*This case study accompanies the IRGC report "Risk Governance Deficits: An analysis and illustration of the most common deficits in risk governance".

A Case Study on Risk Governance of Electromagnetic Fields: Mobile Phones and Power Lines

By Leeka Kheifets, John Swanson and Shaiela Kandel[1]

Power-frequency electromagnetic fields (EMFs) have been present in industrialised countries since public electricity supplies appeared in the late nineteenth century and have, in recent decades, been relatively stable; while the increases in cellular communications and other radio-frequency technologies in the last decade have been particularly rapid.

For power-frequency EMFs, a considerable amount of knowledge has been accumulated. Science has been quite successful during the last decades and resolved several of the issues. The conventional scientific view is that even if there is a risk, it would be unlikely to be of major public-health significance.

For radio-frequency EMFs, there are no persuasive data suggesting a health risk, but research and particularly exposure assessment is still immature. Results for cancer, the most studied outcome, remain controversial. Studies of children and of many other diseases are lacking. This technology is constantly changing, which makes continued research both more urgent and more challenging.

Most reviews are reassuring and conclude that based on current evidence there is no reason for concern. However, a few reach different conclusions. Focusing selectively on positive evidence, they call for an immediate reduction in exposure limits, so far with limited public or political response. Both parts of the issue – power-frequency and radio-frequency – attract public concern.

In risk-governance terms, therefore, the principal issue at power frequencies is how to respond to weak and uncertain scientific evidence that nonetheless causes public concern. For radio-frequency electromagnetic fields from broadcast transmissions and cellular communications, including, particularly, mobile phones, it is the combination of a rapid growth of exposures over a relatively short time, little scientific evidence, but large potential consequences and large public concern that underline risk governance deficits.

Both power-frequency and radio-frequency EMFs are marked by a lack of scientific knowledge (A2) - but to a vastly differing degree. The evidence has sometimes been over-stated by one side but also sometimes minimised by the other (A6). This makes selecting the appropriate policy (B2, B3, B4) difficult with a risk that alarmist or unbalanced presentation of the competing factors could skew the optimum outcome. Also, in the area of policies rather than science, there has been overstatement of the possible consequences by those resistant to the introduction of certain policy measures, or a failure by those advocating the policy measures to recognise that there may be consequences (B6).

These and other risk governance deficits are discussed in detail in this case study.

[1] Leeka Kheifets, Professor of Epidemiology, UCLA School of Public Health; John Swanson, Scientific Advisor, National Grid; Shaiela Kandel, School of Public Policy, Hebrew University of Jerusalem.

We conclude that risk management of EMFs has certainly not been perfect, but for power-frequency EMFs risk management has evolved and can be largely considered a success. Lessons from the power frequency experience can benefit risk governance of the radio-frequency EMFs and other emerging technologies.

Overview of the risk issue

Risk framing

In today's world, technological developments bring social and economic benefits to large sections of society; however, the health consequences of these developments can be difficult to predict and manage. This case study focuses on power frequency (50- and 60-Hz) fields and radio-frequency fields. Both are part of the electromagnetic spectrum, but the frequencies often differ by a factor of ten million, so their physical properties and interactions are very different. Power-frequency fields induce weak electric currents in the body; however, they can neither break bonds nor heat tissue. Radio-frequency fields have enough energy to heat tissue. Exposure guidelines for both extremely low frequency (ELF, which includes power-frequency fields) and radio-frequncey fields are based on acute effects either from induced currents or from heating of tissue, respectively.

Electric and magnetic fields are unavoidably produced wherever electricity is used, and are thus inherent in modern societies. Power-frequency EMFs have been present in industrialised countries since public electricity supplies appeared in the late nineteenth century (they are also produced by electrified transport but the main focus is on the public electricity supply); radio-frequency EMFs as a result of radio and TV broadcasts since the early twentieth century; additional radio-frequency EMFs from radar and related technologies in the mid twentieth century; EMFs from cellular communications just in the last years of the twentieth century; and from wi-fi, RFID and a host of other technologies just in the last few years. All have increased considerably since first emerging, and the increases in cellular communications and other radio-frequency technologies in the last decade have been particularly rapid [Geekzone, 2003].

There are plenty of anecdotal instances of fear of new technologies and their health consequences from the introduction of electricity supplies in the nineteenth century onwards [Beck, 1992]. Safety limits on exposures to high-power radio-frequency sources have always been necessary. However, serious scientific concern about health effects of EMFs, and its emergence as an issue of public concern, probably dates from 1979 with the publication of the first epidemiological study of childhood cancer and power lines [Wertheimer & Leeper, 1979]. Widespread public concern about radio frequencies probably dates from soon after the creation of the first cellular networks in the 1990s.

For power-frequency EMFs, the scientific evidence, originally regarded with some scepticism by much of the scientific community, now justifies the classification of ELF magnetic fields by the International Agency for Research on Cancer (IARC) and WHO as "possibly carcinogenic", based on reasonably consistent epidemiological data for childhood leukaemia, but with lack of support from laboratory studies in animals and cells [IARC, 2002]. For radio-frequency EMFs, there is less evidence. Laboratory evidence, broadly, does not support health effects of radio-frequency EMFs at environmental levels encountered by the public. In particular, animal toxicology experiments have not identified effects. There are suggestions of effects, e.g. on cognition, but these are not regarded as "established". Epidemiological evidence from broadcast radio-frequency EMF or from cellular communications infrastructure is sparse and uninformative. Epidemiological evidence concerning cell phones themselves is, so far, of questionable quality. There have been suggestions of effects, but not from reliable studies. Most importantly the technology is relatively new, thus most studies have not had sufficient latency. Additionally, exposure assessment in the radio-frequency area is still in its infancy and is especially challenging due to rapid changes in technology and its applications [ICNIRP, 2008].

Uses of both power-frequency and radio-frequency bring enormous benefits to societies and thus the appropriate risk governance includes consideration of a large number of trade-offs, including the potential for risk offset, risk substitution, risk transfer, and risk transformation, as well as benefits and costs.

For both parts of the issue the concern about health effects is often tied up with other concerns and the inevitable opposition on visual or amenity grounds to the construction of new facilities [EC, Eurobarometer 2007]. But at power-frequencies, the public concern about health is accompanied by at least some evidence suggesting the possibility of a risk. At radio frequencies, the scientific concern relates more to the lack of positive reassurance about new and far-reaching applications of a rapidly changing technology rather than to robust evidence that the technology is in fact harmful.

In risk-governance terms, therefore, the principal issue at power frequencies is how to respond to weak and uncertain scientific evidence that nonetheless causes public concern. For radio-frequency EMFs from broadcast transmissions and, particularly, cellular communications, including mobile phones, it is the combination of a rapid growth of exposures over a relatively short time, little scientific evidence, but large potential consequences and large public concern that underline risk governance deficits.

