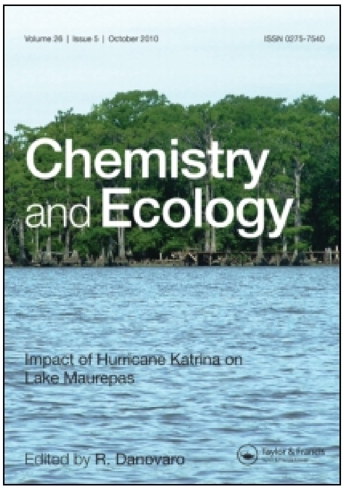

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THE PRECAUTIONARY PRINCIPLE AND THE PREVENTION OF MARINE POLLUTION

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This paper argues that the environmental changes witnessed in the past decade call for a new approach to environmental management; an approach based not on the principle of the assimilative capacity of the environment but on the precautionary principle, and the emerging preventive environmental paradigm. Uncertainties in scientific knowledge and complexities in ecological systems have presented specific failures of the assimilative capacity methodology. It is argued that these failures are not circumstantial in nature, nor are they the result of misapplication of science by scientists. Rather, they represent inherent problems in the use of the assimilative capacity concept in environmental management. The emergence of the precautionary principle is discussed and a formulation of the principle is presented. In conjunction with the operational approach of clean production, we believe that this principle offers a sounder basis for the prevention of marine pollution in the next decade.

KEY WORDS: Assimilative capacity, precautionary principle, environmental management

INTRODUCTION

The past two decades have witnessed unprecedented man-induced environmental change. Terrestrial ecosystems, oceans, and the atmosphere have all suffered severe degradation in largely unpredicted ways (for example forest die-back and depletion of the ozone layer). Some of the more predictable impacts, such as the acidification of lakes and eutrophication of coastal seas, have begun to intensify. Several of these phenomena have affected the marine environment specifically. In the North Sea, for example (ten Hallers and Bijlsma, 1989; Dethlefsen, 1991), algal blooms have caused severe economic damage to fisheries; epidemics have decimated the stocks of seals; fish disease appears to have increased; dolphin and other cetaceans have all but disappeared.

Quite apart from their impacts on the environment these effects have severely challenged the role of science in policy-making, particularly wth regard to the ability of science to predict and therefore prevent potentially catastrophic environmental change. In matters of predictive ability, many of the phenomena described above (e.g. ozone depletion, forest die-back) were missed entirely. When identified as a theoretical possibility in advance (e.g. global warming, lake acidification, eutrophication of coastal waters) science has been unable to predict either the point of onset or the rate of change. Furthermore, when ‘degradation’ has become apparent, scientists have been unable to agree on causes and effects.

It is the contention of this paper that the problems raised by the increasing threat of adverse environmental change have prompted a major re-appraisal of pollution control policy and its basis in science. The concomitant shift in policy from pollution control to pollution prevention has been described by some observers (Bass *et al.*, 1990) as a 'paradigm shift' in environmental management. That is to say, it represents a fundamental re-assessment not only of policy itself, but also of the assumptions which underlie both environmental management, and the relationship of society to its environment.

Perhaps the most fundamental element of this shift has been a movement away from the principle of assimilative capacity, which asserts the capacity of the environment to assimilate wastes and convert them to harmless or ecologically useful products, towards the principle of precaution which calls for action to be taken to reduce environmental inputs even before the onset of damage, if damage is considered likely. Interestingly, these policy developments have been driven as much by scientists involved in the collection and assessment of data (Sperling, 1986; Dethlefsen, 1986) as by the growing awareness of the public, and pressure from the environmental lobby.

It is in the nature of such fundamental changes in outlook (Kuhn, 1962) that a period of confusion follows the demise of the old paradigm, before the newer paradigm becomes established. At the present time, it would be fair to say that we are still to some extent suffering the uncertainties of such an inter-regnum. At the centre of the confusion is the question of the relationship of the precautionary principle to science. Fairly, or unfairly, the principle of precaution has been interpreted by some as being in conflict with the aims and methods of science. In a recent and much-discussed article for example, Gray (1990) has argued that 'the precautionary principle has no place in science'. Advocates of the principle – particularly from non-governmental organisations such as Greenpeace (Johnston and Simmonds, 1990) and the World Wide Fund for Nature (Lutter, 1990) – have argued forcibly against this view.

