysics).

13. **ELECTRICAL** and magnetic interactions with biological materials are important physical principles studied as part of biophysics, as are the electrical and magnetic properties of biological materials. These, together with the areas of cellular biophysics mentioned above, are of great relevance to the issue of Electric and Magnetic Fields (**EMF**) and human health, because they represent a study of the basic mechanisms whereby external EMF can influence living tissue.

14. **IT** is important to have a clear understanding of mechanisms of EMF interaction, because a better case can be made for causation where epidemiological associations have been identified between agents and diseases if a mechanism is a) plausible and b) characterised in a quantitative manner.

15. **ALTHOUGH** there have been instances of the identification of epidemiological associations preceding the precise causative mechanisms, in most cases the strength of association has rendered the mechanism identification as a secondary issue. Because of the '*weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia*' ([1] p 13), the issue of a credible mechanism is of major importance.

ISSUES IN RELATION TO HEALTH GUIDELINES / LITERATURE REVIEW

16. **BECAUSE** my expertise is mainly in the area of biophysical mechanisms and to a lesser extent in the areas of in-vitro and in-vivo laboratory experiments, I will focus on research in these areas when discussing impacts on health guidelines.

17. **ELF** refers to the Extremely Low Frequency portion of the Electromagnetic Spectrum. The EMFs associated with electrical mains power reverse their direction and then return to their original direction, with a frequency of 50 times a second (50 Hz) in New Zealand and Australia together with many other countries. In the United States, Canada and parts of Japan, the frequency is 60 Hz. ELF ranges from approximately 1 Hz to 3,000 Hz.

18. **ELF**, together with Radiowaves, Microwaves and Light, form the Non-ionising Radiation (**NIR**) portion of the Electromagnetic Spectrum. Their properties are quite different from X-rays and other forms of Ionising Radiation. By definition, NIR is unable to ionise atoms, that is, neutral atoms cannot be changed into ions by removing electrons. Since this mechanism is the one responsible for the link between ionising radiation and cancer, the same cannot be said for NIR. There is insufficient energy in each packet or 'quantum' of radiation to cause an ionising event. Although very high voltages are associated with the phenomenon of 'corona discharge' and the production of air ions, the initial ionisation is not caused by these voltages. The voltages (or more precisely, the voltage gradients) contribute to the subsequent avalanche of ionisation, but not the initial event.

19. **ELF** is also quite different from Radiowaves and Microwaves in that these latter forms of radiation interact with matter to cause heating. The amount of energy deposited into the human body from EMFs even from large power

transmission lines, is so small as to be undetectable by measuring a rise in temperature. The body of literature relating to mobile phone safety is thus largely irrelevant to the present case, which involves only ELF EMF. Mobile phones operate at frequencies eighteen million times higher than the ELF EMF frequencies of 50 Hz. At mobile phone frequencies, the issue of raised temperature becomes important, but not at ELF, where the mode of interaction with matter is quite different.

20. **ELF** EMF is arguably not correctly categorised as radiation, since the characteristic wavelength is 6000 km, very much larger than the equipment associated with the fields. In NIR which is radiated (such as radio-waves and visible light), the electric and magnetic fields are in strict ratio. This is not true of ELF EMF, here the electric and magnetic fields are determined by separate processes and they are more or less independent of each other.

21. **EMFs** are associated with electricity wherever it is encountered, whether from man-made sources such as power generation or from natural processes going on within animal or plant cells.

Electric fields

22. **ELECTRIC** fields are associated with such natural activities as combing one's hair or rubbing a glass surface with a dry cloth. Static electricity is a well-known phenomenon associated with getting out of a fabric car seat or walking across a polyester carpet. The small shocks and crackles observed when removing polyester clothing or touching metal objects after collecting 'static', are associated with very high momentary electric fields. People tolerate these electric phenomena as part of everyday living usually without comment.

23. **ELECTRIC** fields exist wherever there is a difference of electric pressure, or voltage, between two objects. In an analogy with the domestic water supply, there is pressure in the water pipes whether the taps are on or not (due eventually to the height of the water-tank or reservoir). Similarly, there are electric fields present wherever there is energised electric wiring, whether the electrical plant or appliances are switched on or not.

24. **IN** regard to electrical utility installations, electric fields are associated with power transmission and distribution lines, with transformer sub-stations and

with power stations and switch-yards. The electrical pressure, or voltage, is particularly high in the case of transmission lines, typically being in the range 33,000 – 500,000 volts (33 – 500 kV). The electric field associated with these transmissions lines exists in the space between the cables and the ground and is directed from the cables down to the ground (or vice-versa).

25. **HOWEVER**, the strength of the electric field is inversely proportional to the distance between the wires and the ground level. Thus, as far a public exposure is concerned, the greater height of the transmission line poles compared to the distribution system poles (for the 240 volt supply), means that the electric fields associated with the former are not necessarily orders of magnitude larger. In addition, trees and other tall objects tend to significantly reduce electric fields experienced by the public out-of-doors.

26. **FINALLY**, the values of voltage of the three main sets of wires of a transmission line at any given instant can be positive or negative and in fact the sum of the three voltages is always zero. A person standing on the ground beneath a transmission line experiences an electric field because he or she is closer to one set of wires than the other two. This 'phase cancellation' is another reason why electric fields due to utility installations experienced by the general public are at best modest. Indoors, the building itself provides additional shielding from external electric fields.

