Perspectives in Radiation and Health: Reflections on the International Conference in Beer Sheva

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Insofar as international conferences reflect the state of development of the subject under discussion, they provide an opportunity to question, at a rather fundamental level, the direction of and progress in the subject. With regard to the effects of radiation on health, many of the problems faced today, including uncertainties in the relationship between risk and dose and the origins of the psychosocial phenomena associated with many aspects of environmental radiation exposure, arise from a lack of adequate frameworks within which to understand the radiopathological impact of radiation exposure and the psychological and social implications of such exposures. It is concluded that in seeking an understanding of the relationship of health effects to exposure, through the underlying radiobiological processes, the perturbation of the dynamic interactions within the components of the organism should receive more emphasis. The public perception of risk from environmental radiation exposure appears to encompass factors in addition to the accrued health detriment. It is argued that the radiological protection of the public might be seen more beneficially in the context of other environmental risks. — Environ Health Perspect 105(Suppl 6):1611–1617 (1997)

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Introduction

Summarizing the Conference on Radiation and Health held in Beer Sheva with the broad range of topics discussed is no simple task, and I do not want to confine myself to repeating what others have said or to create the invidious situation of being perceived as endorsing some work while criticizing other contributions. I prefer, therefore, to discuss the broader picture and to select certain topics for particular attention, based on a large degree on personal interests.

Perhaps the most significant difference between this meeting and those that have gone before is the emphasis on the psychosocial aspects of exposure to radiation. The realization that people are afraid of radiation and its possible effect on their health is not new; it was observed after the atomic bombings in Japan, in the Marshall Islands where the inhabitants of Rongelap exiled themselves from their contaminated homeland, in Goiania in Brazil, where residents of the area surrounding a graveyard objected to the burial of the contaminated victims. We also observed the effects of the Chernobyl accident, both in the most heavily affected regions and much farther afield. Until recently this phenomenon was called radiophobia, but this is an insultingly dismissive term for a real effect that has a massive effect on health in its broadest sense, and is not just lack of illness but affects victims’ well-being and their social and physical environment. The origin of much of this, often unnecessary, health detriment cannot be attributed merely to the effects of fast electrons but also to failure to communicate between professionals and the public. This, therefore, is one of the areas I wish to discuss further.

Undoubtedly the most significant event regarding health and radiation since the realization that radiation caused solid cancers and cancers of the blood-forming tissues, i.e., leukemias, has been the increase in thyroid cancer, first in children and now in adolescents and young adults, following the Chernobyl accident. To date there have been about 1000 cases attributable to the exposure; it is worth noting here that the number of cancers attributed to the atomic bomb exposure in Hiroshima and Nagasaki in the Life Span Study population of nearly 100,000 persons between 1958 and 1987 is some 500 solid cancers and 75 leukemias (1, 2). Despite 50 years or more of radiobiological research, the increase in thyroid cancer came as a surprise to many, including professionals; there was a failure to predict the outcome of a significant exposure. I therefore wish to discuss this aspect of radiological health and to put it into a wider context.

The two failures referred to above have, I believe, a common origin, namely inadequate basic frameworks within which radiological phenomena are rationalized, explained, and predicted. One of the conference sponsors, at the opening of the meeting, asked the participants to pay particular attention to four aspects, namely, basic radiological science, its application to build the structure of radiological protection, its application to provide a legislative structure to protect health, and finally, public perception of radiation risks. This reminds me a little of those puzzles that ask you to identify the “odd man out” in four objects. I have no difficulty in doing this in this case; it is the last of the four, public perception. Figure 1 explains why. I have added a zero box to represent the prevailing framework or paradigm. Ideally, this box should govern the hierarchy of the four boxes below it, but it patently does not. In it we have concepts like targets, tracks, interaction distances, DNA strands, breaks, complex damage, mutations, translocations, etc., all of which may be useful to the professional with respect to the three boxes below but of no value to the lay public. What is more, the profession’s ability to convince the public that these concepts provide a reliable basis for understanding the health effects of radiation is questionable. An early attempt to address the psychosocial aspects of the Chernobyl accident (3) noted that

Public perceptions of radiation risk tend to differ from the assessments of experts on radiation and its effects. In some cases, members of the public perceive greater risks from radiation exposure [while] . . . experts are inclined to base their assessment of risk more on annual deaths, lay people incorporate other factors in their judgements of risk....
I suggest that the public perception is that we, as radiological scientists, work to a paradigm they do not understand and one we cannot agree to use in a consistent way to reassure them about the risks they incur when exposed to radiation. We do not speak their language and they do not speak ours! I believe that as professionals we must overcome this problem and find a direction in which we might look for a solution.

