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Health Risks of Electromagnetic Fields. Part III: Risk Analysis

Lynn M. Brodsky,[2] Riadh W. Y. Habash,[1] William Leiss,[3] Daniel Krewski,[1] & Michael Repacholi[4]

[1]McLaughlin Centre for Population Health Risk Assessment, Institute of Population Health, University of Ottawa, Ottawa, Ontario, Canada; [2]Risk Management Unit, Senior Medical Advisors Bureau, Therapeutic Products Directorate, Health Products and Food Branch, Health Canada, Ottawa, Ontario, Canada; [3]School of Policy Studies, Queen's University, Kingston, Ontario, Canada; [4]Department of Protection of the Human Environment, World Health Organization, Geneva, Switzerland

Address all correspondence to Riadh W. Y. Habash, McLaughlin Centre for Population Health Risk Assessment, Institute of Population Health, University of Ottawa, One Stewart Street, Room 320 Ottawa, Ontario, Canada K1N 6N5; rhabash@site.uottawa.ca

ABSTRACT: The management of potential health risks from electromagnetic (EM) fields presents both scientific and nonscientific challenges. When the scientific evidence is ambiguous, as is the case with EM fields, expert judgment of this evidence becomes particularly important. This article provides biomedical researchers with a comprehensive assessment of the status of EM health risk based on our two previous articles [Parts I and II, *Critical Reviews in Biomedical Engineering,* Volume 31, Issue 3]. Ambiguous evidence also necessitates rigorous public debate. This article also discusses effective risk communication approaches that play a key role in the EM risk issue. Because of uncertainty about health risks associated with EMF exposure, the public is more likely to experience difficulty in evaluating the available information and rely more on perceptions than facts when drawing conclusions. Even the most effective risk communication approaches are not likely to clarify all of the subtleties surrounding EM fields as a population health issue. Thus it is essential that all stakeholders involved in this issue participate in developing consensus solutions.

KEY WORDS: electric and magnetic fields, radio frequency radiation, risk perception, risk communication, risk management.

I. INTRODUCTION

Modern technology offers powerful tools to stimulate a range of benefits for society, in addition to economic development. However, technological progress in the

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broadest sense has always been associated with hazards and risks [WHO, 2002]. Traditionally, risk has been defined from a technical perspective—namely, the product of the probability and consequences of an adverse event. In this case, the adverse event would be exposure to electric and magnetic fields (EMFs). These technical assessments are portrayed as representing the actual risks. However, this approach ignores essential social, economic, and cultural dimensions of risk assessment and management. A broader set of criteria must be used in order to obtain an accurate representation of risk.

Electromagnetic (EM) fields, including both electric and magnetic fields and radio frequency radiation (RFR), have become a driving force of our civilization through their numerous applications in the workplace, in the home, and in the external environment. Most public exposure to EM fields comes from electrical power generation, distribution, and use; transportation and telecommunication systems; scientific, medical and industrial equipment; radar devices; radio and television broadcast facilities; and mobile phones and their base stations.

EM fields might have a biological effect on human cells, which may disrupt cellular processes and in turn lead to adverse health consequences. As the reliance on technologies involving EM fields has increased, so has the public's concern over possible related health risks. This is due to our lack of understanding of the health consequences of increasing levels of exposure of population to EM fields. However, there are several organizations that have initiated research programs to study this issue and thus improve our understanding of the health risks and our ability to manage them.

Risk analysis is implicitly or explicitly used as the foundation of a large number of standards, including those related to environmental protection, occupational safety and health, food safety, medical devices, drugs, and others [Moghissi et al., 2003]. The risk analysis process can be logically divided into three clear and distinct categories: (1) risk assessment; (2) risk management; and (3) risk communication [AAES, 1996].

In recent years it has become widely recognized that a number of determinants (including social and behavioral factors, environmental and occupational exposures, biology and genetic endowment, and health services) affect individual health status and that the health status of individuals and of entire populations are linked. At the same time, risk science has emerged as an important new discipline for the assessment and management of health risks [Krewski et al., 2003].

In order to effectively address potential health risks associated with EM fields, it is important to have (1) a clear understanding of the biological and health effects of EM field exposure; (2) a risk management plan highlighting the possible undesirable consequences of EM field exposure, incorporating the key elements of both risk assessment and risk perception; and (3) effective communication of the biological and health effects of EM exposure and the risk management plan to the public.

In August 1998, an international panel of experts gathered in Ottawa, Canada, to discuss EM issues and address the above three components. A summary of this meeting and a comprehensive review of major research findings in the various related areas, which have been published in full elsewhere [Parts I and II] have been considered for discussion in this article. The goal of this article is to provide biomedical researchers with an overview of EM exposure–health risk assessment. In addition, the article cites a representative selection of reviews and recent research articles that may guide the reader to further references. An evaluation of the literature has been provided in order to develop a sound risk assessment to describe the possibility of adverse health effects from exposure to EM fields. Particular attention is paid to measured and perceived risk as part of a thorough risk management agenda.

