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The precautionary principle and EMF: implementation and evaluation

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Abstract

The precautionary principle, a recommendation to consider action to avoid a possible harm even if it is not certain to occur, is variously defined and interpreted. We present a range of definitions with an emphasis on their requirements for strength of evidence of harm and for actions to be taken. We describe the variety of approaches that have been adopted in developing policy to address the issue of possible health effects of electric and magnetic fields (EMF) in the face of scientific uncertainty. Further, we discuss specific aspects of scientific uncertainty regarding EMF health risks particularly relevant to the development of precautionary principle policy. We define and discuss prudent avoidance and other unique features of applications of the precautionary principle to EMF. We conclude with examples from EMF policy decisions of risk tradeoffs that need to be considered in developing any precautionary principle policy, and provide recommendations for better ways to define and implement the precautionary principle.

KEY WORDS: electromagnetic fields, environmental policy, precautionary principle, risk management

1. Introduction

The precautionary principle is one of many guides society can use when deciding whether to take action to protect people from possible harm. It is essentially a 'better safe than sorry' approach suggesting that action should be taken to avoid harm even when it is not certain to occur.

The choice of possible actions ranges from doing nothing to banning a potentially harmful substance or activity. Many factors can affect this choice; the severity of the potential harm and the degree of uncertainty about whether an activity or substance causes harm are among the most influential. As shown in Fig. 1, these two factors can justify a wide range of actions. The severity of harm and the degree of uncertainty are, in fact, the only factors addressed directly by the precautionary principle as it is typically posited. The severity of harm associated with a risk can vary greatly. When the harm is slight, especially if it is temporary or reversible, it may make sense to do little or nothing to prevent or avoid it. When the harm is great and irreversible or long lasting, significant action to prevent or avoid it can be readily justified. The severity of harm can refer to a large risk to a few individuals, but more often reflects an overall impact on the society or environment.

All risks are to some degree uncertain, but the degree of uncertainty varies. When there is great uncertainty about a risk, it usually makes sense to do nothing (except

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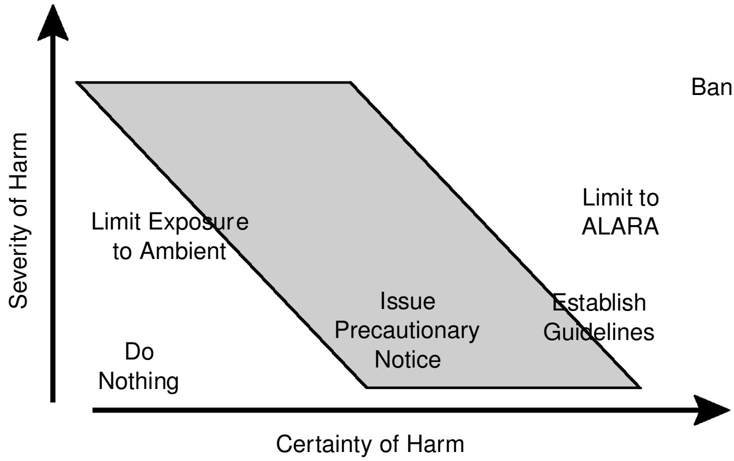

Fig. 1. Range of actions that may be taken in response to risk of harm from a practice or substance. Shaded area indicates combinations of severity and certainty of harm for which the precautionary principle may be useful. (ALARA, as low as reasonably achievable.)

perhaps attempt to reduce the uncertainty) or take steps that are easy and inexpensive and have few negative consequences. When the degree of certainty that harm is occurring is high, the substance or activity in question may be banned or replaced with something not likely to be harmful. Alternatively, severe limits may be implemented if the substance or activity is needed and an appropriate substitute is not available.

Clearly, when the harm associated with a risk is slight and its occurrence very uncertain, little or no action should be taken. Conversely, when the harm is great and there is little uncertainty about its occurrence, significant action is called for. It is in the gray area where substantial harm is postulated but certainty about whether it will occur is low, or where the degree of harm is low but the certainty is high, that policy-making is more difficult and some decision rules are needed as a guide to action. The precautionary principle provides a framework that can help provide a basis for decisions about whether to take action and what action to take in uncertain situations, if it is supplemented by other decision rules and risk evaluation.

In this paper we present various definitions of the precautionary principle, describe its application to policy regulating exposure to electric and magnetic fields (EMF), and make recommendations for future applications.

