Non-Ionising Radiation Protection
How much protection is enough?

John Swanson[a*]

[a]National Grid, 1-3 Strand, London WC2N 5EH, UK

Abstract. Non-ionising radiation protection generally proceeds by establishing a dichotomy. Certain effects are regarded as established, and scientific bodies set exposure guidelines designed basically to prevent such effects. At low frequencies the principal such effect is induced electric fields in tissues, and at high frequencies is heating. For all other effects, regarded as not being established, traditional scientific bodies tend not to set exposure guidelines nor even to propose other precautionary measures, but to leave responsibility for that to non-scientific or political processes and bodies. Both parts of this paradigm are criticised. For established effects, exposure guidelines cannot be set from the science alone but need an understanding of economic, social and political consequences. For non-established effects, the issues are still largely scientific and need the input of scientists.

KEYWORDS: non-ionising radiation; EMFs; health protection; precaution; exposure limits

1. Introduction

Non-ionising radiation refers to electric and magnetic fields (EMFs) with frequencies (and hence quantum energies) below the threshold required to cause ionisation or to break chemical bonds. It thus encompasses the fields produced by electric power systems (which operate at 50 or 60 Hz, in the extremely low frequency (ELF) band); by broadcast radio and television (hundreds of kHz up to hundreds of MHz); and by cellular radio communication systems such as cell phones and wi-fi (hundreds of MHz or GHz). It also includes optical radiation, but in protection terms, this presents a rather different set of issues and is not considered further in this paper. "Radiation" as applied to this whole range of frequencies is actually a misnomer. At distances from the source large compared to the wavelength, electric and magnetic fields are indeed coupled together as described by Maxwell's equations such that they propagate through space as radiation, but at distances close to the source compared to the wavelength they exist as separate fields. Thus, for broadcast and cellular communications, radiation is often the appropriate term, but at power frequencies, true radiation is negligible.

Various bodies provide guidance for protection against adverse health effects of EMFs. Internationally, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which grew out of IRPA, is the body recognised by the World Health Organization, and its guidance[[1]] (or that of its predecessor INIRC) is used by several countries and by the European Union[[2,3]]. The International Committee on Electromagnetic Safety (ICES), a committee under the sponsorship of the Institute of Electrical and Electronic Engineers (IEEE) based in America, publishes guidelines[[4,5]]; their low-frequency guidelines[[4]] are arguably an advance on ICNIRP in terms of detailed scientific underpinning but have not yet been adopted by any country. Nationally, various countries have produced their own guidance, including the UK, whose National Radiological Protection Board guidelines[[6]] were influential on ICNIRP, and Switzerland, Italy and the Netherlands, who have all adopted ICNIRP but added extra provisions.

Broadly speaking, all these guidelines follow a similar scientific paradigm:

- They all identify what can be regarded as "established" or proven effects of EMFs on the body, and, with or without safety factors, set limits to prevent these effects
- They all recognise some evidence for effects at lower levels, but mostly regard this evidence as not strong enough to justify setting quantitative exposure limits
- In some cases, they propose alternative measures to provide some protection against these "non-established" effects

[*] Presenting author, E-mail: john.swanson@physics.org

This paper first explains this existing protection paradigm in more detail, then offers a critique of it, focussing on the interplay between purely scientific judgements as to strength of evidence and broader judgements as to the degree of protection it is appropriate to provide.

2. The existing protection paradigm

2.1 "Established" and "non-established" effects

It is commonplace to recognise that proof is rarely black-and-white, and different standards of proof can be used in different settings. For example, many legal systems distinguish the standard of proof required in civil cases – "balance of probabilities" – from the higher standard required in criminal cases – "beyond reasonable doubt". Science does not generally use these precise definitions but tends to operate with a less-well-defined concept of "established". Some schemes do exist for classifying the strength of evidence, for example the International Agency for Research on Cancer (IARC) scheme which has levels "established", "probably", "possibly", "insufficient evidence", and "probably not". However, standards-setting bodies do not appear to use formal schemes such as this in judging what is "established".

The nature of the "established" effects of EMFs on the body vary with frequency and it is convenient to divide the frequency range into two on this basis. Up to about 100 kHz the predominant "established" effect is the induction of fields and currents in tissues; above about 10 MHz the predominant effect is heating, with an overlap in effects between these frequencies.