Key risk facts

For power-frequency EMFs, the conventional scientific view is that even if there is a risk, it would be unlikely to be of major public-health significance. This is because the evidence, as reviewed by, for example, the IARC and WHO, really only implicates one relatively rare disease, childhood leukaemia, and the exposures that are implicated are at the top end of the normal range of exposure and are therefore also relatively rare. Estimates are of just a few percent of cases of childhood leukaemia being attributable to magnetic fields if there is an effect [WHO, 2007; Kheifets et al., 2006].

This estimate, however, is challenged on two main counts by scientists or members of the public who disagree with the orthodoxy. One objection is that assumptions about exposure-response relationships made in this calculation are incorrect, and thus the attributable fraction of childhood leukaemia could be higher. The other is that the scientific evidence on a number of other, more prevalent, diseases, regarded by WHO as “much weaker”, is being underestimated [California DHS, 2002; SAGE, 2007; Sage C, 2008].

The controversy over EMFs has led to some delays in building new power lines. But most industrialised countries have undertaken relatively little building of new power lines in recent years compared to the existing networks, so such delays are probably not a major cost to society. In some jurisdictions, new power lines have become more expensive as a result of EMF mitigation measures, and there are suggestions that some buildings are built or retrofitted with EMF mitigation measures at significant increased cost, possibly even billions of dollars, though these estimates are very uncertain [Florig, 1992].

With the rapid advances in EMF technologies and communications, people are increasingly exposed to frequencies in the radiofrequency range. Radio-frequency fields produced by radio and TV transmitters have been around for decades; it seems likely that if there were a major public-health issue caused by these, some indication of it would have emerged. However, base stations, and other communication infrastructures, and residential exposures such as wireless monitors used in children’s cribs, cordless phones and wi-fi are much more recent. This is especially true for handheld mobile phones which have only been available since the later part of the 1980s and have become widely used by the general population only during the last decade. Currently there are more than 2.5 billion mobile phone users worldwide, with a penetration in some countries reaching 90% [Geekzone, 2006]. Therefore, even if only a small effect were occurring, this widespread exposure could have large public health consequences.

Risk history

The following table shows the development of key events for power-frequency EMFs:

	Research Results	Reviews etc.	Policy
1960s	Occupational Findings from Russia [Asanova & Rakov, 1966]		Largely discounted
1970s	1979: first residential epidemiologic study [Wertheimer & Leeper, 1979]		
1980s	1982: first occupational epidemiologic study [Milham, 1982] Other studies published but still fairly weak. Numerous laboratory studies but not robust results.		First major research program in New York. [Ahlbom et al., 1987] 1989: first recommendation for “prudent avoidance” in USA. [US Congress, 1989]
1990s	1993: first Scandinavian study published, higher quality but still small. [Feychting & Ahlbom, 1993; Feychting & Ahlbom, 1994; Floderus et al., 1993] Succession of occupational epidemiological studies in utilities. [Loomis et al., 1994; Theriault et al., 1994; Lovely et al., 1994; Savitz & Loomis, 1995] More laboratory results but including failed replications of earlier positive results. [NIEHS, 1999] 1997-9: results of major epidemiological studies from USA, Canada and UK [Linet et al., 1997; NTP 1998; NRC 1997]	Succession of official reviews in UK and USA use language of “no firm/established/conclusive effects” [NRC1997; NRPB, 1992] 1998: NIEHS (USA) classify magnetic fields as “possibly carcinogenic” [Portier & Wolfe, 1998]	Australia, California, Sweden and others adopt precautionary policies. [Kheifets et al., 2005; California Public Utilities Commission, 1993; NBOHS, 1996; Gibbs, 1991] 1992: major USA research program (RAPID). [Energy Policy Act, 1992] 1998: ICNIRP publish exposure limits based on established effects only (now adopted by 30 countries). [ICNIRP, 1998] 1999: official recommendation for “passive regulation” in USA [NIEHS, 1999]
2000s	2000: pooled analyses of childhood leukaemia epidemiology establish association but not causation. [Ahlbom et al., 2000; Greenland et al., 2000]	2002: IARC classify magnetic fields as “possibly carcinogenic”. [IARC, 2002] 2002: Report in California sees strong evidence for several health effects but is not adopted by CPUC [California DHS, 2002] 2005: WHO confirm IARC classification but say evidence for disease other than childhood leukaemia is “much weaker”. [WHO EHC] Other official bodies reach similar conclusions [e.g.SCENIHR, 2007]	2002: WHO start consideration of precautionary measures. [WHO, 2002] Italy, Switzerland and Netherlands adopt precautionary limits. [WHO International Standards Database] 2004: UK starts detailed process to consider precautionary measures. [NRPB, 2004] 2005: WHO Report includes detailed consideration of possible appropriate precautionary measures. [WHO EHC, 2005; WHO EHC, 2007]

		2007: Bioinitiative Report published to counter "official" views, claiming stronger evidence for more effects. [Sage, 2008]	

The following table lists major developments throughout the years for Radio Frequency EMFs

Year/ Technology Introduction	Research results	Reviews	Public responses	Policy
1970s and before	Russian Studies: Positive laboratory findings (e.g., changes in bilogical parameters). [Obrosov & Krylov 1982] Positive studies on Microwave hearing effect at strong, radar intensities [Frey & Messenger, 1973] Positive humans studies on effects of cellphone-like RF signals on EEG [Bise, 1978]			Serve as basis of low exposure limits.
1980s Sale of frequencies for mobile tele-communications and dependance of governments on that income First and second generation networks set up around the world	Positive animal studies on embryo and fetal development due to heating. [O'Connor, 1980]	National and international reports conclude the only established health effect is the thermal effect. No established mechanism of action identified for causing cancer or other symptoms. [AGNIR,1992; NRPB,1993; EC, 1996; NRPB, 1999; AGNIR, 2003;]		Several organizations published Guidelienes based on established thermal effects. [ANSI/IEEE, 1982; ICNIRP, 1984; NCRP, 1986] 1984: establishement of CTIA –International wireless association
1990s Widespread siting of first and second generation base stations. Base statons and faclities become more visible and numerous evoking public concern. High penetration rate of mobile phones into the market	Positive animal studies on effects on brain [Lai & Singh, 1995; Repacholi et al., 1997], and cancer. Subsequent studies, albeit not exact replications, failed to see health effects. 1993: Industry established Wireless Technology Research Program (WTR) Headed by G Carlo. 1996: Studies reporting increase cancer incidence with proximity to radio and TV transmitters [Hocking et al, 1996; Dolk, 1997; Michellozi et al., 2002; Hallberg & Johansson,		Early 1990s claims linking cell phones to cancer surfaced. 1992: First law suit in e.g. Reynolds / Florida, initiated global health fear Other law suits followed. None were won. Resulting in adverse publicity for industry. [Burgess, 2004] Anti tower campains emerged in different countries.	More guidelines published in different countries based on heating effects [IEEE, 1992; NRPB 1993, Australian Interim Standard], 1998: ICNIRP publish exposure limits based on established effects only. [ICNIRP, 1998] 1998: Establishment of International Mobile Manufactorer's Forum (MMF). 1999: European Council recomending adoption of ICNIRP exposure limits in member states. [EC,