2. A brief history

The precautionary principle emerged as a decision rule for regulating environmentally hazardous activities in the Swedish Environmental Protection Act of 1969. This act – which remains in effect today – incorporates the statement that the mere risk of harm, if not remote, warrants protective measures or a ban on the activity that is possibly causing harm.

The *Vorsorgeprinzip*, or 'precaution' principle, followed in German national law in the 1970s (Von Moltke, 1987). Stating essentially that environmental policy requires a precautionary approach, the *Vorsorgeprinzip* has provided a basis for policies regulating nuclear power production, acid rain, and pollution in the North Sea.

The 1987 Ministerial Declaration of the Second Conference on the Protection of the North Sea (Department of the Environment, 1988) introduced the precautionary principle in international environmental law. This declaration limits application of the precautionary principle in marine ecology to damage likely to be caused by substances that are 'persistent, toxic and liable to bioaccumulate', even in the absence of scientific proof of damage. Subsequently, the precautionary principle was adopted in a 1992 amendment of the Maastricht Treaty on the European Union. Environmental policy in the European Community, the amendment states, 'shall be based on the precautionary principle and on the principles that preventative action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay'. The amendment does, however, require that policy development include consideration of available scientific evidence, environmental conditions, costs and benefits, and socioeconomic conditions.

Numerous other international treaties and statements of policy have incorporated the precautionary principle in one form or another. Of particular importance is its appearance in the treaties signed at the United Nations Conference on Environment and Development at Rio de Janeiro in 1992: the Convention on Biological Diversity and the UN Framework Convention on Climate Change (UN, 1992b). The Rio Declaration on Environment and Development (UN, 1992c) features the precautionary principle – with the inclusion of cost-effectiveness – as well.

National environmental law in a number of countries in addition to Germany and Sweden, in particular Australia, Canada, New Zealand, Switzerland, the US, and the UK, has begun to incorporate the precautionary principle, either explicitly or implicitly as an approach. Two examples are the 1992 Intergovernmental Agreement on the Environment in Australia and the 1994 Strategy on Sustainable Development in the UK.

3. Defining the precautionary principle

A wide variety of definitions and interpretations of the precautionary principle have been proposed. These definitions include three basic approaches.

1. Where there are threats of serious or irreversible damage, uncertainty should not be a reason for postponing action to prevent that damage.

   This definition, appearing in such documents as the 1990 Bergen Declaration and the Preamble to the 1992 Convention on Biological Diversity (UN, 1992a), would seem to many to be a watered-down version compared to others, and to provide no direct basis for action. It is, in fact, a strong statement. It could be paraphrased more positively as 'Consider taking action even if there is no conclusive evidence that harm is occurring.' This statement does not, however, provide clear guidance for determining what action should be taken under any specific circumstances. It clearly necessitates additional analysis based on other decision rules.

2. Where there are threats of serious or irreversible damage, precautionary measures should be taken even if cause-and-effect relationships are not clearly established.

Included in the 1992 Convention on the Protection of the Marine Environment of the Baltic Sea Area and other treaties and declarations, this much stronger statement essentially says 'Do something!' in the face of threatened harm. But it does not provide any clearer guidance as to what action should be taken than the first definition. What it does do is rule out taking no action. In this sense, this version (and stronger ones) appears to call for action no matter what and hence to imply that uncertainty alone justifies action.

3. Whenever an action or substance could cause irreparable/irreversible harm, even if that harm is not certain to occur, the action should be prevented and eliminated.

   This definition, found in the Swedish Environmental Protection Act (1969), requires not just some action, but extreme action that totally eliminates the practice or substance that could be causing harm. It forbids consideration of other issues, such as benefits that may result from a practice, as well as consideration of the degree of harm that may be caused and the degree of uncertainty about whether the harm will actually occur.

Although each of the above definitions appears as a precautionary principle, important differences in the requirements for strength of evidence and actions to be taken make these approaches substantively different. The precautionary principle may be adopted when there is 'sufficient evidence' that an action or substance is harmful (Treaty of Maastricht, 1992); when there is no conclusive scientific proof (Cameron and Abouchar, 1991); or when the substance or action has been suggested as a possible cause (*Rachel's Hazardous Waste News*, 1993).