For "non-established" effects, the evidence for their existence is primarily epidemiological, and therefore does not point clearly to a specific mechanism; so the spilt of the frequency range on grounds of mechanism as used for "established" effects does not logically follow for these possible effects. Nevertheless, there is a common assumption that, for the two frequencies most examined – ELF from power systems and RF from cellular communications – any mechanism would be different, given the ten-million-fold difference in frequencies, and this justifies considering the two frequencies as separate issues.

2.2 "Established" effects at low frequencies

EMFs induce an electric field in conducting tissue and hence an induced current. The induced field and current are related by the tissue conductivity. This induced electric field can have effects on nerves. This is clearly an established effect, and is the basis almost universally used for setting quantitative limits.

The critical effect – the effect for which there is clear experimental evidence and which occurs at the lowest fields – is the magnetophosphene effect. This is a flickering sensation in the periphery of the visual field, similar to that produced by mechanical pressure or direct injection of current. ICNIRP, ICES and others use this effect as the basis for setting limits. I am not aware that any of them claim that magnetophosphenes are dangerous or harmful in themselves. Rather, they either regard the purpose of limits as to prevent all effects regardless of the degree of harm, or they regard magnetophosphenes as evidence of effects in the central nervous system, and consider than an effect on the central nervous system in general is potentially harmful. There are in fact some reports of headaches following magnetophosphenes[[7,8]], suggesting that the effect may not be purely localised to the eye and that other effects (which may not be solely instantaneous acute effects) may be occurring in the brain at the same exposure level. ICES cite this as part of their justification for setting limits at a level to prevent magnetophosphenes; but other authors question whether the evidence is strong enough to regard such effects as established[[9]].

Humans appear to be most sensitive to magnetophosphenes at about 20 Hz, where the threshold induced current density is estimated to be about 10 mA m^{-2}. The observed threshold at power frequencies, 50 or 60 Hz, is higher, at perhaps 100 mA m^{-2}, but depending on experimental conditions. Standards-setting bodies have approached this frequency variation in different ways. At 50 Hz, ICNIRP refer to some effects at current densities from 10 – 100 mA m^{-2} but take the threshold for the purposes of setting guidelines as 100 mA m^{-2} then apply a margin of 10 to arrive at a basic restriction of 10 mA m^{-2}. In their 1992 guidance, the UK's NRPB assumed the threshold for actual effects on the nerves could be similar at 50 Hz as 20 Hz (and the reason magnetophosphenes are not observed till higher levels of field at 50 Hz is presumably because they are masked by processing in the brain), but did not apply a safety factor, so arrived at the same 10 mA m^{-2}. ICES take the threshold for the median person as 50 mV m^{-1} at 20 Hz rising to 130 mV m^{-1} at 50 Hz (roughly equivalent to 20 mA m^{-2}, assuming a tissue conductivity of 0.15 S m^{-1}) and apply a margin of 3 to allow for the distribution of thresholds for individuals across a population.

In addition, ICNIRP apply a further margin for public exposure, of a factor 5, with no attempt to justify this figure quantitatively. (It is surely not coincidence that factors of five between public and occupational exposure are also used in other areas of protection, where cumulative effects are at issue, on the basis of the ratio of the working week to the whole week; for the effects considered in EMFs, of course, there is no suggestion of cumulative effects, so that justification of the factor could not apply.) NRPB[[10,11]] in 2004 considered that magnetophosphenes are a specific example of the general phenomenon of effects on synaptic processes in networks of multiple neurons, and decided that 10 mA m^{-2} was an appropriate level to provide protection for people occupationally exposed. However, they offered a partial scientific justification for the factor of 5, which they followed ICNIRP in applying for public exposure, by noting that the public include people who might be more sensitive (examples given being people with epilepsy, a family history of seizure, or using tri-cyclic antidepressants, neuroleptic agents or some other drugs). ICES used a factor of 3 for some, but not all, effects to provide greater protection in uncontrolled than in controlled environments. NRPB noted an estimate of the theoretical lower limit for the sensitivity of neural networks as 1 mV m^{-1} but did not appear to regard this as robust enough to use in standards setting.