Some of this confusion has also been evident to the authors of this paper in their experience as members of the Ad Hoc Working Group on the Annexes to the London Dumping Convention, and as representatives on the Scientific Group on Dumping. Within the context of marine environmental protection, attitudes towards the precautionary principle have varied from enthusiastic advocacy to annoyed incomprehension of, or outright opposition to, something which is perceived to negate the role of science in policy-making.

As with most such disputes, there are elements of truth on both sides of the debate. There are also some misconceptions on both sides. More importantly perhaps, there is as yet no commonly accepted definition of the principle of precaution, so that communication often founders as much on linguistic misunderstandings between protagonists as on ideological differences. The purpose of this paper is therefore to clarify this debate and to offer constructive proposals for the development of the precautionary principle. In particular, we shall be concerned with the relationship of the principle to the development of marine environmental protection at a time when major changes in policy are evident, and the need for environmental protection of the oceans has never been greater.

ASSIMILATIVE CAPACITY: FAILURE OF A PARADIGM?

At the heart of what we have referred to as the older paradigm of environmental management is the concept of assimilative capacity, a supposed capacity of the environment to assimilate wastes without unacceptable impacts. That the concept has failed to protect the environment in the desired ways, is not necessarily a failure of intention, but rather the result either of specific failures in the implementation of the concept in specific circumstances, or else of inherent difficulties in the use of such a concept in environmental management. In the case of the former, we contend that a major misapplication and misunderstanding of the assimilative capacity concept is reflected in the unthinking adaptation of the concept to justify dilute and disperse strategies for highly toxic materials or for persistent synthetic substances with stochastic effects. In addition, however, as we discuss below, we are convinced that there are some inherent difficulties in the application of the assimilative capacity concept.

First we must define exactly what we mean by the assimilative capacity of the environment. The Group of Experts on Scientific Aspects of Marine Pollution (GESAMP, 1986) define assimilative capacity generally as:

"a property of the environment which measures its ability to accommodate a particular activity or rate of activity without unacceptable impact."

In operationalising this definition, several additional concepts have been employed. These include the concepts of limiting environmental capacity, critical pathways, critical target groups, and dose or exposure limits. A full description of these concepts and their interaction within the assimilative capacity methodology is beyond the scope of this paper. Detailed accounts can be found in a number of places (ICRP, 1966; Preston and Jefferies, 1969; Preston and Portmann, 1981).

The basic idea of the methodology is to suppose that one can calculate a limiting environmental capacity for contaminants, that is a level of activity at which certain acceptable dose or exposure limits (to humans) are not exceeded. In principle, of course, there are a large number of possible pathways whereby contaminants released into the environment can impact on man, and a large number of different doses according to the behaviour of different receiving groups. In practice, the critical pathway approach adopts the premise that 'in spite of the complex way in which introduced toxic materials interact with various components in the receiving environment, there will be one or two target/pollutant combinations which will present over-riding problems' (Preston and Portmann, 1981). The approach therefore attempts to identify critical pathway whereby the pollutants impact on man, and critical groups who are most exposed to potential danger.

The problem with this approach is that, on the one hand, the input-exposure model needs to be relatively simple in order to be operational, and on the other hand, the environmental receiving medium, the interaction of the pollutant with the medium, the pathways back to man, and the possibilities for target groupings are all extremely complex, and to a greater or lesser extent subject to inherent uncertainties. In general terms therefore, this modelling exercise can run aground as a result of failures in any number of areas including: identification of critical pathways, critical groups and acceptable exposure limits, and modelling the input-exposure relationship accurately.

It is beyond the scope of this paper to give detailed historical analyses of such failures. But it may be appropriate to draw attention to two particular cases in which the assimilative capacity approach and critical pathway analysis have been less than successful in providing acceptable levels of environmental protection.

The first such case is that of the release of radio-nuclides from the Sellafield reprocessing plant in Cumbria (UK) into the Irish Sea. This case has been accorded a prime position in the list of case studies held to demonstrate the successful operation of assimilative capacity concepts (Preston and Portmann, 1981; GESAMP, 1986; ICES, 1989), but an historical perspective reveals significant failures in the methodology.