27. **ELECTRIC** field is measured in Volts per metre (**V/m**). Inside the home, the values usually encountered are of the order of several tens of V/m. Directly under a 500 kV power-line, fields of 1,000 V/m (1 kV/m) or more are possible. The values of electric field measured indoors are more than likely to be due to sources within the building rather than external to it. In one particular study [2], 14 V/m was measured in homes away from transmission lines and 26 V/m in homes within 85 m of a 735 kV transmission line.

28. **IN** other words, living within a block of transmission lines (at a substantially higher voltage than those existing in Australia) less than doubles the indoors electric field already there due to internal wiring and appliances. On the other hand, Sandstrom et al. [3] have reported electric fields of over 1,000 V/m due to home appliances such as computer screens. Out in the open, at the typical easement boundaries of transmission lines, the electric fields are very variable

because high objects such as trees tend to act as a 'screen'. They are expected to be in a range from 100 – 1000 V/m.

Magnetic fields

29. **MAGNETIC** fields are associated with magnetic materials such as magnetite (an iron ore) and with flowing electricity. The earth has a steady magnetic field which has formed the basis for navigation for several centuries. Magnetic materials are incorporated into such familiar items as fridge magnets and door closers to provide an attractive force. Strong magnets form the basis of devices such as electric motors and Magnetic Resonance Imaging (**MRI**) machines (which are used in hospitals to produce detailed images of the body, especially the brain).

30. **WHEN** electricity flows in a wire or other conductor to form a current (measured in Amperes, or Amps, for short), this will set up a magnetic field. As mentioned in paragraph 29 above, magnetic fields are associated with natural flows of current within the human body associated with such processes as the heartbeat and the functioning of the brain. In general, the larger the current, the greater the magnetic field. If a wire is wound around a cylinder (or core), this intensifies the magnetic field, particularly if the cylinder is of a material such as iron (this will be discussed further below).

31. **IF** the current flows in a straight wire, such as a transmission or distribution line, the magnetic field is directed in a circle around the wire or cable. The strength decreases with distance from the cable. Unlike the electric field, the magnetic field is not diminished by trees or by the presence of other non-metallic buildings. A metallic shell, such as a car body, may reduce the field by a factor of 30% or so, but in general, magnetic shielding is quite difficult (and expensive) to accomplish effectively. However, the 'phase cancellation' referred to above, also acts to reduce magnetic field intensity associated with electrical power transmission and distribution systems.

32. **THE** basic unit for magnetic field intensity is Amps per metre (**A/m**). However, since different materials have different susceptibility to this magnetic intensity, the flux density (in Tesla) is a more appropriate measure when considering effects on objects, including the human body. For non-magnetic substances such as the human body, 1 microtesla (μT) (one millionth of a Tesla) is

equivalent to 0.796 A/m. An older unit, the Gauss, is still in use. 1 microTesla is equal to 10 milliGauss (1 milliGauss is one thousandth of a Gauss).

33. **WITHIN** the home, values of up to half a μT are common. The fields at normal operating positions of some household appliances, such as hair driers and electric shavers, can be over 3 μT. At a personal computer, fields of up to 2 μT can be recorded. In contrast, fields under electrical power distribution lines in residential streets are typically between 0.2 and 2 μT, and 0.2 – 7 μT is encountered at easement boundaries of transmission lines. The range for electric fields is given in paragraph 28.

34. **IN** a manner similar to an irrigation system, a large flow of electricity (or current) is required at a source to supply many individual consumers. If each domestic consumer were to need 100 Amps to supply their appliances, a community of 10,000 would need 1 million Amps. Since there are practical difficulties in carrying such large currents, the universal solution for electrical utilities is to 'transform' the electricity in a number of sub-stations from high voltage, moderate current coming in, to moderate voltage, high current going out. The power coming in (which is the product of the voltage and current) is the same going out (apart from some small losses).

35. **THE** principle of the transformer is simple: the current coming in to the transformer flows in a wire wound around an iron core, forming intense magnetic fields within this core. There is another wire wound around the same core: this is connected to the out-going supply. The intense magnetic field 'induces' current in this second wire. Effectively, the core is formed into a ring, so the intense magnetic fields are contained within this ring. The magnetic fields close to a transformer are quite modest and decrease rapidly with distance.

Current induced in the body

36. **THE** susceptibility of the human body to EMFs is in some ways similar to the way a transformer operates: currents are 'induced' in living tissue by the action of the EMFs acting on this tissue. Both Electric and Magnetic fields have a similar action of inducing electric fields inside the body: these induced electric fields within tissues give rise to the currents within tissue. In this regard, the

human body is no different from other materials such as moist soil or expanses of water. In general, the magnitude of induced current for a given value of (external) electric or magnetic field depends on the amount of 'saltiness' (or conductivity) and the anatomical details of each individual tissue.

37. **AN** important point is that the magnitude of the electric field induced inside the body is about one millionth of that outside the body. An external magnetic field of 10,000 V/m which may be encountered in extreme occupational settings (and represents the International Commission for Non Ionising Radiation Protection (**ICNIRP**) occupational limit), will only produce up to around 10 – 20 mV/m actually within most human tissue (up to around 500 mV/m in bone [4]).

38. **THE** current density that this internal field will produce is determined by multiplying the value of this internal field by the tissue conductivity. The conductivity values for different tissues subjected to electrical power EMFs are well documented [5]. For example, the conductivity of blood is 0.7 Siemens per metre, giving an induced current density of 0.02 (V/m) x 0.6 (S/m) = 0.014 Amps per square metre. This is equivalent to a current of around 1 microAmps per square centimetre. This is less than 1/1,000 of the current that flows across an equivalent area of nerve membrane during the passage of a normal nervous impulse.