II. RISK ASSESSMENT

Risk assessment is an organized process used to describe and estimate the likelihood of adverse health outcomes. Quantitative risk assessment estimates the hazard for an exposure or situation that cannot be measured directly. This process involves several steps: (1) hazard identification (situations that threaten human health); (2) exposure assessment (exposure to hazard is quantified); (3) dose response analysis (amount of exposure that causes harm); and (4) risk characterization (combination of above). For a particular hazard, exposure is combined with dose response to predict a risk for an individual or population.

Risk assessment is a scientific process [NRC, 1983] and, ideally, is entirely free of nonscientific parameters. As currently performed, much of the scientific information upon which risk assessment is based falls into the category of scientific extrapolation and scientific judgment [Moghissi, 2003].

II.A. Scientific Evidence and Extrapolation

Explicit distinctions should be made between the concepts of EM interaction mechanisms, biological effects, and health hazards, consistent with the criteria used by international bodies when making health assessments [Repacholi and Cardis, 1997]. Biological effects occur when EM fields interact to produce cellular responses that may or may not be perceived by people. Deciding whether biological changes have health consequences depends, in part, on whether they are reversible, are within the range for which the body has effective compensation mechanisms, or are likely to lead to unfavorable changes in health.

Two major research programs were launched during the 1990s. The US National

Institute of Environmental Health Sciences (NIEHS) and the Department of Energy (DOE) were commissioned by the US congress in 1992 to develop a comprehensive research program, and together they formed the Electric and Magnetic Fields Research and Public Information Dissemination (EMF RAPID) Program. This five-year program was supported through federal and private funds and focused on health effects, education, and assessment of health risks [NIEHS, 1998]. In 1996, the World Health Organization (WHO) established the International EMF project, which ends in 2005. The mandate of these programs is to conduct targeted research that will permit improved health risk assessments to be made and identify any environmental impacts of EM exposure.

WHO defines health as the state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity. Not all biological effects are hazardous. Some may be innocuously within the normal range of biological variation and physiological compensation. Other may be beneficial under certain conditions, and the health implications of others may be simply indeterminate. A health hazard was generally defined to be a biological effect of EM exposure outside the normal range of physiological compensation and adverse to a person's well-being [Repacholi and Greenebaum, 1999].

While there is a general understanding of the biological effects of EM energy, there is still much to be learned about its long-term health consequences. EM exposure induces circulating currents inside the human body, while RFR causes thermal effects. Nearly all regular electrical appliances and wireless equipment produce EM fields far weaker than those required for inducing currents or producing heat [Habash, 2001, 2003a,b].

Biological studies have shown that weak EM fields can have effects on few biological processes. On their own, these effects do not appear to present a serious health risk. However, their long-term impact is unknown. The level of association between EM exposure and adverse health effects, although limited, has a considerable public impact. Limitations are partly attributed to a gap of knowledge. Further research is needed in many areas in order to better assess the health risk. These include laboratory studies of cells and animals, clinical studies of humans, computer simulations, and human population (epidemiological) studies. No single study or class of study provides the entire answer. Often the results of studies are inconsistent and/or have not investigated the characteristics of the dose–response relationship (field strength, threshold, and exposure duration) and sometimes have found responses only in exposure "windows"—ranges above and below which no effects are seen [Repacholi and Greenebaum, 1999].

Unlike clinical studies, animal studies investigate the response of nonhuman species to EM exposures under laboratory conditions. Animal studies are unable to address many human exposure factors that are sociologically or geographically based, such as personal use of appliances. There is also some uncertainty about the ability to extrapolate evidences from animal studies across species. However, it is widely accepted that the demonstration of an effect in one species increases the plausibility of a similar effect in another.

Cellular studies provide an understanding of the potential physiological alterations at the basic cellular level and are necessary in the assessment of the human health effects of chronic or long-term EM exposure. In assessing the significant amount of data assembled and the wide range of cases studied, the general conclusion seems to be that the current studies indicate no evident pattern of increased health risk associated with EM fields [Parts I and II]. However, there might be rational grounds for possible suspicion of health risks with long-term exposure to EM fields. In order to clarify this matter, further research is required. The inconsistencies among laboratory data, human data, and interaction mechanisms severely complicate the interpretation of the research outcomes. Given the complexity of living organisms, it is difficult to apply and correlate knowledge from these sources.

II.B. Scientific Judgment

The scientific literature suggests that there is no solid evidence for a link between EM fields and adverse health effects. However, the health consequences may not become apparent until years of exposure have accumulated. With chronic diseases such as cancer, it is impossible to establish in just a few years any "proof of risk" or "proof of safety" that can be sustained "beyond all reasonable doubt." This reflects the dilemma of risk assessment.

In completing the risk assessment, one must consider the subset of possible health risks of EM exposure in our daily life that is subject to scientific uncertainty. The pervasive and complex character of EM fields in our environment makes it impossible to ignore even the most remote suggestion of such a risk. More research should be done to (1) determine whether any health effect can be substantiated and related to EM fields, and (2) clarify the relevance of research results. Attention should also be paid to the impact of bias (selection, reporting, and publication) on the existence of health risk. With this information, the scientific community will be able to provide more thorough analyses of health risk and share the information with the public and authorities.