Similarly, definitions of the precautionary principle imply a wide range of actions that should be taken once the strength of evidence requirement has been satisfied. These actions range from prevention or elimination of exposure (Swedish Environmental Protection Act, 1969) to adoption of cost-effective action (United Nations, 1992) to mere consideration of action. When cost-effective actions are called for, what is generally meant is adoption of the least costly action among alternatives that are equally effective at reducing harm. This definition provides no guidance as to how effective actions must be to qualify for consideration. It could be presumed that actions that are as effective as possible would be considered, with cost a decidedly secondary consideration. If, for example, one very expensive type of action could eliminate the possibility of harm, then it would be preferred over any less effective action, regardless of how much less expensive it might be. Otherwise, some other standard would be needed to decide among actions that differ in both cost and effectiveness. Examples of such a standard include a threshold test (harm must be reduced by at least some proportion, or to at least some maximum level) or a cost–benefit test (the value of the incremental reduction in harm between two alternatives must be at least equal to the incremental cost).

Another important difference in the various definitions of the precautionary principle lies in who bears the burden of proof. In some definitions, the burden of proof is shifted from the opponents of a possibly harmful action to its proponents (Wingspread Conference, 1998). Considering that uncertainty about whether or not any harm will result from a proposed action is inherent to situations in which the precautionary principle might be applied, no conclusive proof of either harm or lack thereof is possible.

However, if not taken to an extreme – that is, if the standard is one of weight of evidence rather than of absolute proof – then shifting the burden of evidence to the proponents may have the salutary effect of inducing them to obtain and provide more information about the possible harmfulness of their proposed action.

Finally, definitions of the precautionary principle reflect differing degrees of risk aversion. Those calling for prevention or elimination of harm embody a greater degree of risk aversion than those advocating consideration of action.

In the case of electric and magnetic fields, differing requirements for strength of evidence (e.g. sufficient vs conclusive) and a wide range of interpretations of the strength of evidence of possible EMF health effects have been used, as we will see later, by various review bodies. Thus the willingness of these bodies to adopt or reject the precautionary principle approach will depend not only on their evaluation of the strength of evidence, but also on the definition of the precautionary principle used. We will further discuss differences in defining the precautionary principle as they apply to the EMF issue, but first we will describe EMF science and the variety of approaches that have been adopted in developing policy for the EMF issue under conditions of scientific uncertainty.

4. The state of EMF science

The use of electricity has continued to grow throughout the industrialized world since the first public power station began operation over 100 years ago. Today, developing nations look to electricity as a primary means of creating jobs and improving the quality of life. Though electric power clearly benefits societies in countless ways, concern has been raised about the possible adverse health effects from electric and magnetic fields produced during its generation, delivery, and use.

The question of whether EMF could adversely affect human health was first raised in epidemiological studies, which have examined both occupational and residential exposures. A majority of studies have focused on cancer, particularly leukemia and brain cancer, among other health effects. Though associations have been observed in some studies, there remains considerable uncertainty about the validity and meaning of these associations. Difficulties in exposure assessment, the small magnitude of elevations in risk, the general lack of a dose–response relationship, possible uncontrolled confounding and bias, and differences between studies in specific cancers and exposures identified as the most important all contribute to uncertainty.

Studies in laboratory animals have for the most part been negative. Some cell and tissue culture studies have shown that EMF exposure can induce biological responses; independent laboratories, however, have found it extremely difficult to replicate this work. Furthermore, the relevance of EMF-induced biological responses to cancer development is not clear. Available data show that EMF do not meet the criteria established for known carcinogenic agents, that is, they do not function as either a mutagen or a complete carcinogen. After more than 20 years of research and numerous reviews by expert scientific panels, the question of whether EMF could be a cancer promoter or cocarcinogen remains unanswered. More recently, scientific inquiry has extended into non-cancer endpoints, such as cardiovascular and neurodegenerative diseases.

In the face of uncertainty, public concern about EMF, as well as the ubiquity of EMF exposure and thus the potential for an appreciable public health impact associated with even a small risk, has led to suggestions that the precautionary principle be adopted.

4.1. SCIENTIFIC UNCERTAINTY

While the precautionary principle applies by definition to situations characterized by scientific uncertainty, its application to the EMF issue is especially problematic owing to several specific aspects of EMF science. EMF science involves not only uncertainty as to whether or not exposure is associated with increased risk, but additional uncertainties as well.