2.3 "Established" effects at high frequencies

Above about 100 kHz, significant heating takes place and is the basis for setting guidelines. Guidelines-setting bodies identify a broadly common body of literature. On the one hand, there is evidence at the population level that increases in temperature (eg during heat waves) lead to increases in deaths; on the other hand, there is evidence that individuals can tolerate a certain heat burden, eg by adapting to it through changes in circulation and by sweating, before it becomes a problem. These two observations are compatible if the tolerance of individuals varies, such that there is always one person who is just at their threshold anyway and will be tipped over it by any additional heat burden. The implication of that, however, may be that at the population level, there is no threshold for heating effects; any additional heating, however slight, will potentially have an effect on someone. Alternatively, there may be a level of heating which can be regarded as trivial and therefore safe.

Guidelines-setting bodies have focussed on the acceptable heat burden on typical individuals. They have recognised differing sensitivities through setting lower levels for the public than for occupational exposure, but implicitly have not attempted to provide protection for every single individual. The recommended limits, expressed in terms of specific absorption rates (or, at the higher frequencies where absorption of energy becomes a surface effect, incident power density) aim to limit the temperature rise to 1 °C (ICNIRP and ICES) or the temperature to below 38 °C for whole-body exposure (NRPB). NRPB speak of limiting the RF heat load to a level which is "physiologically trivial".

2,4 "Non-established" effects

ICNIRP, ICES, NRPB and others have all considered the evidence for effects at field levels below these "established" effects and have concluded that the evidence is not strong enough to set quantitative limits; it is incorrect to say, as some people do, that these guidelines do not consider effects other than induced fields and heating. Out of all the effects considered in the scientific literature, certain specific suggestions emerge naturally as the strongest of the “non-established” effects. Thus, at power frequencies, the evidence linking long-term exposure to elevated magnetic fields in the home to childhood leukaemia is regarded as stronger (in the words of WHO[12], “much stronger”) than the evidence for any other health effect. For cellular-communications technologies, the evidence is probably strongest, though still not very strong, for brain tumours or acoustic neuromas. But ICNIRP, ICES, and NRPB all conclude that this evidence is not strong enough to set quantitative exposure limits. Instead, protection against these effects is considered to lie in a different realm, that of precautionary measures or the precautionary principle. Implicitly or explicitly, most guidelines-setting bodies do not regard it as appropriate for them to enter this realm. For example, NRPB are unambiguous: they themselves recommend exposure limits for “established” effects, but they recommend that it is Government which should consider the need for any precautionary measures against “non-established” effects.

Of the various international bodies, WHO venture furthest into precautionary territory. Their Environmental Health Criteria[12] (created by a Task Group in 2005 but not published until 2007) recommends that quantitative limits should be used to protect against “established” effects but then goes on to consider various other measures that could appropriately be used to protect against “non-established” effects. A WHO “Precautionary Framework” (of which only consultation drafts have been published) takes this theme further by considering the principles to use in deciding which of various precautionary measures to adopt. It emphasises that these principles are rational, scientific, and in many cases, the same as would be used in considering protection against established effects.

3. Critique of this paradigm

The existing paradigm can be summarised, albeit in simplified form, as: set exposure limits to prevent all effects that are regarded as “established”; effects that are not “established” should not form the basis of exposure limits (and any action taken should be seen as political rather than scientific and should be formulated outside the standards-setting arena). I wish to offer constructive critiques of both halves of this paradigm.

3.1 Dealing with “established” effects

First, the dichotomy between established and non-established effects serves the purpose for which it is used fairly well, but, analogous perhaps to a fractal, the more closely it is examined, the less clear-cut the boundary is. No-one would dispute that magnetophosphenes are “established”. But part of the justification offered for setting limits for the public below the level at which magnetophosphenes are observed is that some individuals may be more sensitive, something which has not, to my knowledge, been experimentally demonstrated. Is that an “established” effect or merely one which appears likely on theoretical grounds? And if the justification for preventing magnetophosphenes is that other, potentially more serious, effects may be occurring at the same field levels in the brain, what is the actual evidence for that? (ICES do indeed cite the evidence on headaches experienced following magnetophosphenes but ICNIRP do not, and as already noted, that evidence is regarded by some as weak.) That sounds more like a precautionary measure against an unknown risk; certainly the severity of any effects is not clearly understood. How does the strength of evidence for either of those compare to the evidence for magnetic fields causing childhood leukaemia, where there is at least some actual evidence? (Actually, the evidence in favour of magnetic fields causing childhood leukaemia, which comes from epidemiological studies, is reasonably strong, but is outweighed by the evidence against, from laboratory studies and the absence of a plausible mechanism.) I suggest the trigger which forces a reassessment of the seemingly obvious established/non-established dichotomy would come if the evidence for ELF fields causing childhood leukaemia, or for RF fields causing brain tumours, were to become somewhat stronger than it currently is. That would pose the question, exactly how strong does the evidence have to be to justify setting limits? The answer, I suspect, would involve abandoning an artificial dichotomy and recognising that in real life evidence comes in shades of grey.