In summary, the history of the Sellafield releases is as follows. Persistent contaminants were diluted and dispersed on the assumption of models with in-built safety margins based upon the available science at that time. The environmental and health implications of these radioactive discharges are well-documented (Black, 1984; Crouch, 1987; Hunt and Jefferies, 1980; Parker, 1978; Taylor, 1985, 1987).

Despite being able to utilise almost ideal sets of scientific data (for example, much of the material was readily tracked in the environment, many pathways were already well-established, quantitative dose-effect relationships had already been formulated, and there was a measure of agreement on 'acceptable' dose limits) there were significant failures of the assimilative capacity methodology. These failures included the inability of the initial studies to predict one of the critical target groups (shellfish consumers) and to identify a significant pathway (sea to land transfer through actinides enriched in sea-spray). In addition, the input-exposure model failed to account for the build-up in the environment of reservoirs of contaminants which were later to become sources not amenable to reduction. Furthermore, later assessments questioned the safety margins initially used as consumption patterns had changed, transfer factors and dose-effect relationships had been revised, and public acceptability of detriment had altered. The impacts of these failures was that even after inputs had been reduced tenfold (by 1981), doses calculated to the critical group actually rose significantly (Taylor, 1987).

The second illustrative case is that of the control of mercury discharges into Liverpool Bay. This case study has also been reported in the literature as supportive of the success of the assimilative capacity model (Preston and Portmann, 1981). But once again, there were significant failures of the methodology. For example, the average background concentrations of mercury in uncontaminated UK coastal waters (0.2 mg Hg/kg wet fish flesh) in the original analysis has not been borne out by later work (MAFF, 1990) which showed concentrations (including anthropogenic contamination) ranging between about 0.05 mg/kg and 0.15 mg/kg (except for the areas of Liverpool Bay and Morecambe Bay). Another example was the failure of the input-exposure model to incorporate the role of sediments in acting initially as sinks and later as sources of mercury (Krom, 1990). In this case, mercury inputs to the Bay fell sharply over the period between 1972 and 1980, mostly as the result of a single reduction in industrial discharges in the first year. Levels of mercury in fish, however, have still not followed this sharp decline.

In both of these examples the assimilative capacity methodology has been used to justify the continued release of certain levels of pollutant into the marine environment. What is most significant from the point of view of environmental protection is that, in the light of this 'justification', measures which might have been taken to reduce or eliminate those releases were not taken, even though proven technology existed. In the Sellafield case, at least, there is evidence that this would have involved little or no extra cost (Taylor, 1987). For the purposes of our later discussion this aspect of the application of the assimilative capacity methodology is perhaps the most crucial. Before returning to this point however, we examine the inherent difficulty against which models of assimilative capacity must battle. This difficulty, which has been the prime motivation for the precautionary principle, relates to uncertainty, and the limits of science.

UNCERTAINTY, SCIENCE AND THE BURDEN OF PROOF

It is the contention of this paper that the problems which have beset marine scientists in attempting to determine limiting environmental capacities are inherent, rather than circumstantial problems. They have arisen not because some particular scientist has failed to perform his or her task adequately, but rather because of the inherent complexity of ecological systems, and the underlying uncertainty that must be attached to any scientific analysis. Some of these uncertainties are often allowed for by safety factors and conservatism in the scientific analysis. However, others relate to what Wynne (1991) has termed 'indeterminacies' (i.e. uncertainties which defy quantification) in the interaction of human systems with the environment. What is illustrated by these failures, however, is that a scientific methodology has been institutionalised which has severe limitations and is prone to inherent uncertainty.

Of particular interest in elucidating the connection between scientific methodology and environmental management, is the question of the uncertainty which surrounds the establishment of cause and effect relationships. Generally speaking, the question of implicating a particular waste disposal practice in a particular case of environmental damage has the following three main components:

1. the hazard potential of the waste – which might be determined by consideration of toxicity, persistence, bioaccumulation, carcinogenicity, and so on;
2. the evidence for environmental damage – which might have been established by *in situ* monitoring or epidemiological studies on selected species;
3. the establishing of a causal link between the disposed wastes and the environmental effect.