First is uncertainty about the magnitude and specificity of the risk. The risk from exposure to EMF, if real, could be small but affect a large number of people. Alternatively, the risk could be large but affect only a small number of susceptible individuals. Other possibilities are simultaneous exposure to another factor, or perhaps a rare magnetic field event with a certain yet-to-be-identified characteristic, that could lead to an increase in risk. Each of these possible relationships between risk and exposure would, of course, require a substantially different set of precautions to reduce risk, making application of the precautionary principle particularly difficult.

Another important uncertainty is that it is at present unknown which aspect of exposure might be harmful. Some actions, while reducing some aspects of exposure, might inadvertently increase risk by increasing some other, as yet unknown aspect that might turn out to be the culprit. The whole concept of precautionary action in the context of electric and magnetic fields is rooted in the assumptions that less exposure is better and that reducing one aspect of exposure will also reduce any aspect that might be harmful. Neither of these assumptions is a given. In fact, some laboratory research has suggested that biological effects due to EMF vary within windows of field frequency and intensity. While such a complex and unusual pattern is unlikely and would go against some of the accepted tenets of toxicology and epidemiology, the possibility that it may be real must be considered in applying the precautionary principle to EMF.

The absence of a clearly elucidated, robust, and reproducible mechanism of interaction of EMF with biological systems and the plethora of field characteristics that could be relevant make avoidance strategies that fall short of avoiding EMF exposure entirely (which could be accomplished only by not using electricity at all) both difficult to formulate and potentially counterproductive. Since electricity is clearly beneficial to good health, as well as to numerous other aspects of our lives, not using electricity is not a viable option. Thus, unlike the situation with many toxic substances, for which substitutes might be available, this situation allows us only to strive to identify and reduce risks, if they are real, while maintaining the benefits provided by electricity.

5. Application of the precautionary principle to EMF

Governments have responded to the EMF issue in very different ways. While most have not established any standards for EMF exposure, others have developed guidelines, set local limits, or adopted a policy of prudent avoidance.

5.1. EMF GUIDELINES AND LIMITS

A number of national and international organizations have formulated guidelines establishing limits for occupational and residential EMF exposure. These organizations include

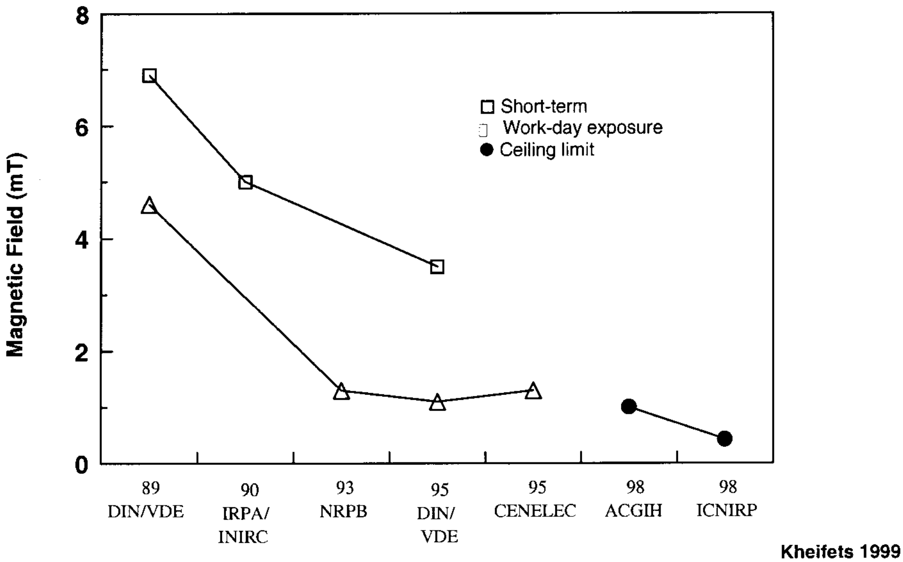

Fig. 2. Changes in occupational magnetic field exposure limits specified by national and international guidelines. DIN/VDE, Deutsches Institut für Normung-Verband Deutscher Elektrotechniker; IRPA/INIRC, International Radiation Protection Association/International Non-Ionizing Radiation Committee; NRPB, National Radiological Protection Board; CENELEC, Comité Européen de Normalization Electrotechnique; ACGIH, American Conference of Governmental Industrial Hygienists; ICNIRP, International Commission on Non-Ionizing Radiation Protection.

the International Radiation Protection Association/International Non-Ionizing Radiation Committee (IRPA/INIRC, 1990), the Comité Européen de Normalization Electrotechnique (CENELEC, 1995), the National Radiological Protection Board in the United Kingdom (NRPB, 1993), Deutsches Institut für Normung-Verband Deutscher Elektrotechniker (DIN/VDE, 1995), the American Conference of Governmental Industrial Hygienists (ACGIH, 1996), and the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998). Guidelines focus on prevention of acute neural and cardiac effects. Evidence of potential long-term effects such as cancer is considered insufficient for guideline formulation.