III. RISK PERCEPTION

In trying to understand people's perception of risk, it is important to distinguish between a health *hazard* and a health *risk*. A hazard can be an object or a set of circumstances that could potentially harm a person's health. Risk is the likelihood, or probability, that a person will be harmed by a particular hazard [WHO, 2002].

The public will likely consider other factors in addition to the technical ones considered for a scientific assessment. While they may include the probability of harm in their view of risk, they will also incorporate the social, political, economic, and cultural consequences. The psychometric approach (Bradbury, 1989) expands upon the technical approach and attempts to identify the cognitive, emotional, and social/demographic aspects of public perceptions of risk. This broader and more meaningful approach to risk evaluation (termed *risk perception*) provides insight into why public assessment of risk differs from the technical assessment and can help explain the public outrage often associated with new technologies.

There are many factors that shape an individual's perception of risks, including age, sex, and cultural/educational backgrounds. In addition, specific characteristics of the risk, such as voluntariness, fairness, and controllability of exposure, as well as familiarity with the technology can influence risk perception. Exposure to EMF can be considered voluntary among cell phone users and involuntary among nonusers. As a result, cell phone users will likely perceive the exposure risk from base stations as lower than nonusers will. In addition, the nonusers will consider EMF exposure as unfair, and this will also alter their perception. The risk will also be perceived as higher by the public if power lines or base stations are installed in their communities without prior discussion or consultation. EMF technology is new and difficult to understand, and the potential health effects are not well defined. This unfamiliarity of EMF technology serves to increase the perceived risk. Consideration of these factors may explain local concerns, possible biases, or assumptions toward the technology. Careful attention to the nontechnical risk dimensions of any project allows policy makers and managers to make informed decisions as part of a thorough risk management program [WHO, 2002].

Risk assessment and risk perception both provide valuable insights into risk management. Traditionally, risk assessment has played a greater role in this process because committees established to deal with this issue are made up of scientific experts. However, poor communication of these risks to the general public has led to a call for the development of a new model for risk management. Approaches to risk differ considerably between technical experts and the general public. Technical experts focus on the quantifiable level of risk and view reasonable risk taking and technological innovation as necessary aspects of social progress. The general public focuses on the safety issues surrounding a particular project and any associated community health risks.

Regardless of how much scientific evidence there is, authorities need to consider the degree of public concern, even if it is low, about the possible risk of EM exposure and how it compares with expert assessment. The challenge of risk analysis will not be resolved by scientific knowledge alone. Reaching beyond a technical assessment of risk and moving toward a more psychometric approach is necessary if the legitimate concerns of the public are to be recognized.

Graham [1998] argues that the public has widespread misperceptions of potential dangers to their health, safety, and the environment. This may be a result of media misrepresentation of potential health hazards. In some cases, serious hazards (such as tobacco smoking or exposure to lead) have been neglected, while less well-established risk (such as the potential cancer risk from chloroform in drinking water) have attracted media attention. EM exposure is one such issue. While some studies report weak links between EM fields and cancer, others provide no such evidence. This makes it difficult for the public to sort out the risk associated with EM exposure. It is essential that reforms to current risk policies be introduced to ensure that they continue to protect the public.

Graham suggests five reforms to strengthen the current risk assessment practices. These reforms are intended to promote greater understanding of risk.

1. The first reform involves incorporating the best available scientific information. This would involve rapid incorporation of new information in risk management policy development, ensuring that risk management decisions are based on up-to-date information.

2. Because scientific knowledge concerning risk is sometimes incomplete, analyses involving probabilistic methods of uncertainly should be employed.

3. If some individuals face greater risk than others, agencies should make these citizens aware of the differential danger. Distributional methods for analyzing variation in risk among population subgroups can be used for this purpose.

4. The public also needs to be properly alerted to the actual risks involved. Analogies often provide a useful way for the public to assess the risk associated with a particular danger. In addition, it is valuable to express the risk relative to other risks faced in everyday life.

5. When assessing risk, it is also essential that a broad range of potential human health and environmental effects be considered. Traditionally, risk is linked to mortality, but effects on quality of life and the environment must be addressed. This is where the psychometric approach can be used to effectively identify the nontechnical determinants of public risk perception.

Because resources are by their nature limited, it is essential that spending reflect relative risk. Hazards need to be ranked on a regular basis according to their relative danger and our ability to effectively reduce this danger. One must consider the feasibility and cost effectiveness of risk reduction strategies. It is also essential to educate the public about these issues. Effective risk communication will only occur once the public is well versed in the concepts of relative risk and risk assessment.

IV. RISK MANAGEMENT

Today, risk assessment methods are widely applied in industrial and government regulatory applications involving new and existing technologies. These contribute to the development of risk management policies and strategies focusing on technological change [Krewski et al., 2003].

Risk management is fundamentally a societal decision [AES, 1996]. It includes not only the outcome of risk assessment expressed in characterized risk, but also numerous other parameters, such as cost/benefit and risk/benefit analyses, views of stakeholders, sociopolitical factors, and other nonscientific judgments [Head, 1986; Fischhoff et al., 1983].