39. **THE** action of an external magnetic field is in many ways equivalent to the action of an external electric field. An external magnetic field of 10 mG or 1 μT will produce an *electric* field of up to around 0.05 *milli*volts per metre within the body [4]. This will give rise to induced current densities of 1/400 of that referred to above in relation to 10,000 V/m electric fields, and 1/400,000 of that across a nerve. Whilst the direction of induced current flow due to the external *electric* field is up and down the length of the body for someone standing below a power-line, the direction of the induced currents due to the magnetic field is quite different.

40. **THE** current becomes larger the further away from the centre of the body and the current path forms a distorted circle, going down one side of the body and coming up the other. Inside the head, the skull forms an insulating boundary, but the induced currents will be greatest at the brain surface, forming circular paths. Under a power-line, a person is subjected to both electric and magnetic

fields, so the total induced current is a combination of the effects of both fields. It is quite difficult to estimate total current, because in some places the two effects will tend to cancel, in other places they will add. The moment when the current induced by the alternating electric field is at a maximum, the current induced by the magnetic field could be zero, and vice versa.

41. **IT** should be borne in mind that ambient electric fields are just as effective in inducing currents within the body as magnetic fields are. In open spaces near transmission lines, the electric fields tend, in fact, to induce larger currents inside the body than the associated magnetic fields.

42. **IT** is important to note that in none of the major large-scale epidemiological studies have any associations been identified between 50/60 Hz *electric* field levels and the risk of cancer. This may be due to methodological issues: it is much more difficult to measure electric fields because of the distorting effects of the meter and of the body itself and it is difficult to get a convenient surrogate (such as 'wire-code' for magnetic fields), because of the shielding effects of buildings and vegetation. One of the conclusions of the original Wertheimer-Leeper study was that no association was obtained with line voltage, which was taken as a surrogate to electric field [6]. The IARC analysis [7] was that 'electric fields are not classifiable as to their carcinogenicity in humans' (p338).

The biophysical mechanism – internal electric fields

43. **EACH** and every cell in the human body has natural electricity associated with it. The cell membrane, which forms the outer envelope of the cell, has a voltage of 0.1 V (approximately) between the outside and the inside. This is not constant: there is also a random variation to this value, some in a range of frequencies relevant to 50 Hz. The induced electric field due to the external magnetic (or electric field) can add to, or subtract from this voltage. The value of this additional voltage is given approximately by the formula $1.5E_{int}a$, where E_{int} is the induced field and a the radius of the cell (0.01 mm). This additional voltage can be compared to the fluctuations naturally occurring.

44. **AS** noted above, an E_{int} value of 250 mV/m would be associated with an external magnetic field of 5 mT (50,000 mG) and this would give rise to voltage fluctuations of only 3.8 microvolts. Thus for a human subjected to a

field of 0.5 μT (5 mG), the voltage fluctuations across cell membranes in the body due to this field will be around one ten thousandth of this. The natural random fluctuations in voltage will be far, far bigger (measured to be around 0.1 mV [8]). The inside of the cell, therefore, would be entirely unperturbed by this 0.5 μT field interacting with the membrane.

45. **IT** has been noted that certain fish possess an ability to detect fields as small as around 1 microvolts per metre [9]. However, these fish possess unique sensory organs which are able to amplify and detect these small signals by a combination of spatial and temporal coherence in nerve firing rates. Humans do not possess these 'electrical' sensory organs. Similarly the ability of humans to detect the earth magnetic field has not been established scientifically. Birds, honeybees, certain fish and certain bacteria on the other hand, possess regions containing biogenic magnetite (a magnetic ore) which are thought to provide the basis for their direction-finding capabilities.

46. **THE** current densities which are induced by magnetic fields at the reference levels are comparable to those flowing in the body because of normal functioning of organs such as the heart, brain and muscles [10]. Thus, far from being 'abnormal', these currents induced from outside sources such as electric power installations are indistinguishable from those already there. In fact, currents are induced by such normal everyday activities as bending forward in the Earth's magnetic field, which is a steady 0.05 mT (500 mG). The movement of the torso interacts with this field to give rise to this induced current, since any conductor moved through a static field gives rise to an induced current. This is the principle behind the dynamo, which can still be found on older bicycles for powering the lighting system.

47. **THE** existence *per se* of publications proposing mechanisms (other than direct induction of current) linking low-level magnetic fields to serious biological effects, do not imply that they are either plausible or generally accepted by the scientific community. I have been associated with several publications proposing mechanisms myself. We acknowledge in these papers that although our models might account for some published experimental data, they do not imply a) that the experimental data is free from artefact b) that our models are flawless. We ourselves point out some of these flaws: nevertheless, we put these hypotheses forward as a contribution to an academic debate.

48. **IN** a review which I published 15 years ago [11], I reviewed some of the mechanisms that had been proposed up to that time. I noted that '*no mechanism has been established whereby environmental 50/60 Hz fields can contribute to deleterious health effects'*. More recent reviews ([12] [13] [14] [1]) reach similar conclusions.

49. **THE** following is a list of some of the proposed mechanisms of low-level 50/60 Hz magnetic fields interactions with biological materials. A brief description together with a reference to a paper in which the model was first described and also possible shortcomings are given below.

Solitons [15] (1981).