Earlier guidelines specified limits for the 'whole working day', with relaxed values for shorter exposures. Later guidelines (ACGIH, 1998; ICNIRP, 1998) specified momentary or ceiling limits and eliminated short-term exposure limits, which had permitted considerably higher field exposures for limited, but not insignificant, periods of time (hours). Overall, magnetic field guidelines have become progressively more stringent, culminating with the latest ICNIRP (1998) guidelines (Figure 2).

For occupational groups, the ICNIRP guidelines specify reference levels (defined as levels at which action should be taken) for electric and magnetic fields of 10 kV/m and 0.5 mT (5 G) for 50-Hz and 8.3 kV/m and 0.42 mT (4.2 G) for 60-Hz fields. For the general public, electric and magnetic field reference levels are 5 kV/m and 0.1 mT (1 G) for 50-Hz and 4.2 kV/m and 0.083 mT (0.83 G) for 60-Hz fields.

Based in part on ICNIRP standards, the German federal government published the first national EMF regulation for residential exposure in 1996 (Federal Government of Germany, 1996). As a result of public pressure in several countries, the European Union has adopted a recommendation based on a modified version of ICNIRP guidelines for residential exposure. Much stricter limits (2–10 mG) have been adopted in Switzerland (Swiss Federal Council, 1999) and proposed in Italy.

In the US, several state and local governments have adopted electric and magnetic field limits for transmission lines (Sahl and Murdock, 1997). These limits, established by regulations in some states (e.g. Florida) and by informal guidelines in others (e.g. Minnesota), are on the order of 10 kV/m within rights-of-way and 2 kV/m at the edge of rights-of-way for electric fields and around 200 mG for magnetic fields. Much more stringent limits for magnetic field exposure (on the order of 2–4 mG at the edge of rights-of-way) have been adopted in some local ordinances.

5.2. PRUDENT AVOIDANCE

More frequently than guidelines, governments have adopted 'prudent avoidance', a concept introduced by M. Granger Morgan, H. Keith Florig, and Indira Nair at Carnegie Mellon University. In a 1989 US Office of Technology Assessment (OTA) report (Nair *et al*., 1989), they suggested prudent avoidance as a policy option. The report defined prudent avoidance as 'taking steps to keep people out of fields both by rerouting facilities and redesigning electrical systems and appliances'; prudence was defined as 'undertaking only those avoidance activities which carry modest costs'. Introduced as 'an example of using incomplete science to make a reasoned judgment in the face of uncertainty', prudent avoidance can be seen as an application of the precautionary principle, which calls for taking simple, easily achievable, low-cost measures to minimize exposure even in the absence of a demonstrable risk.

Since its introduction, prudent avoidance has been adopted in Australia, Sweden, and several US states, including California, Colorado, Hawaii, New York, Ohio, Texas, and Wisconsin. Other states, such as Connecticut and Missouri, and the District of Columbia have rejected a policy of prudent avoidance because of insufficient evidence and lack of scientific consensus on the EMF issue. In Australia, a 1991 government report (Gibbs, 1991) recommended a policy of prudent avoidance which was adopted in 1997. The policy is confined to new transmission lines and represents 'general guidance . . . without undue inconvenience'. In 1993 the Swedish government, acting upon the recommendation of the Swedish Electric Board (Villa and Ljung, 1993), advocated prudent avoidance. This cautionary policy, defined as taking measures to reduce magnetic fields in newly built housing and electrical facilities without great inconvenience or cost, was formalized in 1996 in a guide for Swedish local officials (National Board of Occupational Safety and Health, 1996):

> If measures generally reducing exposure can be taken at reasonable expense and with reasonable consequences in all other respects, an effort should be made to reduce fields radically deviating from what could be deemed normal in the environment concerned. Where new electrical installations and buildings are concerned, efforts should be made to design and position them in such a way that exposure is limited.