Second, the assumption is that all "established" effects should be prevented. Even considered from a purely scientific standpoint, this seems simplistic. In many other areas of health and safety regulation, we act to prevent fatality, or serious chronic injury. For ELF EMFs, we act to prevent headaches, or mild discomfort from nerve stimulation. For RF EMFs, we act to prevent (for most people at any rate) a level of heating sometimes compared to putting on a thin sweater. To be fair, ICES adopt a principle of seeking to prevent aversive effects rather than all effects; at ELF they recognise that discomfort is not an appropriate threshold, and apply a multiplier to arrive at pain thresholds, but even that is temporary pain rather than long-term harm. And to be fair again, there is a debate to be had about how far distraction or interference with cognitive processes could lead to potentially dangerous behaviour; that risk has to be acknowledged in principle even if it seems tenuous in practice. But, without belittling the seriousness of headaches to the sufferer, the disparity is obvious. With RF, where we are dealing with an effect – heating – which can be potentially serious, we arguably do not attempt to prevent that serious harm in all people, but make a judgement as to what is an acceptable level of risk to a healthy individual.

Conversely, of course, in some formulations of EMF guidelines, there are no safety factors applied, and this can seem negligent to people familiar with setting limits eg on chemicals, where sometimes three different factors of ten can be applied. But many of the reasons for applying these factors of ten – interspecies variation, extrapolation between short-term and long-term doses – do not apply when there are data available from humans directly relevant to the effect concerned.

How are we to judge what is an acceptable level of risk of harm; is it a reasonable objective to prevent all established effects (or even all aversive effects) regardless of severity? These questions seem to me largely unanswered in the current EMF world. ICNIRP seem not to address them at all; ICES recognise them as valid questions (eg through the use of a factor to move from an effect to a painful effect) but still appear to present a single answer rather than exploring the issues.

3.2 Dealing with "non-established" effects

Current thinking in mainstream EMF protection circles is that quantitative exposure limits can be used only where an effect is "established"; they cannot be used as a precautionary measure. There would certainly be problems with choosing a quantitative limit if, for instance, knowledge of the exposure-response relationship – or even of the relevant parameter of the field - was inadequate to identify the appropriate limit. But in principle, a quantitative limit is an option for dealing with non-established just as for established effects. In practice, however, the evidence either for ELF fields causing childhood cancer or for RF fields causing brain tumours does not appear strong enough to justify setting blanket exposure limits, which, if set at the levels implicated by the epidemiology, would have drastic consequence on the use of the relevant technologies in society. If protective measures are to be taken in response to that body of evidence, it seems likely they would be of a different nature. To take particular examples, for the RF fields from cell phones, one could consider encouraging hands-free kits; requiring hands-free kits to be included with all phones sold; or requiring phones to be designed such that they can only be used with hands-free kits. For the ELF fields from the power system, one source of those fields arises from low voltage wiring; one could consider requiring changes to wiring practices, or testing to ensure compliance with existing wiring standards.

These are just examples, and there is, in fact, no shortage of options that could be considered as protective measures; what is needed is a choice as to which, if any, it is appropriate to adopt. Why should radiation protection scientists abdicate responsibility or even involvement in that decision?

4. Three case studies

4.1 Magnetic Resonance Imaging

MRI machines produce fields that exceed guideline levels. They clearly do this within the bore, where the patient experiences the field. Exposing the patient to these fields is, of course, the reason for the machine's existence; exposure to patients for medical purposes is excluded from most exposure limits, and separate guidelines for the exposure of patients have been created. However, the machines also produce fields in excess of guideline levels close to the ends of the bore, where staff may be present. For instance, staff may be present for calibration, measurement or cleaning; to provide comfort to patients; or, increasingly, to perform interventional MRI procedures. Some of these involve staff leaning or climbing into the bore itself. There is no health benefit to the individual staff concerned that would compensate for their exposure, so they would normally be included in the scope of occupational exposure limits.