The question of causal links has two components: on the one hand, there is the question of experimental evidence of causality (established through statistical correlations); on the other, there is the question of mechanisms of causality. Both of these aspects have emerged as factors within the debate about causality in relation to either marine pollution or the greenhouse effect.

That all of these factors have been crucial to decisions concerning the disposal of wastes is evident from an examination of the history of environmental policy-making. In the first place, it is clear that the earliest waste management strategies of the industrialised world failed to take action against the disposal of wastes into the environment because (i) they failed to recognise the hazard potential of substances; (ii) they failed to observe environmental damage; and consequently (iii) there was no question of a causal link between emission and effect. In later stages of policy-making the hazard potential (i) was recognised, but crude assumptions about the ability either to sequester or to dilute and disperse wastes in the environment were inadequate to take account of the potential for environmental damage (ii). As actual damage became more evident, policies were modified to monitor and to identify environmental degradation, but often failed to prevent it because of the problems of establishing causal links (iii) between specific emissions and specific effects. For example, wastes from the titanium dioxide industry continued to be dumped for over a decade despite evidence of environmental damage because it was not possible to establish a causal link between disposal and environmental effects (Dethlefsen, 1991). Equally, uncertainties about the scope and timing of the impacts of global warming are being used as grounds for resistance by some parties to abatement strategies.

Several points emerge from this analysis. The first is that uncertainty is an inherent property of the relationship between science and the ecological and human systems which science aims to describe. The second is that, in the light of this uncertainty, it is dangerous in the extreme to require evidence of actual environmental effects and the establishment of causal links before taking measures to reduce the input of potentially hazardous substances into the environment. Finally, it is necessary to reverse (or at least moderate) the 'burden of proof' which has historically operated in environmental protection. In the past, the burden of proof has been placed on the environment, in the sense that emissions have continued until firm cause and effect relationships could be established linking those emissions to environmental damage. In the future, there is a need to provide a framework for environmental protection in which the reduction of emissions of potentially hazardous substances is a priority *in the absence of* firmly established cause and effect relationships. It is to this moderation of the 'burden of proof' that the precautionary principle is addressed.

THE PRECAUTIONARY PRINCIPLE

In the last three or four years, decisions to phase out the dumping of industrial wastes at sea have been taken both nationally and internationally. In 1988, the US introduced its Ocean Dumping Ban Act calling for an end to dumping of both industrial wastes and sewage sludge. In the following year the Oslo Commission (which regulates the disposal of wastes at sea in the North Sea and North Atlantic area) decided under OSCOM decision 89/1 to phase out all dumping of industrial wastes at sea 'except for inert materials of natural origin, and except for those industrial wastes for which it can be shown to the Commission . . . that there are no practical alternatives on land and that the materials cause no harm to the marine environment' (OSCOM, 1989). At the thirteenth consultative meeting of the London Dumping Convention (the global convention which regulates the disposal of wastes at sea) the contracting parties passed a resolution calling for the phasing out of industrial waste dumping by 1995 (LDC, 1990).

These decisions have largely been taken under the impetus of the precautionary approach to marine protection which has emerged since the early eighties, largely through initiatives in Germany and the Nordic countries.

The concept of the precautionary principle ('vorsorgeprinzip') was first developed in the Federal Republic of Germany. It was introduced internationally at the First International Conference on the Protection of the North Sea in 1984. At the second International Conference in 1987, the ministerial declaration formalised acceptance of the principle by agreeing to reduce 'polluting emissions of substances that are persistent, toxic and liable to bioaccumulate, at source'. The declaration stressed the need for such reductions 'especially when there is reason to assume that certain damaging or harmful effects on the living resources of the sea are likely to be caused by such substances, even where there is no scientific evidence to prove a causal link between emissions and effects' (North Sea Ministers, 1987). A similar formulation was proposed by the Nordic Council of Ministers (1989). This formulation of the precautionary principle can be seen as an attempt to remove the need to prove a causal link between specific emissions and specific environmental damage before action is taken to reduce input of substances which have a known 'hazard potential'. The original formulation was in terms of persistent, toxic and bioaccumulative substances, because these substances represent a clearly distinguishable 'hazard potential', but the contention of this paper is that the principle of precaution should apply to all substances which have significant 'hazard potential'.