IV.A. Involving the Public

Love et al. [2002] have classified the public, including stakeholders, into several categories: (1) personally impacted; (2) administratively impacted (regulators, permit writers, elected officials); (3) generally concerned (interest based on ideological, philosophical, moral, religious, and other beliefs) stakeholders; (4) process-concerned stakeholders consisting of those who are concerned over the appropriate role of stakeholders in the decision process; and (5) the uninvolved public. The authors recommend an affirmative outreach to ensure the participation of personally impacted stakeholders in the risk management process. They suggest that the next priority should be given to the inclusion of administratively impacted stakeholders. Generally concerned and process-concerned stakeholders should be accommodated after the other two categories have been heard.

Two suggested risk management approaches stress the importance of involvement in risk management. The NRC 1983 model incorporates analysis (traditional risk assessment) along with deliberation (communication, discussion, and debate) [NRC, 1996]. The advantage of this framework is that it requires input from both scientists and stakeholders. The second framework is the US Presidential/Congressional Commission of Risk Assessment and Risk Management's Framework for Environmental Health Risk Management (FEHRM). It views risk management as a six-stage cycle, with stakeholder collaboration at the center, linking and interacting with all of the other stages of risk assessment and management [Presidential/

Congressional Commission, 1997]. Both of these models are progressive and ensure that the public's perception of risk is integrated into the risk management plan [Gray, 1998].

It is important to involve the public in risk management decisions. The experts need to listen to the public because in a democratic society, these stakeholders have a right to be heard. In addition, their views will reflect values about risks. This is currently lacking in the risk assessment approach. Allowing stakeholders to voice their opinion will also enhance communication. While this is initially time consuming, it will produce a more sound management plan in the long run. Finally, incorporating more diverse points of view will only enrich the final discussion and debate [NRC, 1996].

It is important that the public play a more active and progressive role in the risk management process. Chess [1998] suggested that regular public meetings should be held, citizen advocacy councils should be established, industry's commitment to the process should be improved, and public participation should be evaluated. The author also stressed the importance of early involvement by the public so they have an opportunity to play a role in final outcomes.

Even if the risk associated with a perceived hazard is low, the affected public will view it as unacceptable if industry officials have not shared information and allowed public involvement in project planning. Public participation in risk management offers many advantages to industry. It will provide an opportunity to defuse public anxiety associated with the technology, enhance public trust, improve industry credibility, create a positive working relationship between industry and the public, facilitate cooperation, and ultimately help the organization acquire regulatory approval. While this seems to be a logical step in project planning, it is not included in many management plans.

Sour gas drilling in Calgary illustrates the value of public participation in risk management. In 1984, Canadian Occidental Petroleum (COP) adopted the traditional approach (no public involvement) and submitted a proposal to drill sour gas wells adjacent to a residential area in northeast Calgary. While the proposal fully met regulatory requirements, the application triggered outrage from the community. The media also got involved, and a call for reassessment of the project ensued. However, a press conference, which presented the reassuring findings of the reassessment, failed to impress the public.

In 1999, COP prepared a new drilling application. In addition, they also incorporated a major public involvement plan so they could work with the major stakeholders and develop a proposal that was sensitive to the needs of the community. The response was overwhelming. Representatives from 18 community associations formed a stakeholder committee to identify and address all the issues and questions of concern to the public and review COP's proposal. During a series of consultations, the stakeholders developed a general consensus and recommended that the sour gas drilling could proceed on the condition that certain recommendations were accepted.

While the situation in Alberta demonstrated a clear progression in the attitudes of industry and consequent benefits, such has not been the case in Quebec. Beauchamp [1998] traced subtle changes in risk management stemming from interactions among Hydro Quebec, scientific experts, and the government. There was only limited involvement of the public.

The construction of high power transmission lines (315 kV and higher) in Quebec is subject to an environmental impact assessment. Once the assessment is complete, its results are made public, and public hearings can be held at the request of individuals or institutions. The Minister of the Environment and Wildlife then mandates the Bureau d'Audiences Publiques sur l'Environment (BAPE) to conduct a public hearing.

In the 1980s, Hydro Quebec made numerous requests to the Quebec government to erect power lines. Even though experts were hired to assess the health effects, their recommendations were largely ignored, and the construction of the power lines proceeded. However, the government did monitor Hydro Quebec. They encouraged Hydro Quebec to conduct epidemiological studies and take into account human exposure to EM fields when constructing their power lines.

In 1992, experts from Laval University presented a report on the relationship between EM fields and human health. This served to heighten public awareness of the associated risk. While the project received approval, the government recommended a feasibility study to assess the human health effects of EM exposure. While Hydro Quebec demonstrated greater accountability to the public with each subsequent proposal, they still continue to build their power lines with little regard to public objections. According to Beauchamp, it is unlikely that the government will convince Hydro Quebec to change its strategy and consider the health effects, given their ambiguous nature. Because the government continues to approve Hydro Quebec's proposals, there is little incentive to change. This was particularly evident in light of recent ice storms. Because of potential critical power shortages from these storms, the government authorized the construction of three power lines without considering their environmental impact.