	2002].			1999]
2000s Introduction of third generation and technologies and other (UMTS, TETRA, DECT, WIFI, WIMAX WILAN)	2001: Funding for WTR ceased. Carlo claimed industry's cover up,of troublesome findings. [Carlo & Schram, 2001] 2000-2004: International epidemiological study launched INTERPHONE. Publication of final results delayed. Positive Human Laboratory studies on sleep [Hillert et al., 2007] cortical excitability [Ferrari et al., 2006], and other subjective symptoms [Health Council of Netherlands, 2004; Hutter et al., 2006]. Results for cancer, remain controversial [Lahkola et al., 2007; Hardell et al. , 2007]	2000: EC communication on the precautionary principle. [EC, 2000] 2000: IEGMP Report "Stewart report". Recomends adoption of precautionary approach and addressing public concern . [IEGMP, 2000] Reviews by different authors, teams and institutions have reached different conclusions [SCENIHR,2007;Sage,2007; Hyland,2000;Health Council of the Netherlands, 2000; Health Council of the Netherlands, 2002;;Zmirou et al.,2003; Goldstein et al., 2003; Ahlbom et al., 2004; IEGEMF, 2007]	G. Carlo's Statements heightened public suspicion as to the relationship between industry and scientific research. Numerous new facilitiy sitings raise public concern. Class action suits emerged based on conspiratorial conduct of industry (not directly linked to brain cancer). Media and anecdotal reports of cancer clusters around mobile phone base stations heighten public concern.	2000: Reevaluation of the application of the precautionary principle to EMFs was initiated. 2001: Industry agrees to publicise SAR levels of mobile phones. 2002: Launch of WHO precautionary framework [WHO, 2002] Most of Europeen countries adopted ICNIRP a few developed stricter levels (e.g. Greece, Italy) or precautionary policies (e.g. Australia, Israel, New Zealand, Sweden, Switzerland). [WHO,International standards database}

Risk system

For power frequencies, since the issue first emerged in 1979, there have always been the twin drivers of scientific and public concern; but the balance between these has changed over time.

The initial scientific evidence was weak; indeed, some of the scientific community was rather dismissive. But some serious follow-up research was performed, of increasing quality as time progressed. The initial motivation for funding such research was at least in part a response to public concern, but over time, the issue became seen as one warranting investigation regardless of the public concern. Public concern on the issue, in turn, has only partly been responsive to the actual scientific evidence. In part also, it has followed concern about electricity infrastructure, particularly opposition to building new power lines. It has fluctuated over time, being most prominent in the USA during the 1980s and early 1990s, but probably more prominent in Europe since then. It has also been an issue in more affluent communities in several of the Central and Latin American countries as well as in Japan, Korea, Taiwan, Australia and New Zealand [Kheifets et al, 2006].

For radio-frequency fields, however, the research was not initiated by an epidemiological finding or other scientific data on the possible existence of a health risk. Instead the driving force has been a concern over the fast dissemination and penetration of new communication techniques together with the notion that the biophysical interaction between radio-frequency fields and humans may not be fully known or understood [ICNIRP, 2008].

In both cases, the invisible and involuntary nature of EMF exposure, its presence within the sanctity of the home and the putative health outcome of cancer, particularly leukaemia, among children have all heightened public anxiety. Association with radiation, at least in name, also does not help. Consequently, media coverage has been intense and the issue has been brought to a wide public awareness. EMF is also relevant as a case study because of controversy within the scientific community [Slovic, 1987].

Stakeholders involved

The most influential group in risk management over the years has been what might be called “establishment” scientists; the type of scientist who becomes eminent and respected by their peers and accordingly tends to populate review groups and bodies which recommend exposure limits or other policies. Such scientists perhaps tend to be cautious in accepting new results. This could be seen as innate conservatism reinforced by a like-minded peer group, or could be seen as the appropriate exercise of maturity informed by experience in withholding judgment. The major and influential reviews throughout EMF history have tended to be produced by such people, but usually involving an extended and intensive process of examining the evidence. The best organised review groups have structured their examination of the evidence in such as way as to prevent casual dismissal and force justified decisions.

Other scientists have taken positions to both sides of the mainstream. On the one hand, there are senior scientists who feel confident enough to declare that the evidence does not justify concern, that there are no effects, or that effects are exceedingly unlikely at exposure levels to which the public is exposed. In their view, research should cease, or other public-health issues should receive higher priority. On the other hand, some scientists have viewed the evidence for health effects as considerably stronger than the conventional assessment. We can infer therefore that individual evaluations are significantly affected by prior beliefs as to whether EMF could be causing any effects.

The divergence of views between scientists has been most evident in legal or quasi-legal settings, such as litigation or siting or permitting hearings for new facilities. The adversarial legal system employed in the USA, UK and elsewhere encourages the polarity of views, and many of the scientists most represented on review groups have declined to become involved in this activity, leaving the field clear for people willing to espouse less nuanced views. This effect also occurs in the media, and it is there that scientists willing to take an unambiguous stance have had the most influence.

Although best practice often promotes risk assessment and risk management as separate activities, in EMFs, they have often been performed by the same people. Thus, for example, the same body of scientists who make up ICNIRP both evaluate the evidence and make recommendations for exposure limits. The WHO Environmental Health Criteria in 2005 contained science chapters and policy chapters, approved by the same scientifically constituted Task Group. In principle, there should be a separate stage where officials and ultimately politicians decide separately on the risk management measures to be adopted. In practice, this has often amounted to rubber-stamping of recommendations from scientists, as, for example, when the EU initially simply adopted the ICNIRP recommendations on occupational exposure limits. Only really in recent years with the more explicit thinking about precautionary measures has an identifiably political step in risk management, separate from the scientific risk assessment, been apparent.

Alongside scientists, the issue has been driven by activists, who have often first engaged with the issues through opposition to a local infrastructure project. For some EMFs may have only been another weapon in the armoury of opposition. However, for others, EMFs have become a matter of genuine conviction, sometimes to be pursued once the immediate trigger is no longer an issue. A subset of these activists became engaged as a consequence of their own illness or of that of a friend or relative, which they attribute to EMFs.

Other important parties involved in the risk management process are government and public authorities. Accountable for their decisions, they integrate societal, economic and political considerations into the decision making process. Charged with the health protection of their population they often look at other decision makers (e.g., government officials in other countries) to benchmark their policy. This has resulted in a convergence of EMF policies around the world (e.g., adoption of ICNIRP guidelines by most countries in Europe) as well as a legitimisation of EMF precautionary policies in recent years.