Good data are only starting to be published[[13,14]], but it appears that movement at a speed of 1 m s^{-1} through the static field within 0.5 – 1 m of the end of the MRI machine could exceed the occupational limits, as could the switched-gradient field (which has a complex waveform but a predominant frequency around 1 kHz) within about 1 m (for worst-case conditions, probably less in practice). If the exposure guidelines were enforced, therefore, it would appear that such procedures would have to cease.

This issue came to a head in Europe, where a European Directive[[3]] is in place that would require member states of the European Union to give legal force to the ICNIRP exposure guidelines. When the MRI community realised the potential consequences of this they protested loudly, claiming, for instance, that if MRI were stopped because staff could not be present to perform the necessary procedures, it would be replaced with CT scans, which carry a larger known risk to the patient.

The debate is not completely straightforward. It is unclear, for example, how far the MRI community has looked for ways of designing machines or for work practices which would avoid high exposures. There are also reports of MRI staff experiencing effects attributable to EMF exposure, such as nausea (probably attributable to moving the head in a high static magnetic field), which prompts a debate about exactly how undesirable such effects are in staff charged with medical responsibility for patients. But broadly, it does appear that the combination of ICNIRP setting guidelines that prevent all established effects of fields, followed by the decision by the EU to implement these guidelines without adequately weighing up the consequences, has led to a situation where the adverse consequences for healthcare outweigh any benefit.

4.2 Precautionary measures applied to magnetic fields from high-voltage power lines

Of all the "non-established" effects of EMFs for which precautionary measures might be considered, the scientific evidence is probably strongest for the possibility that power-frequency magnetic fields cause childhood leukaemia. It is this evidence which led to IARC[[15]] classifying ELF magnetic fields as "possibly carcinogenic", the only such classification yet made for EMFs of any frequency, though the evidence was not strong enough to warrant any higher classification than "possibly". Accordingly, several countries have considered, and in some case adopted, precautionary measures in respect of magnetic fields. Such fields actually come from a variety of sources, and high-voltage power lines are not necessarily the one that accounts for the majority of high exposures. But high-voltage power lines are a visible source, which attracts concern or opposition for other reasons (eg the visual impact), and therefore precautionary measures have often focussed on such lines.

Where measures have been adopted they have often involved restrictions on homes (and other specified land uses such as schools) close to power lines, either directly through setting a distance or indirectly through setting an exposure level which can be achieved by maintaining a certain distance. Thus, Italy has a limit of 10 µT on the 24 hour median value of the field from a power line where exposure is for more than 4 hours per day; the Netherlands Ministry of Housing, Spatial Planning and the Environment advises that the annual average fields from power lines should not exceed 0.4 µT for dwellings, schools and creches where this is reasonably possible; Switzerland has a limit for new installations of 1 µT from power lines in "sensitive use locations" (with the possibility of exemptions if all technically and operationally feasible and financially viable measures have been taken). It should be noted, however, that considerably fewer countries have adopted precautionary measures than have adopted limits against acute effects with no additional precautions; and countries which have adopted any EMF restrictions at all appear to be in a minority when viewed globally.

To decide on rational grounds what measures if any to introduce, factors both scientific and social need to be considered. Science needs to provide estimates of what field levels might produce what health effects with what likelihood; what sources produce these field levels and under what conditions; and what effect the various measures considered would have on exposures. But information is also needed on the cost of the various measures, their impact on other factors such as land use and security of electricity supply; and, in a democracy, on the public attitude to the these possible risks and the measures that might be implemented. This drawing together of information from multiple sources to allow a rational decision has been undertaken most thoroughly perhaps in the UK, with the Stakeholder Advisory Group on ELF EMFs[16], which performed a fairly detailed cost-benefit analysis of the option of restricting development close to power lines, and concluded it was not in the overall interests of society on a mainstream view of the science.

4.3 Speculation as to health effects from new RF technologies

The issue of power-frequency magnetic fields and childhood leukaemia considered in the previous section exemplifies one type of precautionary debate: what action to take when we have a body of actual scientific evidence suggesting an effect, but not strong enough to be regarded as "established", merely "possibly" a health risk. A contrasting type of precautionary issue is where we have no real specific evidence of health hazards, but neither do we have evidence of safety; then, in the absence of knowledge one way or the other, the possibility of a health risk emerging in the future may make us think about precautions.