50. **THE** protein strands on the cell membrane surface are assumed to act as electric field detectors. These disturbances are conducted to the inside of the membrane via solitary-wave (soliton) propagation along protein trans-membrane strands. Inside the cell, this ELF signal is assumed to couple to enzymes, altering reaction rates. The precise energetics of this scheme has not been investigated, but according to Adey's own estimate, thermal noise can only be overcome by a co-operative molecular system 300m in extent. (The actual cellular distances are 30 million times smaller).

Cyclotron resonance [16], (1985).

51. **CLASSICAL** equations of a charged particle moving in a combined static and alternating magnetic field. The model requires values of viscosity (or collision frequency) many orders of magnitude smaller than those expected in membrane channels.

Ion parametric resonance [17], (1991).

52. **SIMILAR** to the above, but involves the energy levels produced when a calcium ion binds to a membrane site. Adair [18] has presented four theoretical reasons why such a mechanism cannot operate.

Magnetite particles [19] (1992).

53. **THE** hypothesis is that brain tissue contains micro-crystals of the magnetic ore magnetite, which respond to external magnetic forces giving rise to intense volume currents in the surrounding tissue. *'However, work with this theory would suggest that such effects can occur only with large magnetic fields and are not applicable to the normal human environment...'* [20].

Free radical lifetimes [21], (1992).

54. **FREE** radicals are dangerous to cellular processes and are formed due to a variety of causes. Normally they re-combine without causing damage, but if their lifetimes are extended the chance of their escaping and causing damage increases. Magnetic fields do extend free radical lifetimes, but only at levels above a few hundred mG and in chemical rather than biological systems. Adair [22] has discussed the possibility of this occurring at environmentally relevant magnetic field levels and considers this to be unlikely.

Stochastic resonance [23] (1994).

55. **THIS** is a phenomenon whereby a signal in a noisy environment becomes actually easier to detect because of the noise. It has been suggested that such phenomena may add to the acute sensitivity of the sense of hearing and of smell. However, the amount of enhancement is modest and is inadequate to explain the huge disparity between membrane noise and induced voltage discussed above. Adair [24] has also shown the model to be inadequate to explain EMF effects.

Radon progeny and particulate deposition [25] [26] (1996, revised 1999).

56. **THIS** is primarily associated with strong *electric* fields (specifically corona discharge) close to transmission line cables and is relevant *only to those areas associated with high ground emissions of the radioactive gas radon or where there are pre-existing accumulations of pollutant particles.* It is an indirect mechanism, because the ELF fields are influencing the primary putative cause, radon (and progeny) or particulates. To be credible, the electric field gradients in the lining of the airways of the lung have to be unrealistically high (at least for radon progeny). Neither the form of cancer usually associated

with radon progeny, lung cancer, nor the forms associated with pollutant particulates, lung and skin cancer, has been associated with EMF in the major epidemiological studies.

57. **THE** Environmental Health Criteria (EHC) Breakout Group (see paragraph 9) on mechanisms considered that three direct mechanisms stood out as being possible 'explanations' for a low magnetic field effect: induced currents in neural networks; interactions with biological magnetite, and influence on free radical pair lifetimes. However, it was considered that tissue was unlikely to be responsive below 10 mV/m induced in neural networks (corresponding to 200 μT), or 5 μT for effects on magnetite and 50 μT for effects on free radicals.

58. **THE** overall conclusion of the Group, which was reflected in the final monograph was that *'None of the three direct mechanisms considered above seem plausible causes of increased disease incidence at the exposure levels generally encountered by people. In fact they only become plausible at levels orders of magnitude higher and indirect mechanisms have not yet been sufficiently investigated. This absence of an identified plausible mechanism does not rule out the possibility of adverse health effects, but it does increase the need for stronger evidence from biology and epidemiology'* ([1], p 117).

59. **IN** regard to the radon progeny deposition hypothesis, the Group considered that *'it seems unlikely that corona ions will have more than a small effect, if any, on long-term health risks, even in the individuals who are most exposed'* [1], p 117.

60. **ANOTHER** indirect effect considered was the possibility of high internal tissue fields (up to 650 mV/m) resulting from contact with certain types of domestic plumbing [27]. This hypothesis has been put forward as a possible explanation of the epidemiological data. However, since this relates to house wiring rather than external electricity transmission systems, it is not relevant to this Inquiry.

61. **THE** so-called 'melatonin hypothesis' [28] dealt with possible repercussions of altered melatonin output patterns: it did not consider the fundamental question of how these patterns might be altered by weak magnetic fields. In other words, the hypothesis did not suggest how the pineal gland or other components of the systems controlling the circulating melatonin levels might

be influenced by magnetic field exposure. A recent review [29] confirms this view.

62. **IN** summary, there is currently no generally accepted and plausible biophysical mechanism to account for the excess cases of childhood leukaemia identified from epidemiological studies (assuming that the excess is real, rather than a methodological artefact).

In-vitro studies

63. **THE** research literature on the effects of power-frequency EMFs (particularly magnetic fields) on biological tissue samples in laboratory experiments is vast. It should be pointed out, however, that the majority of these research reports have investigated field strengths many times higher than the 0.3 μT cutpoint used in epidemiological studies. Many have been at or near the General Public limits of 100 and 904 μT in the ICNIRP and Institution of Electrical and Electronic Engineers (**IEEE**) standards respectively [30] [31].