The proponents of the EMF technology (industry) are also influential actors. Industry's relation to scientific research on health effects has been controversial. On the one hand corporations are attacked for not providing sufficient funds for research, suggesting a lack of concern as to the safety of their technology. On the other hand when they do sponsor studies, they are accused of having done so only to influence the findings.

Motivations for all actors - scientists, regulators, industry or activists - are undoubtedly mixed, with conviction and altruistic motives juxtaposed with unavoidable pragmatic and personal motives. Many activists feel an obligation to society to promote the view they hold and the actions which should stem from it; many scientists feel an obligation as part of being a professional scientist to play their part in uncovering truth. Equally, some scientists have found EMFs a welcome source of research funding, while some activists have found EMFs a platform from which to have national influence and, in some cases, to generate a living.

Risk handling process

As with many other agents, international guidance or exposure limits on occupational and public exposure to EMF is based on avoiding risks to health that are well understood and for which there is good scientific evidence [ICNIRP, 2002]. Such guidance is relatively uncontroversial, and because it addresses effects at much higher levels of exposure (principally experienced occupationally) than the public generally experience, it is often viewed by the public as not addressing their concerns [California Department of Health Services 2002, Sage C. 2008]. It should be noted that a different paradigm on setting limits was implemented in the former USSR. There, changes in biological parameters attributed to EMF exposure were treated as definitive and relevant to human health, which lead to much stricter limits being adopted in many of the Soviet bloc countries.

Concerns about power-frequency EMFs emerged in the early 1980s, an era when there was less sensitivity in official circles to the need for public engagement or communication than today. Early responses were partly driven by a sense that this issue could be managed by conventional scientific expertise. The scientific evidence at the first stages was, by any objective standards, fairly weak (see table 1). Thus, many early official responses had a large element of attempted reassurance about the weakness of the evidence, which at times could sound like dismissal of the concerns. Further research was commissioned, but in part as a response to public demand or as an issue-management tool, rather than solely as a scientific endeavour in its own right. Many official reports recognised some evidence of possible effects at low levels, but used terminology such as "no conclusive evidence", "no reliable evidence", "no established effects". This terminology was factually correct, and accurately reflected the concern of those organisations to focus on identifying any effects where the evidence would be strong enough to warrant, in their estimation, regulatory action. Nonetheless it probably contributed to a sense of the evidence being downplayed or even ignored.

This response evolved over time through the 1980s and 1990s. Some better quality research, suggestive of effects though still far from conclusive, emerged, together with a staggering quantity of other research of variable quality, some frankly poor. This contributed to a sense that this issue was not going to disappear, and that perhaps the way to deal with it was for good-quality research groups to perform studies as close to definitive as possible. For many of the health outcomes studied the issue could be largely dismissed, however, the newer and better epidemiological studies served to strengthen the evidence that there is a statistical association between childhood leukaemia and unusually high exposures to magnetic fields in the home, though the cause of that association is far from certain.

Over the same period, most jurisdictions continued a policy of being prepared to base protective or public-health measures only on fairly robust evidence, and therefore not being prepared to take action over the EMF concerns. A few jurisdictions, however, started taking action. Notably, some Scandinavian countries adopted precautionary approaches, albeit not terribly specific in their requirements, and Australia and California (and some other US states) adopted precautionary policies (then known under the label "prudent avoidance") where modest amounts of money should be spent to reduce exposures where practicable [Kheifets et al 2005]. It is arguable that some of these measures were more motivated by issue management than by genuine public-health concerns; and it is arguable they were partially successful in that, for example, in California it may be that the measures adopted for mitigating EMFs in building new power lines did contribute to reduced public opposition.

The trends in the management of the issue accelerated with something of a step change around the turn of the millennium. First, the US NIEHS officially classified EMFs as "possibly carcinogenic" in 1998. Then two influential pooled analyses of the epidemiological studies on childhood leukaemia were published in 2000, and in 2001 IARC classified EMFs as possibly carcinogenic. None of these, of course, actually changed the evidence, but between them, they contributed to a sense that EMFs were now a legitimate unresolved scientific issue; it had become thoroughly mainstream and had shed something of its "fringe" reputation in scientific circles.

At the same time, particularly in Europe, the precautionary principle was becoming more discussed and accepted, for reasons amply explored elsewhere [Hyland,2000; Health Council of the Netherlands, 2000 and 2003; SCENIHR, 2007; Sage, 2007; Zmirou et al., 2003; Goldstein et al., 2003; AGNIR, 2003; Ahlbom et al., 2004; IEGEMF, 2007; Gee, 2001]. Some scientific bodies, such as ICNIRP and the UK's HPA, felt and still feel that they should act only on established science; but in other scientific circles, and certainly in political circles, there was an increased willingness to consider what measures would be appropriate when dealing with uncertain scientific evidence. Following the IARC classification, the WHO International EMF Project started considering possible precautionary measures, and this was influential.

Thus, since about 2001, there has been a change in the tone of the debate on risk management: less of "how can we keep the lid on this" or "how can we educate people to understand why it shouldn't be of concern", and more of "how can we do something measured and reasonable that is a correct response to the scientific evidence but also might serve to satisfy public concern".

For radio-frequency EMFs, the risk-management landscape has been different. Most notably, the body of scientific evidence so far (albeit deficient in many important aspects) does not amount to the same "possibly carcinogenic" label that applies to power-frequency EMFs [Ahlbom et al., 2004); therefore, this debate has been conducted largely in the absence of any robust scientific evidence. This has allowed players in risk management to take divergent views, some saying that as there is no good evidence of harm there is no justification for any protective measures, and the emphasis should be on managing (or, often, resisting) what is seen as unreasonable public concern. Others have argued that given the gaps in knowledge and the potential scale of the impact if there were to be an effect, there is every reason to take inexpensive protective measures now.

Another difference with radio-frequency EMFs is that the technology is new and developing continually in a competitive environment; the infrastructure is being rolled out at impressive speed and with considerable visibility within communities, and there are strong pressures, both commercial and social, not to brook any unnecessary delay. This combination of a much wider set of scientific viewpoints and more focussed pressures gives the RF risk-management debate perhaps a sharper edge. One reflection of this is in research priorities. A successful model of research funding is to have industry funding, maybe jointly with government, but managed by an independent body.

The attitude toward public involvement in the risk handling process for both power-frequency and radio-frequency EMFs has evolved from no involvement and a defensive approach to public concern, to recognition of the need to communicate to the public and finally to being open to public input. Civic involvement in EMF issues has become more accepted worldwide. This can be in form of public hearings, information meetings and even inclusion of activists in advisory committees that oversee research priorities and policy development [SAGE 2007].

Risk governance deficits

Both power-frequency and radio-frequency EMFs are marked by a lack of scientific knowledge (A2); there is no certainty as to existence of effects from low level chronic exposure, or, if they exist, their scale. This, however, can best be seen not as a risk-governance deficit in itself, but as the backdrop against which other deficits may emerge.