This is, in some people's eyes, the situation with cellular communications. Cell phones have been in widespread use for perhaps something over ten years, and therefore there has been widespread exposure to the radiation they produce for only this period. If they were to cause, for example, brain cancer, we might expect a latency period of rather longer than ten years. So, logically, we might consider there is the potential for a public-health problem in the future which we have not yet been able to observe – and a massive problem at that, given the prevalence of cell phones and the networks that support them worldwide.

How seriously to view this risk is partly a question of philosophy. Some people will be naturally optimistic about the benefits of new technologies and disinclined to fetter them unless there is actual evidence. Others will be more pessimistic and inclined to think there is a track record of new technology having adverse consequences; better safe than sorry. But it is also a scientific question. The argument depends on humanity being newly exposed to the radiation with the advent of cellular communication systems. But radio-frequency exposure has been around for much longer, with broadcast radio and TV for many decades. If, to the human body, radio-frequency radiation is radio-frequency radiation, then we are probably safe; if there were to be effects from cellular communications, we would probably have seen them already with broadcast. But if any effects depend on the specifics of the radiation, either its frequency, or, more likely, its modulation (the respect in which cell-phone radiation most differs from broadcast), then humans will not previously have been exposed to the aetiologically relevant radiation, and disaster could still, in principle, ensue. So the approach to take to precautionary measures is at least in part a scientific debate about what features of radiation we think could be biologically relevant. And of course, this debate repeats itself with each new technology with a new modulation that is introduced; is wi-fi, for example, to be regarded as presenting essentially the same exposures as cell phones and therefore covered by the same research, or is it a new exposure requiring its own research?

5. Conclusions: the common theme

Protection against EMFs broadly works well; there is no evidence of people dying or coming to serious harm (except for a few instances of accidental over-exposure of workers in front of high-power broadcast antennas, something which should clearly be prevented regardless of exposure limits). But this is partly because, by lucky chance, the major technologies that produce EMFs – eg the electric power systems and radio communications – generally operate naturally at levels which do not produce significant effects in humans. Consequently, exposure limits set so as to prevent all effects do not have a dramatic effect on society's use of (and benefit from) these technologies; the technology continues to operate relatively (though not entirely) unaffected.

However, there is no doubt that problems do arise where compliance with exposure guidelines becomes an issue in practice, and cannot be resolved as long as scientists attempt to set limits in isolation from consideration of the consequences of those limits. Health protection cannot be considered as a purely scientific matter, to be delivered in isolation by scientists. Nor can a division where scientists consider just the science, then politicians or other officials do the rest, be considered ideal (especially not if, as is often the case when this split is described by scientists, the implication is that the scientists are clever and the politicians or officials not quite as clever!) The issues that arise in EMF protection intertwine science with broader issues about costs, impacts, priorities, and public attitudes. The judgement about what level to set limits at is fundamentally not a purely scientific one; it could only be a purely scientific judgement in the unlikely scenario where there were no adverse consequences of restriction exposures at all. If there are no adverse consequences, one would indeed chose to set limits to prevent all effects regardless of severity; but in the real world, where there are consequences, the severity of those consequences affects the decision as to what level of protection to provide. Facing up to this need to balance effects (both the severity of them and the strength of evidence for them) against the consequences of preventing those effects provides a better outcome for society. It also avoids the current position of making largely arbitrary (and arguably not always scientific) choices about what effects justify prevention.

ICNIRP recognise this in a separate paper[[17]], stating "ICNIRP recognizes that the acceptability and adoption of a complete system of protection also requires data and evaluations based on social, economic, and political considerations." But their actual exposure guidelines[[1]] do not seem to reflect this understanding, and indeed say that when the basic restrictions are exceeded, appropriate protective measures "must" be implemented. This implies that the guidelines, once having been promulgated, by a purely scientific body, should be applied without regard for "social, economic and political" consequences; and it is exactly that approach which leads to the problems exemplified by the MRI case study.

Equally, though, for the other half of EMF protection, consideration of possible precautionary measures for effects not regarded as "established", the same lesson applies: scientists should not leave it to politicians; the issues are scientific and we should not be afraid of providing our input. I suggest some of the public concern about low-level EMF exposure arises because of an understandable if incorrect perception that the mainstream scientific community is dismissing the issues when it chooses not to engage in them.

The common theme is that effective protection of public health requires both scientific and non-scientific input. Science alone cannot answer the question "how much protection is enough?"

Declaration of Interest

The author is employed by National Grid and worked on this paper with its approval, but the views expressed in this paper do not necessarily reflect those of National Grid.

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