64. **MANY** of the phenomena studied have been of little or no relevance to cancer initiation or progression. Of those that have been studied, (the patterns of gene activation, the rate of DNA transcription and/or RNA translation, cell calcium signalling, the activity of certain key enzymes, cell proliferation rate as examples), the outcomes have been inconsistent. They have been so lacking in coherence that laboratory data were classified as 'inadequate' by IARC to provide a basis for determining carcinogenic potential.

65. **PERHAPS** because of this variability, it has been possible, by selective citing of evidence, to present an apparently coherent case for ELF being causal of major illness, including childhood leukaemia. Fortunately, modern bibliographic retrieval systems[1] allow lists of relevant and similar peer-reviewed studies to be constructed. There are several databases specifically of EMF-related studies[2].

66. **HOWEVER**, all peer-reviewed papers are not of the same quality (as judged by leading experts in the particular biological discipline involved). Major

[1] Such as the free PubMed facility, at http://www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed
[2] One which requires no subscription is at http://www.emf-portal.de/_index.php?l=e which has over 11,400 publications categorised according to EMF exposure type, biological end-point and outcome.

reviews of the EMF in-vitro literature (such as those referred to at [1] [32] [13] [33]), have attempted to evaluate studies in term of strength of evidence, taking both quality and consistency into account. Another major review, often referred to as the 'California Health Report' [34] found that, in relation to in-vitro mechanistic studies, they '*did not find a pattern of evidence providing much clarification*'.

67. **THE** overall conclusions of Task Group for the EHC monograph [1] in relation to in-vitro studies (in relation to cancer), was that:

> '*Generally, studies of the effects of ELF field exposure of cells have shown no induction of genotoxicity at fields below 50 mT. The notable exception is evidence from recent studies reporting DNA damage at field strengths as low as 35 μT; however, these studies are still being evaluated and our understanding of these findings is incomplete. There is also increasing evidence that ELF magnetic fields may interact with DNA-damaging agents. There is no clear evidence of the activation by ELF magnetic fields of genes associated with the control of the cell cycle. However, systematic studies analysing the response of the whole genome have yet to be performed. Many other cellular studies, for example on cell proliferation, apoptosis, calcium signalling and malignant transformation, have produced inconsistent or inconclusive results*' (p 10).

Animal Studies

68. **THE** EHC monograph [1] summarises details and outcomes of 10 studies on rodents of long-term effects of magnetic fields alone and 28 studies of magnetic fields in combination with known carcinogens. Interestingly, only 1 of these 38 studies used fields as low as 0.3 μT, although 2 (including the study conducted in Adelaide, Australia) used 1 μT as one of the exposure levels. Only 1 out of the 10 studies using EMF alone showed an increase in tumour incidence, and deficiencies in study design may have contributed to this.

69. **SEVEN** of the combined studies showed an increase in incidence or severity due to EMF, one showed a slight decrease. The remainder showed no effect.

Five of the seven studies just mentioned were from the same laboratory and a replication study of one component of these in another laboratory in another continent showed no effect. However, it has been suggested by the first group of investigators that the responses may be different in different sub-strains of the type of rat used (Sprague-Dawley).

70. **THE** incidence of abnormalities in embryos has been widely studied. The California Health Report [34] noted that the '*DHS reviewers felt that studies on chicken embryo developments under magnetic field exposure show a somewhat consistent pattern of results than* (sic) *may deserve further investigation.*' (p 77) In support of this, they present a table summarizing the outcomes of 25 studies on chicken eggs, a small number with exposures as low as 1 μT, but with a pulsed waveform which cannot be readily compared to the sinusoidal waveforms of power line magnetic fields.

71. **THE** EHC task group [1], on the other hand, reviewed a much larger number of studies and their conclusion was as follows:

> '*The exposure of mammals to ELF magnetic fields of up to 20 mT does not result in gross external, visceral or skeletal malformations. Some studies show an increase in minor skeletal anomalies, in both rats and mice. Skeletal variations are relatively common findings in teratological studies and often considered biologically insignificant. However, subtle effects of magnetic fields on skeletal development cannot be ruled out. Very few studies have been published which address reproductive effects and no conclusions can be drawn from them.*
>
> *Several studies on non-mammalian experimental models (chick embryos, fish, sea urchins and insects) have reported findings indicating that ELF magnetic fields at microtesla levels may disturb early development. However, the findings of non-mammalian experimental models generally carry less weight in the overall evaluation of developmental toxicity than those of corresponding mammalian studies.*' (p254)

72. **OVERALL**, the lack of a credible biophysical mechanism, coupled with inadequate data from in-vitro and in-vivo experiments, in my view makes a

direct causative link between power line magnetic field exposure and childhood leukaemia unlikely. Indirect causation (as may eventuate from increased deposition of particulate matter or contact currents from particular plumbing systems) remains speculative, awaiting experimental or other confirmation.

EXPOSURE GUIDELINES

73. **THERE** are two major sets of ELF-EMF guidelines currently in place worldwide. The ICNIRP guidelines [30] were published in 1998, differing only in some relatively minor details from an earlier set published 8 years before [35]. More recently, the International Committee on Electrotechnical Standards of the US-based IEEE published a Standard [31], covering power frequencies. A comparison between the two standards is provided in Appendix A of my evidence. It is of note that the IEEE standard, which has a more up-to-date review of the literature, has a General Public magnetic field limit nine times higher than ICNIRP. ICNIRP is currently revising its ELF guidelines, but it is impossible at this stage to give a firm timetable on progress.