There are of course some difficult questions raised by this approach. It is crucial to be able to determine which class or classes of materials belong to the initial 'hazard potential' category. Greenpeace (1989) have called for this 'hazard potential' category to include all persistent synthetic substances. Again there are good grounds for this categorisation since persistent synthetics are those a) for which there are no established biogeochemical cycles and b) which will, by definition, not easily be transformed by the processes of biodegradation. Broader definitions of the precautionary principle such as one due to Sperling (1986) have called for the 'hazard potential' category to include not only all synthetics but also 'natural substances in great concentrations or amounts', and this categorisation is certainly supported by the potential impact of marine eutrophication (for example). It is also supported by the potentially catastrophic impacts of global warming.

On the question of 'hazard potential', the authors of this paper strongly disagree with Gray (1990) who states that the precautionary principle is being misused when applied to substances other than those to which the North Sea Declaration applies it (i.e. persistent, toxic and bioaccumulative). Our reasons for this disagreement are as follows. First, it is not clear to us that the North Sea Declaration did so limit itself when it came to consider atmospheric inputs. Secondly, in the subsequent implementation programmes, action *was* scheduled for nutrient inputs such as nitrates and phosphorus which are implicated in eutrophication. Finally, whatever the case for the North Sea agreements, it is clear to us that the principle can and logically should be extended to any potentially harmful substance. It should not be forgotten that CFCs were once classified as harmlessly non-toxic and do not bioaccumulate, yet their persistence and chemical properties have the capacity for massive perturbation of the global ecosystem. Equally, carbon dioxide is a fully degraded, natural gas, harmless to man in moderate quantities, and yet this substance poses what is potentially the biggest environmental threat that we face.

On the other hand, another criticism that has been raised against some formulations of the precautionary principle is that in concentrating attention on the marine environment, it does so to the possible detriment of the terrestrial environment, by forcing the onus onto land-based waste disposal options. We are entirely in agreement with this potential drawback. A particular concern is raised of course by the increased threat to potable water supplies, which might be posed by the transferral to land of wastes presently disposed of in the marine environment.

In summary, we would therefore like to propose the following definition, which draws together what we believe to be the essential elements of the precautionary principle, whilst addressing those criticisms which we perceive to be valid. The formulation below has been denoted as a principle of *precautionary action*, thus indicating that it relates to a requirement for *anticipatory procedures*. The principle is fundamentally about action in the face of uncertainty or doubt, and relates to the quality and state of scientific evidence about cause and effect.

The Principle of Precautionary Action

Anthropogenic inputs into the environment of unnatural substances or of natural substances in unnaturally large quantities should be avoided so far as is ecologically sensible.

Ecologically sensible has the following prerequisites:

1. that preventing a release to one compartment of the environment will not cause environmental damage elsewhere;
2. substances should be prioritised for action in relation to their liability to cause harm.

Harm shall include any significant perturbation from normal relating to the physical, chemical or biotic components of an ecosystem.

Significant shall be defined in relation to natural fluctuations in numbers in biota or fluxes of substances, or with respect to disease or disturbance in biota and man.

In considering the *liability of substances to cause harm,* due regard shall be paid to the following:

1. the *level of scientific knowledge* with regard to that substance, particular attention being paid to the uncertainties and complexities of ecosystems, the limited ability of science to provide definitive cause-and-effect relationships, and the potential for irreversible effects, such that action may be justified even without such definitive evidence;
2. the *persistence* of the substance in the environment, particularly where synthetic substances are not rapidly biodegraded into natural substances;
3. *toxicity* of a substance as indicated by biological testing across a wide range of biota and environmental conditions;
4. the *bioaccumulability* of a substance as indicated either by laboratory and environmental studies, or by structural activity relationships;
5. *stochastic effects* as indicated by carcinogenicity or mutagenicity tests;
6. *natural fluxes* of the substance in the ecosystem.

In respect of these definitions, it needs to be understood that both 'harm' and 'significant' are terms which reflect subjective judgements. Equally, the assessment of the level of scientific knowledge and the degree of uncertainty is to some extent a subjective one which has both political and social implications. These judgements go beyond a scientific assessment. Science may strive towards an objective quantification of effects, but any evaluation will involve political components of ethics, aesthetic and economic value, and cultural priorities. As a consequence of this, any system of anticipatory action will have to involve prior notification, consultation and participation of interested parties in a process of debate which has dimensions of both science and policy.