In the US, prudent avoidance has been interpreted to mean everything from adopting the best available practices to implementing low-cost steps (defined in California as actions costing less than 4% of a project budget) in constructing new lines. Most recently, the National Institute of Environmental Health Sciences (NIEHS), as required by the Energy Policy Act of 1992, submitted a report to Congress on the results of a 5-year research programme investigating the health effects of extremely low-frequency (ELF) EMF (NIEHS, 1999). The report states that

> the NIEHS believes that there is weak evidence for possible health effects from ELF-EMF exposures, and until stronger evidence changes this opinion, inexpensive and safe reductions in exposure should be encouraged.

While noting that aggressive regulatory concern is not warranted, because the use of electricity and therefore exposure to ELF-EMF is ubiquitous, the report states that 'passive regulatory action is warranted such as a continued emphasis on educating both the public and the community on means aimed at reducing exposures'. Although regulatory actions are not in the purview of the NIEHS, they suggest that

> the power industry continue its current practice of siting power lines to reduce exposures and continue to explore ways to reduce the creation of magnetic fields around transmission and distribution lines without creating new hazards. We also encourage technologies that lower exposures from neighborhood distribution lines provided that they do not increase other risks, such as those from accidental electrocution or fire.

This recommendation is in most respects consistent with the application of the precautionary principle.

6. The precautionary principle and EMF policy: specifics

Application of the precautionary principle to EMF policy has several unique and interesting aspects; among them are the use of everyday exposure levels as a benchmark, the distinction between new and existing electrical facilities, exposure to children, and the involuntary nature of the exposure. Several risk tradeoffs are also involved.

Since, as discussed above, it is presently unknown what, if any, levels or characteristics of exposure might be harmful, several applications of the precautionary principle have used existing EMF exposure levels as a benchmark. In Sweden, the national authorities call for application of the precautionary principle in situations where fields 'radically deviate from what could be deemed normal in the environment concerned' (National Board of Occupational Safety and Health, 1996). Similarly, the New York Public Service Commission limits new construction to designs 'that produce magnetic fields no stronger that those already common throughout the state' (Stilwell, 1996).

Limiting application of the precautionary principle to new facilities is common to most policies that have adopted it. Implicit in the focus on new facilities is consideration of costs, which are typically higher for retrofitting existing facilities than for modifying the design of new ones. Because the epidemiologic evidence for EMF effects has been strongest for childhood leukemia and because children are often afforded extra protection, some proponents of the precautionary principle have suggested that special consideration be given to schools and day-care facilities (as, for example, in Sweden). Formal policy analysis, which includes cost-effectiveness calculations, would also tend to give more weight to exposure to children because of the increase in potential lost years of life. As discussed in some detail in a paper by Keeny and Von Winterfeldt in this issue (Keeny and von Winterfeldt, 2000), EMF policy decisions require consideration of the tradeoffs inherent in any decision. Tradeoffs to consider include the potential for risk offset, risk substitution, risk transfer, and risk transformation (Graham and Wiener, 1995), as well as benefits and costs. Reducing the potential risk of EMF health effects by reducing one aspect of exposure while increasing another, unknown aspect that might be harmful, is an example of risk offset. Risk substitution is exemplified by the tradeoff between exposure to higher levels of EMF from ground currents in the home and risk of fire and electrocution when ground current is reduced by disconnecting the grounding wire from metal water pipes. An example of risk transfer is the shift in exposure burden from one group of people to another inherent in some mitigation strategies; for instance, moving transformers from a classroom to a hallway. An example of risk transformation is the small but real risk of injury associated with additional construction needed for mitigation.

Finally, voluntary and involuntary sources of exposure carry different risk perception implications (Slovic, 1987); if an exposure is viewed as involuntarily imposed, perceived risk increases. Although the concept of prudent avoidance spans suggestions for personal or voluntary exposures as well as those perceived as involuntarily imposed, most of the so-far-adopted policies focus on exposures that are regarded as involuntary.

7. EMF and politics

The lack of a scientific basis for decisions about EMF opens the door to political decision-making. Various interest groups have argued for or against a precautionary approach in past debates on the EMF issue, basing their arguments on different interpretations of the evidence available.