74. **HOWEVER**, neither ICNIRP nor IEEE bases their limits on epidemiological data. ICNIRP devote several pages of the published guidelines [30] to discussion on the epidemiological literature available at the time. Whilst acknowledging '*data .. are apparently consistent in indication a slightly higher risk of leukaemia among children'* they go on to say *'In the absence of support from laboratory studies, the epidemiological data are insufficient to allow an exposure guideline to be established'*. (p. 503). Similarly, IEEE state in their Scope that *'there is not sufficient reliable evidence to conclude that long-term exposures ... cause a disease., including cancer.'* (p. 1). In summary, both sets of limits are designed to protect against established hazards, which if they were to occur, would be almost instantaneous.

75. **SINCE** the limits are intended as instantaneous thresholds, it is not valid to compare them to the magnetic fields averaged over several hours, as they are in epidemiological studies. For example, a person exposed to 100 μT for 30 min and then 0.1 μT for the remaining 23.5 hours of the day receives an Arithmetic Time-Weighted Average (**TWA**) magnetic field of 2.2 μT.

76. **IN** the combined analysis of Ahlbom et al. [36], Geometric rather than Arithmetic TWA was used. In the situation identified in paragraph 75 above, the Geometric TWA is 0.11 μT. The detailed analyses of the instantaneous exposure experienced by members of the general public as they go about their daily lives, shows a wide variation, with peak values one or two orders of magnitude larger than the TWA value [37]. It is thus quite possible to exceed the ICNIRP limits and yet to record a TWA of less than 0.4 μT. It is also possible to be in the 'above 0.4 μT' category in an epidemiological study and yet to experience lower peak magnetic field values than a person in the 'below 0.4 μT' category.

77. **THE** recent EHC monograph [1] recognises the place for a precautionary approach to magnetic field exposure. In chapter 1 of this monograph, a summary of precautionary approaches is given and this is reproduced in **Appendix B** to this statement of evidence. Of particular note is the third dot point: '*Provided that the health, social and economic benefits of electric power are not compromised, implementing very low-cost precautionary procedures to reduce exposure is reasonable and warranted*' (p 13).

78. **RISK** and benefit have to be weighed up and since the risk (in terms of possible extra cases of leukaemia) in comparison to other day-to-day risks is not ranked high, the phrase 'very low-cost' has been used. I can recall that this particular dot point and the phrase just referred to was a matter of lengthy debate among the 21 members of the Task Group at its week-long meeting in October 2005. There was a final voting process to approve the wording, particularly of the first chapter. It thus represents a consensus view.

79. **THE** composition and role of this Task Group is explained on page xiv of the monograph [1]:

> '*their function is to evaluate the accuracy, significance and relevance of the information in the document and to assess the health and environmental risks from exposure to the part of the electromagnetic spectrum being addressed*'.

80. **TASK** Group members are appointed because of specific expertise and to provide appropriate geographical representation. '*Task Groups conduct a critical and thorough review of an advanced draft of the ELF EHC monograph and assess any risks to health from exposure to both electric and magnetic fields, reach agreements by consensus, and make final conclusions and recommendations that cannot be altered after the Task Group meeting* ([1] p. xiv)'.

81. **THE** advanced draft referred to, was prepared by experts in various fields. The chapters were broken up and grouped into a number of topic areas which were then fully debated line-by-line in Break-out Group meetings. Task Group members were mainly academics. Although there were some 6 observers from industry, 5 of them had doctoral qualifications and they were not permitted to participate in the consensus and recommendations process just referred to.

82. **NEITHER** WHO nor the EHC Task Group is in favour of reducing the limits to arbitrary lower levels as a precaution against possible leukaemia risk. It is recognised that the cut-points used in the epidemiological studies represent arbitrary levels, designed to optimise statistical power. They do not represent a threshold for effect as are those underlying the ICNIRP or IEEE limits. If EMF is directly or indirectly causal, it is impossible to determine a) whether there is a threshold b) what that threshold consists of in terms of field parameters. The encouragement of measures to *reduce exposure* is thus the most prudent public health approach at the moment.

83. **IN** Australia, the national radiation authority, ARPANSA, is currently drafting a Standard to replace the Interim Guidelines, based on the IRPA document [35]. The Working Group, which I chair, has been seeking to resolve several issues, including the disparity between the ICNIRP and IEEE standards and the proper place of the precautionary approach in a Standard. A consultation draft was issued for public comment in December 2006[3].

84. **ONE** of the features of this draft is that it incorporates a new analysis of the science underlying the limits, including more recent analyses than in the IEEE Standard and an update on the literature on epidemiology and low level

[3] This can still be accessed at http://www.arpansa.gov.au/publications/Drafts/dr_elf.cfm

effects. The draft has mandatory precautionary requirements and principles of precautionary measures are discussed in an Annex. In revising this draft, the Working Group is making a number of changes to respond to public comment, in particular the precautionary requirements and measures are being strengthened.

85. **THE** Working Group has recently considered the SAGE[4] report and its recommendations on a precautionary approach. In addition, it has noted the response by the relevant UK authority, the Health Protection Agency (**HPA**), contained in a letter from the HPA CEO (Prof Pat Troop) to the UK Minister for Public Health[5]. Significantly, Prof Troop, although supporting many of the SAGE recommendations, notes that in relation to a 120m wide corridor for power lines (that is, 60m from the centre line to the nearest *building*) is *'not supported by the cost-benefit analysis, even assuming a causal link'*.