It is also worth remarking on what some may feel is a notable absence from this formulation. We have made no explicit reference to economic feasibility or costs for reductions demanded by the precautionary principle. In our view however, the relevant aspects of the question of economic feasibility are subsumed within the phrase – "ecologically sensible". In the broadest sense, the ecological system encompasses the human system. To the extent that economic costs represent damages to human welfare within the ecological system, the above definition therefore includes the consideration of economics. It is our belief, however, that economic considerations in this ecological sense must take a full account of environmental externalities (health and employment effects for example), and should view pollution prevention costs not as sunk costs but as investments in improved welfare.

In the above formulation we have attempted to take on board several criticisms of the 'precautionary principle'. Most importantly, however, it should be clear that the principle does not *ignore* science, rather action should follow an exhaustive study of the *available* scientific knowledge of effects, where this is appropriate. The essential departure from past approaches to pollution control is that action to prevent release of substances may be taken *in advance* of an established causal link between the substance and harmful effects. In the following section, we discuss briefly the implications of this form of the precautionary principle for environmental management.

PREVENTIVE ENVIRONMENTAL PROTECTION

Having articulated the principle of precautionary action, we are led to consider its implementation. It is beyond the scope of the present paper to give a full account of this matter. Elsewhere (Jackson, 1990 & 1992; Jackson and Wynne, 1992), considerable attention has been devoted to this issue. Here, we confine ourselves to a brief discussion of the ideas of preventive environmental protection, and in particular the concept of clean production which we believe to be crucial to the implementation of the precautionary principle.

The operational impact of the precautionary principle is to force consideration of technological options to reduce environmental burdens of all potentially hazardous substances. Thus, for example, in the case of mercury emissions into Liverpool Bay, the assimilative capacity method 'justified' the continued release of certain amounts of mercury from an anthropogenic source, even after the environmental impact of those releases was acknowledged. The precautionary principle, by contrast, would have called for progressive reductions in anthropogenic input, on the basis of the potential hazard of mercury in the environment. It would have forced the introduction of emissions reduction programmes, not simply to the extent that emissions were reduced below levels which (according to some simple – but uncertain – input-exposure model) exposures were deemed acceptable, but rather to the extent that such reductions did not increase environmental burdens elsewhere. This kind of impact is very much in accordance with the recent movement away from control-oriented strategies for environmental management towards prevention.

Control strategies rely on two principles. The first is the assimilative capacity of the environment, where provided that sufficient care is taken, then accordingly, waste disposal into the environment is an appropriate waste management strategy even for potentially hazardous wastes. The reliance on end-of-pipe measures to control the input of particular contaminants into particular media. The problem with this second principle is that it can lead to the transfer of pollutants from one medium to another, without really solving the problem of environmental pollution. End-of-pipe control of mercury-contaminated wastes is a case in point. Although solving a local water pollution problem, the sulphide purification process for mercury contaminated wastes (for example) requires the dispose of sludges containing mercury. The disposal problem is then merely transferred to the sludge, rather than being solved.

By contrast with this end-of-pipe approach the preventive paradigm calls for reductions in the generation of wastes, rather than control or disposal of them after generation. A variety of new terms have been used to describe this paradigm shift. Pollution prevention, source reduction, and waste prevention are terms which have emerged, particularly in North America (US OTA, 1986; Campbell and Glenn, 1982; INFORM, 1985 & 1990), to describe this framework.

One of the difficulties faced in the early days of the new preventive paradigm is that it has not always been made clear to what extent various approaches are or are not truly preventive. For example, it is not always clear whether best available technology means best end-of-pipe technology, which suffers from the difficulties already discussed, or whether it refers to strictly preventive process-integrated solutions to environmental protection. The same is true of the term source reduction. Does the sulphide purification solution to mercury pollution count as source reduction or not, for example? From one point of view, this end-of-pipe solution is acting on the sources of pollution to the marine environment but from another, it does not act on the source of mercury contamination. Clearly, a more preventive approach must address the generation of the wastes themselves, rather than simply focusing on the point of entry into the environment.