The EM issue is difficult to assess because scientific studies suggest no conclusive risk. However, if nothing is done, the public may view this response as irresponsible disregard for public safety. Dolan et al. [1998] recommend that until science can provide a clearer view of the issue, committees should engage the public in open discussions. Woodley [1998] argues that the public is still confused about the health risks associated with EM exposure. It is imperative that an effective risk communication program be established so the public can learn what the health risks are and what needs to be done to reduce these risks. One approach that was recommended is prudent avoidance, discussed below.

IV.B. Public Meetings/Citizen Advocacy Councils

While public meetings can provide a powerful forum for individuals and groups to voice their concerns, they are not encouraged for a number of reasons. Chess argued that they are not always effective because all individuals may not have an opportunity to express their views, representation may be biased in terms of demographics, issues are often oversimplified, and there is not always time to properly convey ideas.

Citizen advocacy councils remedy some of these problems. They are a better medium for input of ideas and permit better communication, information exchange, and interaction among individuals. However, they require a large commitment of time, and the councils may not represent the prevailing viewpoints. The success of these councils is also contingent upon the offending industry.

It is essential to have the full support of the industry. There are a number of ways in which industry can improve the success of the process. They can hold public meetings early on and supplement public meetings with group discussions. Meetings should be held in neutral areas to enhance the comfort of all involved. It is important to evaluate the success of public participation and look for ways to improve the process. Industry representatives can assess the relationships among stakeholders, reviewing cooperation and conflict between the parties and how it was handled. This feedback will be helpful in managing future interactions among stakeholders.

One problem associated with incorporating a variety of viewpoints into a risk management plan is that it can lead to differences in the evaluation of risk. Risk enables one to evaluate undesirable future consequences of a particular hazard. Scientists offer an objective view of the risk, which they define as a function of the probability and the seriousness of the undesired consequences.

Two major ingredients are necessary for success. First, the level of risk must be identified. Second, legislation must be proposed to manage or limit exposure. In order to characterize and communicate the risk and uncertainties associated with EM fields, Bailey [1998] recommends a probabilistic approach. He argues that the scientific basis of EM exposure limits needs to be reexamined and carefully presented to the general public because misconceptions are prevalent.

IV.C. Consistent Risk Management

Agencies involved in developing risk management must be more consistent in their decision making. For instance, the US Environmental Protection Agency (EPA) [EPA, 1990] decided to implement reforms that would reduce the incidence of cancer, while the Food and Drug Administration (FDA) [Gelles, 1993] decided to forego reforms in HIV/AIDS testing in favor of cost cutting. The EPA's decision led to an incremental cost/effectiveness ratio of \$6.25 to \$35 million per case of cancer avoided. The FDA rejected an initiative that would have led to a cost–effectiveness ratio of $12 to $24 million per case of HIV/AIDS avoided. Guidelines of these magnitudes of investment in health protection need to be adjusted to better reflect the public's willingness to pay.

IV.D. Precautionary Approaches

There has been an increasing movement to adopt precautionary approaches for management of health risk in the face of scientific uncertainty. Several risk management policies promoting caution have been developed to address public concerns in the face of uncertainty. These include both prudent avoidance and the precautionary principle [WHO, 2000].

1. Prudent Avoidance

In 1989, the EM issue became a public concern, and in 1992, it became an important risk communication issue. However, regulators and scientists were unprepared to respond. They adopted "prudent avoidance" as in interim policy option [Foster et al., 2000]. Prudent avoidance is defined as taking steps to keep people out of EM fields by rerouting facilities and redesigning electrical systems and appliances. This policy refers to taking certain steps to reduce exposure that may be done with minimal cost, until more is known about the possible health effects. In addition, the policy encourages the adoption of individual or societal actions to avoid unnecessary exposures to EM fields that entail little or no cost [Habash, 2001].

Prudent avoidance becomes an attractive option because it serves to minimize exposure to the perceived problem with minimal costs. For instance, no radical changes to power lines or base stations should be implemented until science has shown clear evidence that there is a health risk. By acting prudently, management can embrace a wide range of sensible actions that take into account the research results and community concerns.

Dolan et al. [1998] provided a number of prudent avoidance strategies that can be implemented for design and construction of power lines. These include monitoring the distance between these lines and population centers, provide shielding from EM fields, and arranging the lines and configuring the conductors to minimize the EM exposure. Another option may be to locate the lines underground, but this is very costly and thus not necessarily prudent.

An excellent example of the prudent avoidance policy in action is found in Ireland. McManus [1998] described how this policy was adopted when dealing with the EM issue. When constructing new power lines, power utilities ensure that they are at least 50 meters from any building. When a new housing project was encroaching on existing power lines, prospective home buyers were encouraged to call the Department of Public Enterprise to express their concerns. All calls were carefully handled, and information packages were sent to all callers to ensure the public was made aware of the issues. They even surveyed and measured the EM fields at the new house and the concerned caller's current home to permit comparisons.