86. **ANOTHER** statement worth highlighting is that::

> *'HPA notes the costs of any proposed precautionary approaches should be considered alongside other potential uses for the money, for example, to improve services for the treatment of leukaemia, or to enhance research into the causes and treatment of leukaemia'.*

87. **MY** own view (which is not necessarily that of ARPANSA nor the Working Group) is that there is a *possibility* that reducing exposure may result in a modest reduction in leukaemia incidence. However, since there is no guarantee that a) it will or b) that the reduction would be detectable by statistical means, careful consideration has to be given to weighing up risk against benefit. The low population density close to the proposed overhead route of the transmission line acts to further move this balance away from risk towards overall benefit. Wide easements, placing restrictions on land use, do not appear to be justifyable on social or economic grounds.

[4] SAGE is an acronym for: Stakeholder Advisory Group on ELF EMFs. The interim assessment can be found at: www.rkpartnership.co.uk/sage/Public/SAGE%20first%20interim%20assessment.pdf
[5] See: http://www.hpa.org.uk/radiation/understand/radiation_topics/emf/hpa_response_statement_sage.htm

ISSUES RAISED IN SUBMISSIONS

88. **IN** dealing with issues raised in submissions, I will first deal with some misapprehensions which have appeared in several submissions, and I will then comment on some generic issues raised by three or more submitters. Finally, I will offer some comment on specific issues within my expertise raised by particular submitters.

89. **SEVERAL** submitters used the phrase *'EMF and ionized particle emissions have been proven to cause numerous diseases including childhood leukaemia*'. Firstly, EMF has not been *proved* to cause any disease: its causation of childhood leukaemia is at present not established, according to major reviews. The California Report, in stating that the 3 authors are 'inclined to believe' that EMF causes some degree of increased risk, is careful not to make a conclusion that scientific proof has been attained.

90. **SIMILARLY** ionized particle emissions: the increased production of air ions through corona discharge ('crackling') on transmission lines has not been shown to lead to any disease. The hypothesis, which has been discussed in paragraph 56 above, is conjecture. There is evidence that inhaling pollutant particles increases certain cardio-respiratory diseases, but there is no evidence of it increasing childhood leukaemia. The enhancement of ion concentrations and particle deposition downwind of power lines has been measured and found to be only a few percent [38]. In a recent UK childhood leukaemia study [39], childhood leukaemia incidence was found to be the same, irrespective of whether the child's residence was up- or down-wind from the nearest transmission line. I have added a note in paragraph 18 to clarify the distinction between ionizing radiation and air ionization due to corona discharge.

91. **A** number of submitters referred to the cumulative effects (of power line EMFs). It is unclear whether this is referring to cumulative in location or cumulative in time. Both are inaccurate. Multiple power lines can lead to enhancement or reduction, depending on the configuration of the lines. One of the advantages of three phases in three separate sets of conductors, is that the net current is zero and the magnetic fields are substantially reduced. For a two-circuit system 'reverse phasing' of the second circuit leads to further reduction in EMF. Regarding cumulative effects in time, the evidence of

biological effects increasing in severity with duration of exposure (over months or years) is inadequate to make any conclusion.

92. **A** number of submitters raised easement width as a major issue, some arguing for the SAGE 'corridor' of 120m, others for larger corridors, up to 600m. I am of the opinion that the opposition to the 'corridor option' by HPA (see paragraphs 85 above) is soundly based. The magnetic field level at property boundaries in suburban streets (due to distribution wiring) varies widely, but can approach the 6 μT shown as a worst-case scenario in the Notices of Requirement Documentation Part II page 54. Fields of up to 5 μT are found at the easement boundaries of transmission lines generally[6] The width of easements for Victorian 500 kV lines is around 65m and field levels at boundaries quoted as 0.5 – 4 μT (SP-Ausnet pamphlet).

93. **SEVERAL** submitters have suggested undergrounding the entire 186km section presently proposed as an overhead line. The graph on p 55 of the Notices of Requirement Documentation Part II, shows that the maximum magnetic field will be expected to fall by around 40% (by undergrounding) and that the estimated values at the easement boundary for an *overhead* line will be achieved at around 6 m from the centreline of an *underground* cable configuration. However, there will still be a strip of land approximately 45m wide above an underground cable where the peak field will exceed 0.4 μT at ground level. For young children, exposures measured at ground level are more appropriate than at 1 m from the ground. For people concerned with levels above 0.4 μT, those concerns would still persist with an underground cable. It should also be pointed out that one of the present 110 kV overhead lines, with no easements (and thus areas immediately below the lines which would exceed 0.4 μT) is to be replaced.

94. **DR SMART**, in section 3 of his submission (0235), covers some of the mechanisms, in-vitro, and in-vivo, work that I commented on earlier. He rightly points out that he has '*merely skimmed the surface*' (3.12). I am familiar with most of the work he describes and some of it has been covered above.

[6] See ARPANSA fact sheet at: http://www.arpansa.gov.au/pubs/factsheets/mag_fields.pdf).

95. **HOWEVER**, his section 3 does tend to focus on the more contentious papers, which when added to the mix of total studies available tend to lose some of their apparent sensational impact (described as '*chilling*' in 3.10).

96. **FOR** the same reason, I would contend that his first conclusion in 13.1, which relies largely on the view of the California Health Report [34], may also be over-stated.

97. I would also take issue with the contention that '*the level of 100 μT is so high and impractical in the real world that it represents no regulation at all*'. Leaving aside that the fact that IEEE is 9 times higher, in drafting the ARPANSA standard, the (Australian) industry has argued consistently that the proposed occupational levels (based on ICNIRP, but slightly different from them) are too *low*. In other words, the levels are being criticised as being over cautious and a barrier to effective work practices, possibly causing economic flow-on.