The fundamental principle of the preventive approach is to avoid, eliminate or reduce the generation of wastes. This pro-active approach addresses the potential causes of pollution. This is in contrast with the reactive, effects-oriented approaches of traditional waste management strategies such as the assimilative capacity approach. The preventive response to the problem of mercury contamination in fish calls for a reduction in the generation of mercury containing wastes. It focuses therefore on technological change, on the design of production processes and consumption patterns, and on material usage.

Much of the thinking implicit within this emerging paradigm has been incorporated into the concept of "clean production", a term coined by a group of experts convened to advise the UNEP Industry and Environment Office on how to proceed with a new global information network on low and non-waste technologies. They defined clean production as: "the conceptual and procedural approach to production that demands that all phases of the life-cycle of a product should be addressed with the objective of prevention or minimisation of short and long-term risks to humans and to the environment" (Baas *et al.*, 1990).

The clean production response to mercury contamination (for example) addresses (initially at least) the industrial process itself. In the case of the chlor-alkali industry for example, mercury is used to conduct an electric current through a brine solution for electrolysis. There is an alternative technology which employs a semi-permeable membrane to establish the current (ICI, 1988), eliminating the need for mercury altogether.

Where this sort of process modification is not possible, clean production requires a questioning of the product. In the case in question, clean production would address the use of chlorine in society. Although chlorine provides some benefits to society (e.g. purification of water supplies) it also contributes significantly to environmental burdens itself. Chlorine is widely used in organic solvents, in pesticides, chemical cleaners, dielectric isolators, propellants, and a wide variety of other uses, including of course, plastics and PVC. Many of these uses are inherently dissipative, even though the carcinogenic properties of chlorinated compounds are now well-known. In other words, addressing the problem of mercury, taking a preventive, clean production approach propels us towards addressing the problem of chlorine. Conversely, reducing the problem of chlorine, enables us to improve significantly the problem of mercury.

To take the analysis further, consider only one of the uses of chlorine. PVC is a relatively safe material during use, but it generates large amounts of hazardous waste and high occupational risks during production, does not degrade well as a post-consumer waste, and poses high respiratory risks in fires. Nevertheless, these factors are seldom factored into decisions about the use of PVC, and we find that it is widely used in packaging for example, which again is an inherently dissipative, relatively short-term use of the material.

Generally speaking therefore, the preventive approach forces us to question the links between the various elements in the industrial process. Clean production requires that we examine not only production processes, but product cycles and consumption patterns generally. The basis of this examination must pay attention to all of the material flows through society. Until we engage whole-heartedly in this process, we will not be able to reap the benefits of improved environmental quality.

CONCLUSIONS

In conclusion, we would like to emphasise our conviction that the precautionary principle is not, as some have claimed, 'unscientific'. On the contrary, it reflects some of the essential elements of the scientific method. Science, when true to its principles, does not deal in positive proof. Rather it operates through hypothesis formulation and refutation, and honours not only the uncertainties of the natural world, but also the imperfections of human perception and analysis. The need for scientific analysis, operating within the framework of the precautionary principle, has never been greater. By contrast, the assimilative capacity approach makes unrealistic demands on science, and has signally failed to prevent environmental damage on an unprecedented scale. We are convinced that this failure is a result not of circumstantial factors or intended misuse by scientists, but rather of inherent limitations in the methodology. The precautionary principle has been formulated in an attempt to overcome those limitations.

The crucial difference between the two approaches might be summarised in the following way. On the assumption that effects can be predicted adequately and levels of acceptable damage can be agreed, the assimilative capacity approach allows for the emission into the environment even of substances which are known to be toxic, provided that discharges do not exceed those for which calculated exposures are deemed acceptable. Reductions in input will be demanded only to that level. The precautionary approach, by contrast, calls for progressive and continued reductions in releases of all potentially hazardous materials into the environment, to the extent that these reductions do not increase environmental damage elsewhere.

In summary, the precautionary principle, appropriately formulated, offers significant advantages in the protection of the environment as a whole. In conjunction with the operational approach of clean production, the principle provides a firm basis for a truly preventive strategy for environmental management.

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