In the early period of power-frequency risk management, the main deficit can be seen in retrospect as a tendency by the mainstream, “establishment” scientific community to manage the issue purely on the basis of their assessment of the science, with limited regard for alternative scientific views (A2) or for the legitimacy of lay public perceptions of scientific issues (A3), and, consequently, insufficient consideration of risk communication as a policy option (B3). To be fair, these should be seen in the context of the times. The initial scientific evidence was, objectively, weak, perhaps not as weak as sometimes painted at the time, but still legitimately regarded by conventional scientific assessment as likely to amount to little in the long run. It was not, perhaps, until the late 1990s that the evidence started firming up (though still amounting to only a “possible” risk), and around that time, the mainstream scientific community did change so as to recognise that. It is a matter for debate to what extent there should have been earlier recognition of the emerging science. Similarly, the culture of the time was not open to lay recognition or involvement in scientific issues. Further, activists, for example campaigning against a proposed new power line, would naturally have a temptation to state the evidence as strongly as possible. The evidence has often been over-stated by conventional standards (A6), a deficit in itself, but also contributing perhaps to a minimisation of the risk as presented by the establishment through a desire to counter the exaggerated claims.

In more recent years, whilst there are still circles where the evidence and the legitimacy of the issue tends to be minimised or even dismissed, such views are noticeably rarer. The main issue now is selecting the appropriate policy (B2, B4), with a risk that alarmist or unbalanced presentation of trade-offs could skew the optimum outcome and encounter public opposition. For example, exaggeration of the adverse consequences of taking protective measures could tilt the debate one way, whereas exaggeration of the scientific evidence could tilt it the other.

With radio-frequency EMFs, the fundamental vacuum in the scientific evidence, largely an inevitable consequence of the recent introduction of new or rapidly changing technologies, prompts a debate about early warnings [Gee, 2001] (A1, B1). A clear distinction should be made between evidence of the absence of an effect and the absence of evidence of an effect – for radio-frequency EMFs this distinction is sometimes intentionally or unintentionally obscured (A6).

For example, while studies of children, who might be more sensitive, are largely lacking (the absence of evidence of an effect), it is sometimes stated that children are not affected or are no more sensitive (evidence of the absence of an effect).

In risk governance terms, the issues concern the correct action to take when a new technology cannot be expected to manifest any early warnings until years after it is introduced. Relevant factors include whether it is appropriate to forgo the enormous benefits cellular communications have brought to societies both developed and developing on the basis of rather little scientific evidence; how robust an early warning has to be under these circumstances; whether a proactive surveillance, if it existed, would provide reassurance that early warnings would be detected; and how the debate changes if precautionary measures are available which have no or low cost. The absence of a widely agreed answer to this problem underlies much of the disagreement on appropriate risk management and can be seen as a deficit.

Both the power-frequency and radio-frequency EMFs issues have exhibited two further common problems. One is that, even when it is desired to include a wide variety of interests and groups within the risk governance process, there is uncertainty as to what weight to give to small but vocal groups or groups with largely local concerns (A4).

The other is that, almost inevitably, different groups have represented the science to their best advantage, sometimes to the point of distortion (A6). An example from one side would be the highlighting of a single, seemingly positive, experimental study, without considering the weight of evidence from the totality of relevant studies, which may often present a consistently negative picture that casts doubt on or outweighs the single positive study. An example from the other side would be references to numerous negative studies when many of them may not be especially relevant to human health or may not have had a resolving power to detect an effect (due to limited size or relevance of the biologic model) (A6). Similarly, over-simplistic arguments, based on crude energy considerations, of the impossibility of any effects have been used.

Likewise, in the area of policies rather than science, those resistant to the introduction of certain policy measures have sometimes tended to overstate the possible adverse consequences or side-effects of policy implementation (B3); or, conversely, those advocating certain policy options may fail to recognise that these policies can have consequences (B6). To give examples of these: for power-frequency EMFs, where one major source is the high-voltage power line, there are a set of interrelated issues about land use and land values adjacent to such lines, the different economic interests of nearby residents from society as a whole, the availability of land to meet broader societal objectives, etc. The consequence of any EMF mitigation measure for these wider issues has to be considered. This may not be appreciated by the proponents, but equally, may be overstated by the opponents of such measures. Similar issues apply with, e.g., cell-phone base stations, and in both cases there are issues of equity (B4) between those experiencing the exposure and receiving some benefit, those experiencing the exposure and not receiving direct benefit, and society as a whole. Radio-frequency EMFs and, particularly, cellular communications, have an undeniably enormous impact on societies. They have a downside (e.g., contributing to collisions if used when driving, the environmental consequences of disposal, and, perhaps, some adverse social effects of changing communication patterns), but there is broad agreement that the overall effect is positive, through improved communication generally as well as specifics such as expediting help in medical emergencies. It would be hard to justify restricting those benefits, but there is dispute as to the extent to which various precautionary measures would in fact limit the use of and benefit from these technologies. Another specific example concerns Magnetic Resonance Imaging (MRI). This technology is enormously beneficial to society, but can produce exposures to medical and technical staff that exceed the ICNIRP occupational limits. In 2004, the EU passed a Directive requiring the ICNIRP limits to be given force in member states [EC, 2004]. Protests at the time about the effect on MRI were not effective, perhaps partly because they were not well supported by evidence and may have seemed like exaggeration. Subsequently, following a high-profile campaign by the MRI community, it was accepted that these limits will result in real and unjustifiable limitations to the use of new MRI technologies, and the implementation has been delayed to allow time to find a solution [EC, 2007].

Once some jurisdictions have taken action, there is understandable pressure on others to take the same or further action; no regulator, or even less, politician, wants to be seen to be lagging behind in public protection. This can lead to a "race to the bottom" where the measures taken can become disconnected from scientific reality. This is exacerbated when stricter limits are adopted in some countries (e.g., Russia and China) but are not enforced (and, if truly implemented, would severely hinder many new and existing technologies). These implementation and enforcement failures (B5) affect not only the countries in which they occur but also are often misrepresented in other countries as examples of superior protection. On the other hand a long latency for cancer and other diseases coupled with a short time horizon of decision-makers can lead to a systemic bias for taking no action (B8).

Finally, regulatory policy on EMFs has been directed more at some sources than others. More policies focus on power lines and particularly transmission lines than on other sources such as distribution lines and appliances which can constitute a more significant source of exposure. For radio-frequency EMFs, policies focus more on base-station siting whereas other sources such as mobile phones can contribute more to individual exposure. This is partly a consequence of policy formation being driven by public concern but partly a result of dispersed responsibility between institutions (B10).