2. Precautionary Principle

Another recent process introduced to risk management is the precautionary principle. WHO has described the precautionary principle as "intended to prevent or limit possible harm caused by agents or activities before it has been established that the activity or exposure constitutes harm to health."

One form of the principle dictates inaction when action may pose a risk. It can also involve choosing less risky alternatives when available and for taking responsibility for potential risks. The precautionary principle is another management tool that could be adopted to deal with the health risks associated with EM exposure. It reflects the need to take action at reasonable expense and with reasonable consequences for a potentially serious risk without awaiting the results of scientific research.

The precautionary principle is an extremely conservative decision that leads to prudent actions in the face of uncertainty. This principle has been incorporated into numerous international treaties and declarations throughout Europe and several countries. In fact, Italy, Switzerland, and New Zealand have adopted it to help set precautionary limits for EM exposure.

While Foster et al. [2000] support the use of the precautionary principle as a policy tool for environmental and health protection, they argue that its greatest problem is its extreme variability in interpretation. To deal with this criticism, they offer a clear set of guidelines that can be used when implementing the principle. These guidelines address the proportionality of risk (measures appropriate to the desired level of protection) and call for nondiscrimination and consistency when dealing with comparable risk. They also suggest a cost/benefit analysis of action versus inaction and a close examination of recent scientific development. The authors view the precautionary principle as part of the risk management decision making process and argue that implementation of these guidelines will reduce the ambiguity often associated with the principle.

Balzano and Sheppard [2003] argue that the precautionary principle, which has "become ever more influential in environmental and health policy in the European Union and elsewhere," still lacks an agreed-upon definition and practical guidance on how policy can be derived without undue arbitrariness." Nevertheless, EMF regulations in Switzerland and Italy incorporate special exposure limits for sensitive use locations such as playgrounds and schools. These limits are up to 100 times lower than the EMF exposure limits for the general public. In the UK, the National Radiological Protection Board recommended the government initiate a study to evaluate application of the precautionary principle to EMF.

V. RISK COMMUNICATION

Today, communication with the public about environmental risk from technology plays an important role [WHO, 2002]. According to the US NRC, risk communication is "an interactive process of exchange of information and opinion among individuals, groups, and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risks that express concerns, opinions, or reactions to risk messages or to legal and institutional arrangements for risk management."

Wiedemann [1998] argues that many of the problems surrounding the EM issue involve communication. The general public is not properly informed of the risks associated with EM fields, and as a consequence, anxieties and fears about this technology abound. He provides an excellent set of guidelines that can be used to remedy this situation.

It is essential that any communication involve a comprehensive discussion of the risks associated with EM fields as well as the technology itself. Key technological questions that must be answered in a brief and concise manner include the following: (1) How does EM technology function? (2) What power levels are used with EM sources? (3) What is the difference between thermal and nonthermal effects of EM fields? (4) What is the difference between EMF and RFR and how do they differ with respect to their effects? When answering these questions, the expert should ensure that they (1) classify questions and problems in terms of their importance to the communication partner, (2) explain in a comprehensible manner using simple language, (3) avoid lecturing, and (4) provide assistance in understanding.

Clear and effective discussions about EM technology will serve to facilitate further communication about the risks associated with EM fields. The next step involves the planning and organization of the stakeholder discussion. Clarification of the discussion's goals at the outset will enhance the process. These goals could include (1) fair distribution of risks, (2) legitimizing risk taking expectations, (3) awareness of the EM issue, and (4) knowledge of the interests, concerns, fears, and attitudes of other group members.

Effective communication demands a clear set of rules. It is essential that all members have the opportunity to express their viewpoint, discuss views of others, respond to criticisms, and ask questions.

Because communication about EM technology will form an essential part of this process, it is important that the explanations provided are clear and unambiguous. Once this background has been firmly established, it will be easier to discuss the risks associated with EM technology.

V.A. Role of Communication in Risk Assessment

Bailey (1998) provides concrete guidelines on how to ensure the development of a comprehensive EM risk assessment. Good communication is essential. He argues that the experts need to be responsive to the concerns and interests of the stakeholders. In addition, when assessing the health risks of EM fields, scientists need to follow guidelines, such as those developed by the EPA [EPA, 1996] and the International Agency for Research on Cancer (IARC) [IARC, 1992]. This will ensure the process is based on solid scientific principles and not influenced by any of the stakeholder groups. An exhaustive review of available data is necessary to ensure an accurate and comprehensive assessment. It would also be useful to document the procedures used to prepare the risk assessment, thereby allowing an evaluation of the entire process. Bailey also recommends a transparent evaluation to permit further scrutiny and evaluation by a broader audience. This will serve to strengthen the risk assessment. To further ease stakeholder apprehension, Bailey suggests that scientists acknowledge the uncertainties surrounding their claims and prepare their assessment using clear and unambiguous language.

V.B. Role of Communication in Risk Management

Incorporating risk communication into models of risk management may appear to be more time consuming than simply relying on risk assessment. However, greater emphasis on communication in the long term can simplify matters.