Media attention has often exacerbated interpretative differences, spotlighting one construal and downplaying the other, with considerable impact on public concern. During the 1980s the possibility that EMF might cause cancer became an issue of intense concern when wide media coverage of research results served to magnify public perception of risk. Public concern has been a major factor in regulatory decisions on EMF reduction. Although large environmental organizations have never taken up the issue, small community groups have had substantial influence.

The electricity industry has also influenced decisions on EMF by supporting research and advocating science-based decision making. In the meantime, it has resisted major precautionary actions but supported easily implemented, low-cost ones.

8. Criticisms of the precautionary principle as it applies to EMF

As it has been implemented in EMF policy, the precautionary principle – or, more specifically, prudent avoidance – has been criticized as going too far and not far enough. The harshest critics, questioning both the scientific and political arguments invoked by the authors of the prudent avoidance policy, have called it 'the abandonment of science' (Electromagnetic Energy Policy Alliance, 1991). In the eyes of these critics, to accept prudent avoidance is to give in to an irrational fear of the unknown and to reject the scientific approach of hazard evaluation. There is also a concern that adoption of prudent avoidance might set an undesirable precedent for dealing with controversial public health issues that involve scientific complexity and uncertainty. Further, critics are concerned that it might not be possible to stop at cost-effective exposure reduction strategies; they feel that if policy is driven by public concern rather than science, the public will eventually push for ever more costly options.

Issues of fairness and environmental justice have also been brought up as arguments against the precautionary principle as it has been used in EMF policy. Since, for example, the precautionary principle suggests reducing high exposures in new school construction, it could lead to environmental injustice because disadvantaged children might be more likely to attend older schools.

Critics on the other side of the precautionary principle debate find the precautionary principle and prudent avoidance too utilitarian, especially when they incorporate cost-effectiveness considerations. The issue of environmental justice has emerged on this side of the debate as well, with the postulate that poorer communities have higher exposures to both EMF and other toxic substances and thus require or deserve more aggressive protection than might be afforded them if straightforward cost-effectiveness analysis were relied upon for setting policy.

9. Discussion

Risks are always present in all aspects of our lives and there is always some uncertainty associated with those risks. We as individuals and as a society can and do make decisions under uncertainty. And while the possibility of risk does not in itself justify action, uncertainty does not in itself justify inaction. Rather, both a proposed precautionary action and its alternative (not taking that action) should be evaluated in terms of the probability of false-positive and false-negative errors and their consequences. When societal losses from false-negative errors are more compelling than losses from false-positive errors, precautionary action is justified (Graham, this issue).

The precautionary principle is vague and allows for widely different interpretations. A general framework therefore is all the precautionary principle at its best can provide. Additional decision rules are necessary as a guide to whether actions should, in fact, be taken in the face of uncertainty in a given situation and, if so, which action among competing alternatives should be chosen. Such guidance should be based on consideration of tradeoffs and cost–benefit analysis.

Along with consideration of the benefits of electricity, the enormous societal costs of electric and magnetic field reduction have made considerations of cost and cost-effectiveness in the application of the precautionary principle essential. Both the benefits of electricity and potential mitigation costs are enormous, easily justifying the need for better scientific knowledge for more informed decisions.

Because it is unlikely that any one alternative will be preferred with respect to all of the objectives, defining objectives for decisions is vital, as is accepting that it will probably be necessary to make tradeoffs among those objectives. Other criteria will need to be developed and applied and might depend on the specifics of who is practicing the precautionary principle and in what setting. How prescriptive these criteria are will depend on whether an individual, an industry, or a government is applying the precautionary principle, as well as whether human health or the environment are to be protected. To our knowledge, the precautionary principle has never been used in an occupational setting, although there are some similarities between prudent avoidance and the ALARA (as low as reasonably achievable) principle used in radiation protection.

The precautionary principle is increasingly advocated in environmental policy and has been implemented as an EMF issue management tool by individuals as well as state and national governments. While it is attractive as a general principle, the specifics of implementation make all the difference. To be more useful, the precautionary principle needs to have direct ties to risk evaluation. Currently, the precautionary principle and careful risk analysis are viewed, partially due to differences in terminology, as completely different approaches. Both science and judgement play a pivotal role in any evaluation of risk. Adoption of the precautionary principle does not eliminate, and perhaps increases, the need to reduce uncertainty. Any such policy should provide for means to monitor and refine the consequences of action, as decisions made in the face of uncertainty will not be right all the time.

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