Conclusions

Introducing new and widespread technologies, technologies that require visible infrastructure dispersed throughout society and which trigger many public "fright factors", is almost inevitably going to create public concern and opposition at a time when trust in conventional science and risk management is declining [Cvetkovich et al., 1999]. Thus, we should not see the current public concern as a failure of risk management per se; the question being, is the position worse than it should have been if we had managed the issues better? In some ways, that question will only be answered definitively at some point in the future when hindsight is complete. If health risks turn out to be real, we will be criticised for not recognising early warnings sooner and acting so as to protect public health. If there turn out to be no health risks, we will be criticised for not managing the issue more robustly so as to reduce its impact. In the meantime, we can only make our best guess and hope we did not make any crucial mistakes.

Against that backdrop, we conclude that risk management of EMFs has certainly not been perfect. Deficits can be easily be identified, most obviously, attempts by the "scientific establishment" to manage the issue purely as a scientific issue without fully recognising the many facets of the social dimension to risk management, coupled sometimes with a disinclination to accept the possibility of any risk from a beloved technology that undoubtedly brings vast public benefit.

These deficits apply to the earlier years for power-frequency EMFs; risk management in that issue has evolved and can be largely considered a success. Scientific uncertainty has been greatly reduced, by limiting potential health consequences (narrowed to much fewer health outcomes and limited health impact). For the remaining uncertainty, we increasingly see openness to new scientific ideas and to lay perspectives whilst retaining scientific integrity and insisting on a valid scientific basis for policy; willingness to face up to the implications of an absence of evidence; moves to avoid prejudice and bias in both reviews of the evidence and in research priorities; understanding of both the nature and validity of the social dimensions of a scientific risk issue; thought put in to understanding communication strategies; and stakeholder engagement in the decision making process.

These deficits are perhaps still seen in the radio-frequency issue, which is a more recent issue and where the pressures, commercial and other, are stronger. It remains to be seen if lessons from the power frequency experience will be applied for radio-frequency risk management. The main lesson to be learned from power-frequency experience is that an open and proactive approach to research allowed for a successful management of a potentially volatile issue that could have had tremendous societal costs. While some uncertainty remains, it is widely accepted that the health effect, even if real, is not of major public health significance. And while there is still some disagreement, continued research, public involvement and voluntary low and no-cost exposure reduction measures allow for a manageable process of building and upgrading power line infrastructure.

One can learn from these examples specifically when introducing new technologies, which may be prone for the same deficits, into the market. A good example is nanotechnology, where the rate of developments in the research on potential impact of the technology is at a lag behind that of the rate of the changes in the technology and its applications.

References

[AGNIR, 1992] AGNIR, Electromagnetic fields and the risk of cancer, Report of an Advisory Group on Non-ionizing Radiation, *Doc NRPB* 3(1)

[AGNIR, 2003] AGNIR, Health effects from Radiofrequency electromagnetic fields, Report of an Advisory Group on Non-ionizing Radiation. *Doc NRPB* 14(2)

[Ahlbom et al., 1987] Ahlbom A., Albert, E.N., Fraser-Smith, A.C., et al., Biological effects of power line fields, New York State Power Lines Project: Scientific Advisory Panel final report.
Albany, NY, New York State Department of Health

[Ahlbom et al., 2000] Ahlbom A., Day, N., Feychting, M., Roman, E., Skinner, J., Dockerty, J., Linet, M., McBride, M., Michaelis, J., Olsen, J. et al., A pooled analysis of magnetic fields and childhood leukaemia, *Br J Cancer* 83, 692-8

[Ahlbom et al., 2004] Ahlbom et al., Epidemiology of health effects of radiofrequency exposure, *Environmental Health Perspectives*, **112** (17), 1741-54, http://www.civil.ist.utl.pt/~joana/DFA-riscos-net/2007-08/epidemiology.pdf

[ANSI/IEEE, 1982] ANSI/ IEEE, Safety Levels with Respect to Radio Frequency Electromagnetic Fields 300kHz to 100GHz, Report No. ANSI C95.1 1982 American National standards Institute, The Institute of Electrical and Electronic Engineers Inc, New York

[Asanova and Rakov, 1966] Asanova, T.P. and Rakov, A.N., Health conditions of workers exposed to electric fields of open switchboard installations of 400–500 kV (In Russian), *Gig Tr Prof Zabol*;10, 50–2

[Australian Federal Government, 1998] Australian Standard (Interim), Radiofrequency Fields Part 1: Maximum exposure levels 3kHz-300GHz, Standards Australia Homebush

[Beck, 1992] Beck, U., Risk Society: Towards a New Modernity, New Delhi, Sage

[Bise, 1978] Bise, W., Low power radio-frequency and microwave on human electroencephalogram and behaviour, *Physiol Chem Phys*, 10 (5), 387-98

[Burgess, 2004] Burgess, A., Cellular Phones, Public Fears and a Culture of Precaution, New York, Cambridge University Press

[California DHS, 2002] California Department of Health Services, California EMF Program, Policy document, www.dhs.ca.gov/ehib/emf

[California Public Utilities Commission, 1993] California Public Utilities Commission, Decision 93-11-013

[Carlo and Schram, 2001] Carlo, G. and Schram, M., Cell phones invisible hazards in a wireless age, New York, Carroll and Graf

[Cvetkovich et al., 1999] Cvetkovich, G. (ed.), et al., *Social trust and the Management of Risk*, London, Earthscan Publications Ltd

[Dolk et al., 1997a] Dolk, H., Elliot, P., Shaddick, G., Walls, P., Grundy, C., Thakrar, B. and Kleinschmidt, L., Cancer incidence near radio and television transmitters in Great Britain, 1. Sutton Coomefield transmitter, *AM J Epidemiology* 145,1

[Dolk et al., 1997b] Dolk, H., Elliot, P., Shaddick, G., Walls, P., Grundy, C. and Thakrar, B., Cancer incidence near radio and television transmitters in Great Britain, 2. All high power transmitters, *AM J Epidemiology* 145,10

[EC, 1996] Commission of the European Communities, Non ionizing radiation sources exposures and health effects, Luxembourg, Office for Official Publications of the European Communities

[EC, 1999] European Council, Recommendation directive 1999/519/EC on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), *Official Journal of the EC L199*, 30 July, 1999, 59-70

[EC, 2000] Commission of the European Communities, Communication on the Precautionary Principle, Brussels 02 February, 2000, http://europa.eu.int/comm/off/com/health_consumer/precaution.htm

[EC, 2004] Corrigendum to Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

[EC, Eurobarometer 2007] European Commission, Eurobarometer 272a: Electromagnetic fields

[EC, 2007] European Commission, Proposal for a Directive of the European Parliament and of the Council amending Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC), Brussels 26 Oct,2007, COM (2007) 669 final 0230(COD)

[DOE, 1992] United States Department of Energy, Energy Policy Act of 1992, Pub L No 102-486, 106 Stat 2776 (Sec. 2118)

[Ferreri et al., 2006] Ferreri F. et al., Mobile phone emissions and brain excitability, *Annal of Neurology*, 60 (2), 188-196