Difficult situations are likely to arise, and dealing with these in the early discussion or planning stages will only serve to enhance the overall risk management plan. Properly planned discussions will enhance credibility and provide greater understanding among the individuals within the group. It is essential to evaluate the effectiveness of the communication and note where improvements can be made.

Leiss and Paoli [1998] highlight the importance of establishing effective risk communication in risk management. They argue that risk communication about EM issues is weak, because there is insufficient explanation of terminology and, more importantly, the risk associated with EM fields. The authors suggest that risk communication occur during the planning stages of a project, not after transmitting stations and antennae have been installed.

Kruk [1998] notes the merits of involving the general public and the media in environmental risk management. He argues that EM fields have particular characteristics that can elicit alarm from the public. EM fields are thought to pose a health threat to those particularly vulnerable in society, children, and the elderly. EM fields can also be perceived as an ongoing, long-term danger. While power lines and communication towers are visible, EM fields are invisible and not readily detectable. Technologies involved are new, unfamiliar, and often intimidating. There is also an inequitable and morally objectionable distribution of EM benefits and risks, as reflected by individuals living close to high-voltage power lines.

While society has become increasingly informed and educated about environmental issues and more demanding about consumer information access, people are still anxious about scientific and technological innovation. Genetically modified foods, cloning, bovine somatotrophin, and EM fields represent several of the recent advances that have the potential to create uneasiness among the general public simply because of poor communication.

The EM background environment must be carefully assessed. Because of more assertive consumer activism, there is widespread skepticism and uncertainty about risk mismanagement. For instance, the public has not always been properly informed of the health risks associated with asbestos, tobacco, and silicon breast implants. All of these were initially believed to be safe.

Bovine spongiform encephalitis (BSE or mad cow disease) scares in Britain have led to uneasiness among the public about things as basic as their own food and food processing standards. It is easy to see how the alleged health effects of EM fields are equated with tobacco and BSE.

V.C. Media Coverage

Conflicting safety reports from the experts and sensationalistic media coverage frequently add to anxiety. Media reports often lack the scientific/industrial knowledge necessary to accurately assess the facts. Also, because of time and space constraints and the fact that sensationalism sells, there is often a biased presentation of the information.

Media coverage must also be carefully monitored. It is often irresponsible, using scare tactics to enhance arguments. Sensational headlines such as “my mobile gave me cancer” do little to dispel the myths of EM dangers. They fail to quantify the risks associated with EM fields, and their coverage often focuses on nontechnical issues. Reports often have an anti-industry tone. This is likely due to their information sources, rather than industry experts. Scientists have an important role in shaping public perception because they are generally viewed as having greater credibility. It is the responsibility of scientists to provide accurate information to the media and balance the information flow between the media and activists.

V.D. Role of Industry

Industry also influences public perception, but not always in a positive way. The safety of new technology has not been properly addressed by industry; as a consequence, fear among the public is widespread. Industry is urged to take a more active role in public education to improve their failing credibility and avoid costly commercial consequences.

Industry should think carefully when communicating with the public. It is important to ensure that the person or organization is experienced, listens to public concerns, has integrity, and communicates in simple language (not very technical or defensive). The communicator must be more responsible when reporting risks associated with EM technology. There is often uncertainty and disagreement among industry experts concerning the level of risk.

The importance of good risk communication between the industry and concerned residents is essential when one considers the problems encountered with mobile phones, base stations, and power lines. Base stations, for instance, continue to be a public concern even though cellular phones expose users to 1000 time stronger fields than the actual base stations [Byus et al., 1999]. People that do not use cellular phones will likely oppose the towers because they are exposed to some level of risk without any perceived benefits. While these stations are not constructed in residential areas, the public is still outraged because of poor relations with the service providers. Phone companies as yet do not recognize the merit of a monitoring service to ease public concern, particularly because it is too expensive. As a result, the public continues to protest, and the construction of new phone towers has been halted.

The WHO EMF program has been instrumental in bridging the gap between the media, industry, scientists, and the general public. WHO's publications have provided valuable and readily accessible information to concerned parties.

V.E. Role of the Internet

One way to effectively communicate EM risk to the public is through the Internet. Leiss and Paoli [1998] stress the need for solid risk management practices that incorporate established risk communication when dealing with the EM issue. They argue that the Internet is a valuable resource for finding EM information and thus "aids in the empowerment of citizens."

The Internet can be used to gather resources, ask questions, and provide an opportunity for the public to become skilled interveners. It facilitates exchanges between experts and the stakeholders and forces industry to be open and accountable. Leiss and Paoli termed the Internet a "public stage with an international cast and audience." The Wireless Information Resource Centre (www.wirc.org), an independent nonprofit organization, has launched an informative website that provides up-to-date, impartial and objective information about research on the health effects of wireless technology.

Despite its many advantages, the public must exercise caution when reviewing Internet resources. Not all information is peer reviewed, and some may be simply anecdotal in nature. Also, because activists maintain many of the sites, the information may be biased.