98. **THERE** is also a scientific inaccuracy in comparing 30 μT with fields from a microwave oven. The distance microwave oven frequencies are from ELF (8 powers of 10) is the same as the distance between AM radio and visible light: they just do not compare. The 100 μT from a mobile phone handset is to do with the pulsing current drawn from the battery. It is not to do with the radiofrequency radiated from the antenna. It is true that users of mobile phones are exposed in localised regions to ELF fields well above 0.4 μT for extended periods. This needs to be considered in developing a consistent precautionary approach.

99. **IN** regard to Dr Bennet's submission (0925), I would agree that a precautionary approach is warranted, the question is the extent of this precaution, which must be proportionate to the strength of evidence. This has been described by HPA as '*weak*', with the '*least weak*' evidence for an association with childhood leukaemia. I would dispute the statement in 9e that '*it is generally accepted that there is a risk to human health...*'. I would concede that if 'is' is replaced by 'may be' then this statement is true. To quote from Prof Troop's letter[7]:

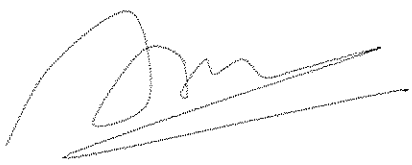
[7] at: http://www.hpa.org.uk/radiation/understand/radiation_topics/emf/hpa_response_statement_sage.htm

'HPA supports precautionary measures that have a convincing evidence base to show that they will be successful in reducing exposure, are effective in providing reassurance to the public, and where the overall benefits outweigh the fiscal and social costs'.

100. **THERE** is no convincing evidence that undergrounding or having a 600 m or 120m corridor would provide an overall benefit.

CONCLUSIONS

101. **MY** overall conclusion is that the lack of a credible biophysical mechanism, combined with the inconsistency of animal and laboratory data make it unlikely that either magnetic or electrical fields associated with electrical transmission lines are a direct cause of illness, including childhood leukaemia. Indirect mechanisms (such as influences on deposition rates of pollutant particulates) lack substantiation. However, in view of the epidemiological evidence of an association of magnetic fields, at least, with childhood leukaemia, some level of precaution is warranted. The benefits of efficient power delivery are considerable, hence the weakness of the evidence of harm, together with the relative sparseness of the population directly affected need to be borne in mind when deciding on an appropriate level of precaution. The level of precaution incorporated into the design and routing of the proposed transmission line appears to me to be appropriate and consistent with the philosophy of WHO, ICNIRP, HPA (UK) and other national and international bodies, including ARPANSA..



Andrew William Wood

27th January 2008

APPENDIX A

Comparison of ICNIRP and IEEE limits at 50 Hz

Note: for Magnetic Field values in mG, multiply values by 10.

Magnetic Fields	ICNIRP (1998) (μT)	IEEE (2002) (μT)
Occupational head & torso	500	2710
Occupational limb	500	75800
General Public head & torso	100	904
General Public limb	100	75800

Electric Fields	ICNIRP (1998) (kV/m)	IEEE (2002) (kV/m)
Occupational	10	20, but painful discharges may be experienced
Occupational Controlled Circumstance	20 under conditions in which adverse indirect effects from contact with electrically charged conductors can be excluded.	20 may be exceeded if conducting object not in reach
Occupational (other)		28 peak
General Public	5	5
General Public Controlled Circumstance		10 Right of Way (ROW)
Other		7.1 peak or 14.1 in ROW

APPENDIX B

(Extract from reference [1] p13)

Implementing other suitable precautionary procedures to reduce exposure is reasonable and warranted. However, electric power brings obvious health, social and economic benefits, and precautionary approaches should not compromise these benefits. Furthermore, given both the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia, and the limited impact on public health if there is a link, the benefits of exposure reduction on health are unclear. Thus the costs of precautionary measures should be very low. The costs of implementing exposure reductions will vary from one country to another, making it very difficult to provide a general recommendation for balancing the costs against the potential risk from ELF fields.

In view of the above, the following recommendations are given.

- Policy-makers should establish guidelines for ELF field exposure for both the general public and workers. The best source of guidance for both exposure levels and the principles of scientific review are the international guidelines.

- Policy-makers should establish an ELF EMF protection programme that includes measurements of fields from all sources to ensure that the exposure limits are not exceeded either for the general public or workers.

- Provided that the health, social and economic benefits of electric power are not compromised, implementing very low-cost precautionary procedures to reduce exposure is reasonable and warranted.

- Policy-makers, community planners and manufacturers should implement very low-cost measures when constructing new facilities and designing new equipment including appliances.

- Changes to engineering practice to reduce ELF exposure from equipment or devices should be considered, provided that they yield other additional benefits, such as greater safety, or little or no cost.

- When changes to existing ELF sources are contemplated, ELF field reduction should be considered alongside safety, reliability and economic aspects.

- Local authorities should enforce wiring regulations to reduce unintentional ground currents when building new or rewiring existing facilities, while maintaining safety. Proactive measures to identify violations or existing problems in wiring would be expensive and unlikely to be justified.

- National authorities should implement an effective and open communication strategy to enable informed decision-making by all stakeholders; this should include information on how individuals can reduce their own exposure.

- Local authorities should improve planning of ELF EMF-emitting facilities, including better consultation between industry, local government, and citizens when siting major ELF EMF-emitting sources.

- Government and industry should promote research programmes to reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure.

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