[Feychting and Ahlbom, 1994] Feychting, M. and Ahlbom, A., Magnetic fields, leukemia, and central nervous system tumors in Swedish adults residing near high-voltage power lines, *Epidemiology* 5, 501–9

[Feychting and Ahlbom, 1993] Feychting, M. and Ahlbom, A., Magnetic fields and cancer in children residing near Swedish high-voltage power lines, *Am J Epidemiol*, 138, 467–80

[Floderus et al., 1993] Floderus, B., Persson, T., Stenlund, C., et al., Occupational exposure to electromagnetic fields in relation to leukemia and brain tumors: a case-control study in Sweden. *Cancer Causes Control*, 4, 465–76

[Florig, 1992] Florig, H. K., Containing the costs of the EMF problem, *Science*, 257(5069), 468

[Frey and Messenger, 1973] Frey, A. H. and Messenger, R., Human Perception of Illumination with Pulsed Ultrahigh-Frequency Electromagnetic Energy, *Science*, 181 (4097), 356-8

[Gee, 2001] Gee, D. et al., Late Lessons from Early Warnings, European Environmental Agency, http://reports.eea.eu.int/environmental_issue_report_2001_22/en/Issue_Report_No_22.pdf

[Geekzone, 2003] Geekzone, News: Number of mobile phone users worldwide to increase to 2 billion by 2007, 08 August, 2003, http://www.geekzone.co.nz/content.asp?contentid=1245

[Gibbs,1991] Gibbs, H., Inquiry into Community Needs and High Voltage Transmission Line Development, Sydney, New South Wales Government

[Goldstein et al., 2003] Goldstein, L. S. et al., Comments on long term exposure of Eμ-Pim 1 transgenic mice to 898.4MHz microwaves does not increase lymphoma incidence" by Utteridge et al., *Radiation Research*, 159, 75-276

[Greenland, et al., 2000] Greenland, S., Sheppard, A., Kaune, W., Poole, C. and Kelsh, M., A pooled analysis of magnetic fields, wire codes, and childhood leukaemia, *Epidemiology*, 11, 624-34

[Hallberg and Johansson, 2002] Hallberg, O. and Johansson, O., Melanoma incidence and frequency modulation (FM) broadcasting, *Arch Envir Health*, 57, 32-40

[Hardell et al., 2007] Hardell, L., Carlberg, M., Soderqvist, F., Mild, H. K. and Morgan, L., Long term use of cellular phones and brain tumors: increased risk associated with use for more than 10 years, *Occup Envirn Med*, 64, 626-632

[Health Council of the Netherlands, 2000] Health Council of the Netherlands, Electromagnetic fields committee,GSM base stations, The Hague: Health Council of the Netherlands, Publication No. 2000/16E

[Health Council of the Netherlands, 2004] Health Council of the Netherlands, TNO Study on the effects of GSM and UMTS signals on Well Being and Cognition, The Hague, Health Council of the Netherlands, Publication. No. 2004/13E

[Health Council of the Netherlands, 2002] Health Council of the Netherlands, Electromagnetic fields committee, Mobile phones: A health based analysis, The Hague, Health Council of the Netherlands, Publication No. 2002/01E

[Hillert et aé., 2007] Hillert L, et al., The effects of 884 MHz GSM wireless communication signals and headache and other symptoms: an Experimental Provocation study, *Bioelectromagnetics*, 29(3), 185-196

[Hocking, B et aé., 1996] Hocking, B., Gordon, I. R., Grain, H. L. and Hatfield, G.E., Cancer incidence and mortality and proximity to TV towers, *Med J Aust*, 165,601, http://www.who.int/docstore/peh-emf/EMFStandards/who-0102/Worldmap5.htm

[Hutter et al., 2006] Hutter, H. P., Moshammer, H., Wallner, P., and Kundi, M., Subjective symptoms, sleep problems, and cognitive performance in subjects living near mobile phone base stations, *Occup and Envir Med*, 63, 307-313

[Hyland, 2000] Hyland, G. J., 'Memorandum' - Potential Adverse Health Impacts of Mobile Telephony', http://www.emfguru.com

[IARC, 2002] International Agency for Research on Cancer, Monographs on the Evaluation of Carcinogenic Risks to Humans, *Non Ionizing radiation, Part 1: Static and Extremely Low – Frequency Electric and Magnetic Fields*, 80

[ICNIRP, 1984] International Commission on Non-Ionizing Radiation Protection, Interim Guidelines on Limits of Exposure to Radio-frequency electromagnetic fields in the frequency range from 100kHz to 300GHz, *Health Physics*, 46 (4)

[ICNIRP, 1998] International Commission on Non-Ionizing Radiation Protection, Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300GHz), *Health Physics*, 74 (4)

[ICNIRP, 2002] International Commission on Non-Ionizing Radiation Protection Statement, General approach to the protection against non ionizing radiation, *Health Physics*, 82 (4)

[ICNIRP, 2008] International Commission on Non-Ionizing Radiation Protection, ICNIRP statement on EMF-emitting new technologies, *Health Phys*, 94(4), 376-392

[IEEE, 1992] IEEE Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields 3KHz, New York, IEEE standard C95.1

[IEGEMF, 2007] IEGEMF, SSI Report of the Swedish Radiation Ptotection Authority, Recent Research on EMF and Health Risks, Fourth Annual Repot from the SSI's Independent Expert group on Electromagntic Fields, 2007:04

[IEGMP, 2000] Independent Expert group on Mobile Phones, Mobile phones and Health, (Stewart Committee), National radiation Protection Board, Didcot U.K. NRPB

[Kheifets et al., 2006a] Kheifets, L., Afifi, A. and Shimkhada, R., Public Health Impact of Extremely Low Frequency Electromagnetic Fields, *Environmental Health Perspectives*, 10,1289/ehp.8977

[Kheifets et al., 2005] Kheifets, L., Sahl, J., Shimkhada, R., Repacholi, M., Developing policy in the face of scientific uncertainty: interpreting 0.3 µT or 0.4 µT cut points from EMF epidemiologic studies, *Risk Analysis*, 25 (4), 927-935

[Kheifets et al., 2006b] Kheifets, L., Van Deverter, E., Lundell, G. and Swanson, J., Le principe de la precaution et les champs electriques et magnetiques: mise en oeuvre et evaluation, *Environment, risques et sante*

[Lahkola et al., 2007] Lahkola A. et al., Mobile phone use and the risk of Glioma in five North European countries, *Int. J. Cancer*, 120, 1769-1775

[Lai and Singh, 1995] Lai, H., and Singh, N. P., Acute, low intensity microwave exposure increases DNA strand breaks in rat brain cells, *Bioelectromagnetic,* 16, 207-10

[Linet et al., 1997] Linet, M.S., Hatch, E.E., Kleinerman, R.A., et al., Residential exposure to magnetic fields and acute lymphoblastic leukemia in children*, N Engl J Med,* 337, 1–7