VI. DISCUSSION

The subject of EM health risk is of broad interest particularly to the scientific community. The mission of the authors throughout these three articles is based on the notion that the scientific conclusion must be based on the best available information. Reliable information comes from various sources, including peer-reviewed literature as well as reports of government agencies, private organizations, panel meetings, and others that have not been subjected to independent peer review.

Part of this article presents the conclusions of an international panel of experts gathered in Ottawa, Canada, to discuss issues related to EM human risk and to address matters related to risk communication and management plan to the public. A weight-of-evidence evaluation of recent literature [Parts I and II] indicates that the evidence for a casual association between exposure to EM fields and adverse health effects is weak. The evaluation presents a number of risk management challenges.

In spite of a vast array of studies investigating the association between EM fields and human health, a number of unresolved issues still remain. These continue to raise public concern that there could be some degree of risk from EM exposure. Science has been under fire for not addressing the key issues surrounding the risk.

At the scientific level, characterization of potential adverse health effects associated with exposure to EM fields has been difficult. Following extensive efforts by the scientific community, including well-funded broad-based research programs coordinated by national and international organizations, epidemiological and toxicological studies conducted to date have provided ambiguous evidence of human health hazards.

The management of EM risks is complicated not only by scientific uncertainty about the level of potential risk, but also by public perceptions of risk. Public concern is heightened by a lack of understanding of EM fields, which cannot be seen or sensed, but are ubiquitous in our environment. Public concerns may also be heightened by media reports on EM fields, which are generally not based on a comprehensive evaluation of the weight of scientific evidence in support of a documented population health risk, but rather on reports of individual studies that might attract the attention of the public.

Effective risk communication, particularly between experts and the public, is critical to the successful management of subtle and complex environmental health issues such as EM fields. However, public misperceptions of risk cannot be corrected by designing more elaborate communication programs in which the scientific "facts" are presented in a way that is understandable to the majority of the general population. Even if this could be accomplished, effective communication of risk alone does not address issues of equity, environmental justice, or cost-effective allocation of population health protection resources.

What is needed is greater public involvement in the risk-management decision-making process, including individuals and stakeholder groups. Participation in the development of an appropriate risk management strategy can go a long way toward the achievement of consensus solutions that enjoy the support of interested and affected parties, even if all participants do not fully understand all of the scientific complexities involved in the evaluation of risk. With technologically based risks, such as those that may be associated with EM fields, industry has a particular responsibility to take a leadership role in open participatory discussions on risk management strategies. As risk management options are debated, consideration will need to be given to the level of risk that might be associated with exposure to EM fields and the attendant scientific uncertainty about EM risks. In addition to considering risk, social values and economic costs and benefits will require consideration.

The evaluation and management of potential human health risks from EM fields presents many challenges. When the scientific database is ambiguous, as is the case with EM fields, expert judgment of the overall weight of scientific evidence becomes particularly important. Because of this uncertainty about EM risks, the public is more likely to experience difficulty in evaluating the available information and rely more on perceptions than on facts when drawing conclusions. Effective risk communication techniques assume even greater importance in issues such as EM fields than in cases where risks are more clearly delineated and the need for risk mitigation actions more obvious. However, because even the most effective risk communication techniques are not likely to clarify all of the subtleties surrounding EM fields as a population health issue, it is important that all stakeholders in this issue participate in developing consensus solutions. Decisions reached with the participation of interested and affected parties need not remain static, but can be updated as new information becomes available. The need for ongoing review of interim decisions is particularly important with emerging risk issues such as EM fields, where greater clarity and understanding will accompany the accumulation of new knowledge.

Wartenberg [1998] discusses three approaches for inferring risk: weight-of-evidence review, meta-analysis, and quantitative risk assessment. The weight of evidence involves a comprehensive review of the literature, encompassing all kinds of studies. While the EPA and IARC have set guidelines on how to evaluate these studies, this process can lack objectivity. Meta-analysis includes a systematic review of the literature and use of statistical methods to combine and summarize the results of individual studies to reveal consistent patterns or discrepancies. However, quantitative risk assessment estimates the hazard for a situation that cannot be measured directly.

VII. CONCLUSION

The results of our most recent reviews [Parts I and II] have revealed that there is no conclusive and consistent evidence to suggest that exposure to EM fields can cause cancer and other adverse health effects. While research conducted to date has been unable to resolve the uncertainty about EM health risks, government and industry should take effective steps to address concerns about such risks. These include (1) independent and unbiased research to further our understanding of the potential health effects of EM fields; (2) transparency and full divulgence of data on EM emissions from various sources; (3) public access to the latest scientific research on health effects associated with EM fields; (4) communication with individuals and groups on the scientific uncertainty associated with EM; (5) an assessment of risk that reaches beyond the technical approach and considers the psychometric approach, which incorporates the cognitive, emotional, and social demographic determinants of risk; and (6) public participation in risk management actions taken in response to concerns about the potential health risks of exposure to EM fields.

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W. Leiss is the NSERC/SSHRC Chair in Risk Communication and Public Policy at Queen's University. D. Krewski is the NSERC/SSHRC/McLaughlin Chair in Population Health Risk Assessment at the University of Ottawa.

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