[Loomis, et al., 1994] Loomis, D.P., Savitz, D.A., Ananth, C.V., Breast cancer mortality among female electrical workers in the United States, *J Natl Cancer Inst*, 86, 921–5

[Lovely et al., 1994] Lovely, R.H., Buschbom, R.L., Slavich, A.L., et al., Adult leukemia risk and personal appliance use: a preliminary study, *Am J Epidemiol*, 140, 510–17

[Michellozzi et al., 2002] Michellozzi, P., Capon, A., Kirchmayer, U., Forastiere, F., Biggeri, A., Barca, A. and Perucci, C.A ., Adult and childhood leukemianear high power radio station in Rome Italy, *Am J Epidemiol*, 155,1096-103

[Milham, 1982] Milham, S. Jr., Mortality from leukemia in workers exposed to electrical and magnetic fields (Letter), *N Engl J Med*, 307, 249

[NBOHS, 1996] National Board of Occupational Safety and Health, National Board of Housing, Building, and Planning, National Electrical Safety Board, National Board of Health and Welfare, Radiation Protection Institute, Low-frequency electrical and magnetic fields: The precautionary principle for national authorities, Guidance for Decision-Makers, Stockholm, National Board of Occupational Safety and Health

[NCRP, 1986] NCRP, Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, NCRP report No. 86, Bethesda, MD, National Council on Radiation Protection and Measurements,

[NIEHS, 1999] NIEHS, Report to Congress, Electric and Magnetic Fields Research and Public Information Dissemination Program (EMF –RAPID), NIEHS Report on health effects from exposure to power line frequency electric and magnetic fields*,* Research Triangle Park, NC, National Institute of Environmental Health Sciences, National Institutes of Health Publication No.99-4493

[NRC, 1997] National Research Council, Committee on the Possible Effects of Electromagnetic Fields on Biologic Systems, Possible health effects from exposure to residential electric and magnetic fields, Washington, DC, National Academy Press

[NRPB, 1992] National Radiological Protection Board, Electromagnetic fields and the risk of cancer, Report of an advisory group on non-ionising radiation (Abstract), Chilton, Didcot, Oxon, UK, National Radiological Protection Board (Documents of the NRPB, vol. 3, no. 1), http://www.nrpb.org.uk/Absd3-1.htm

[NRPB, 1993] National Radiation Protection Board, Restrictions on human exposure to static and time varing electromagnetic fields and radiation: scientific basis and recommendations for the implementation of the Board's Statement, *Doc NRPB*, 4 (5), 7

[NRPB, 1999] National Radiation Protection Board, Advice on the 1998 ICNIRP guidelines for limiting exposure to time-varing electric and electromagnetic fields (up to 300GHz), *Doc NRPB*, 10 (2)

[NRPB, 2004] National Radiation Protection Board, Review of scientific evidence for limiting exposure to EMFs, NRPB, 15 (3)

[NTP, 1998] NTP, Studies of magnetic field promotion in Sprague-Dawley rats, Research Triangle Park, NC, National Institute of Environmental Health Sciences, National Toxicology Program, Electric and Magnetic Fields Research and Public Information Dissemination Program (EMF-RAPID)

[Obrosov and Krylov, 1982] Obrosov, A.N. and Krylov O.A., Biological and therapeutic action of microwaves, *Vopr Kurortol Fizioter Lech Fiz Kult,* 2, 1 - 8

[O'Connor, 1980] O'Connor, M.E., Mammalian Teratogenesis and radio-frequency fields. *Proc IEEE***,** 68, 56-60

[Portier and Wolfe, 1998] Portier, C.J. and Wolfe, M.S. (eds), *Assessment of health effects from exposure to power-line frequency electric and magnetic fields: Working Group Report*, Research Triangle Park, NC, National Institute of Environmental Health Sciences, National Institutes of Health Publication No.98-3981

[Repacholi et al., 1997] Repacholi, M.H., Basten, A., Gebski, V., Noonan, D., Finnie, J. and Harris, A.W., Lymphomas in Eμ-Pim1 transgenic mice exposed to pulsed 900MH electromagnetic fields, *Radiation Research*, 147, 631-40

[SAGE, 2007] Stakeholder Advisory Group on ELF EMFs, Precautionary approaches to ELF EMFs: First Interim Assessment: Power Lines and Property, Wiring in Homes, and Electrical Equipment in Homes, R K Partnership LTD UK, http://www.rkpartnership.co.uk/sage/

[Sage C., 2008] Sage, C., Bioinitiative working group Report 2007, Setting prudent public health policy for electromagnetic field exposures, *Rev Environ Health*, 23 (2), 91-117

[Savitz and Loomis, 1995] Savitz, D.A. and Loomis, D.P., Magnetic field exposure in relation to leukemia and brain cancer mortality among electric utility workers, *Am J Epidemiol*, 141,123–34

[SCENIHR, 2007] European Commission, Scientific committee on Emerging and Newly Identified Health Risks, Possible Effects of Electromagnetic Fields on Human Health, Brussels, European Commission DG Health and Consumer Protection

[Slovic, 1987] Slovic, P., Perception of risk, *Science*, 236, 280–285

[Theriault et al., 1994] Theriault, G., Goldberg, M., Miller, A.B. et al., Cancer risks associated with occupational exposure to magnetic fields among electric utility workers in Ontario and Quebec, Canada, and France: 1970–1989, *Am J Epidemiol*, 139, 550–72

[US Congress, Office of Technology Assessment, 1989] US Congress, Office of Technology Assessment, Biological effects of power frequency electric and magnetic fields—background paper, Washington, DC: US GPO (Pub. no.OTA-BP-E-53), http://www.ota.nap.edu/pdf/data/1989/8905.PDF

[Wertheimer and Leeper, 1979] Wertheimer, N.and Leeper, E., Electrical wiring configurations and childhood cancer, *Am J Epidemiol*, 109, 273-84

[WHO, 2002] World Health Organization, Precautionary Principle Workshop, Luxembourg

[WHO, 2005] World Health Organization, Environmental Health Criteria no 238: Extremely Low Frequency Electromagnetic Fields Task Group Draft, Oct 2005

[WHO, 2007] World Health Organization Environmental, Health Criteria No.238 Extremely Low Frequency Electromagnetic Fields

[WHO, 2003] World Health Organization, International Standards Database, http://www.who.int/docstore/peh-emf/EMFStandards/who-0102/Worldmap5.htm

[Zmirou et al., 2003] Zmirou, D. et al., Mobile telephones, base stations and health, Current state-of-art knowledge and recommendations, A report to the Director General of Health of France

International Risk Governance Council

Chemin de Balexert 9
1219 Châtelaine
Geneva – Switzerland

www.irgc.org

Tel.: +41 22 795 17 30
Fax: +41 22 795 17 39