Paradigms*

I view the principal aim of radiation biology as providing a basis for risk assessment for radiation exposure. Standards are set, where possible, on the basis of direct measurement in humans, through epidemiology, of the relationship between absorbed dose and effect. However, little direct epidemiologic information exists on exposure regimes that have proved to be important in environmental exposure, i.e., at low doses and dose rates. Direct measurement is not ruled out (6,7), far from it, and the Chernobyl accident and other situations that have given rise to exposure of populations to environmental sources of radiation should provide some such direct information. In parallel, a reliable theoretical basis for radiation biology is required so that risk can be reliably and confidently predicted in those situations for which there is no direct measurement. Such theoretical frameworks are developed within paradigms.

The currently used paradigm evolved from target theory, in which radiation was regarded as "randomly fired bullets" and the critical biological entity in the cell that is destroyed or modified by radiation to achieve the biological effect as the target. Over the years this simple concept has been elaborated upon, in some cases with the incorporation of essential information relating to molecular structures. Perhaps I can summarize without too much loss of rigor by saying that the current paradigm seeks to correlate the well understood physical processes of ionization and excitation and their spatial and temporal distributions with biological effect through the induced physicochemical mechanisms taking place in the cell and predominantly, in the case of stochastic effects, through the activation or suppression of specific genes. This is an essentially linear concept and it does not appear to work very well.

In this context a linear process is one in which the end result is equal to the sum of the component parts or steps whereas a nonlinear process is one in which the total is more or less than the sum of the component parts, indicating gain or loss from interaction with the surrounding environment. Interest lies in the situations where there is gain, for example in hurricanes where the energy of the system increases because of transfer from, for example, the ocean. It is this phenomenon that makes the future evolution of such systems so difficult to predict.

Many of us study radiobiology to better assess the risks of radiation exposure. We should employ another paradigm here to express what is considered relevant to include under the term risk. At present we seem to have a quite simple and linear concept relating radiation-induced health detriment alone, to effective dose which emerges from box 3 in Figure 1. The psychosocial consequences, for example, are not included. As noted above, the lay person may have a much broader concept of detriment that may be far from linear.

In one important sense the former paradigm is subsumed by the latter (contrary to what is implied in Figure 1) because in practice the assessment of risk is contingent on employing the predictive capabilities of the former paradigm. If the robustness of the former paradigm is called into question, as is the case when experts disagree over the assessment of the radiological consequences of a given situation or—as in the case of the thyroid cancer after Chernobyl—when the experts simply get it wrong, then so is that of the latter. This points to a serious situation that should be addressed. In this section I discuss only the basis of our understanding of direct health consequences and leave the question of what should be included under risk to the discussion of psychosocial effects.

If we regard illness as a perturbation of the stable, normally healthy, life process, we might inquire about the origin of this stability. We are familiar with the stability associated with the equilibrium, i.e., the lowest available energy state, but the "only living systems at equilibrium are dead ones," (S Takeso, personal communication) so this cannot be the origin of the stability. Stability in non-, or far from, equilibrium states is associated with the dissipation of energy and in living systems this is available through the metabolic process. The point I wish to make is an obvious one, yet it seems not to be reflected in our thinking about the disturbance of stability in the life process by radiation, namely, that attention must be focused on the dynamics of the system as well as the structure. I can best illustrate this point by referring to a rather simple physical system, the candle.

A great British physicist remarked that "There is no better, there is no more open door by which you can enter the study of natural philosophy, than by considering the phenomena of the candle." A truly astonishing remark today but we should take it seriously as its author Michael Faraday (8) preferred to lecture in his famous series of lectures to children at the Royal Institution, on the candle, even when he was uncovering the very basis of the science of electricity and magnetism. It was the appreciation of the utility of the candle that so fascinated him. He observed, "I cannot imagine a more beautiful example than the condition of adjustment under which the candle makes one part subserve to the other to the very end of its action."

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*In this context the term paradigm was most notably used by the philosopher Thomas Kuhn in his *Structure of Scientific Revolutions* (4). It is clear that sociologists, scientists, and philosophers see the term as having different meanings [5]. I use the term here in its sociological or practical sense as used by Kuhn. In this context a coexisting theory is not implied; it reflects what scientists actually do in the pursuit of research.
The candle has evolved from Irish bog wood through the taper to its present form. In a candle we see the controlled, i.e., stabilized, combustion of solid hydrocarbons, a process in which the physical properties of the components, including the environment, have to be critically matched. For example, the appropriate viscosity and surface tension for the melted wax has to be matched with the porosity of the wick, the heat from the flame has to be sufficient to generate convection currents in the surrounding air but not so great as to prevent the formation of a cup at the base of the wick in which the molten wax is retained. Interactions are therefore the key to this process. In the candle we can see two kinds of failure: structural failure, due for example to a broken wick; and a phenomenon such as "guttering," where the candle burns unevenly and inefficiently, perhaps due to a perturbation of the essential interactions that give rise to the stability—for example, a draft disrupting the convection current that forms the cup. In such systems stability can be affected by both structural and dynamic factors, and in the latter case there need be no residual evidence of the cause of the instability; it certainly will not be found in the structure of the candle. In radiobiology attention is confined to the structural changes radiation induces in DNA and other cell components. This leaves unaddressed any perturbations of essential interactions, e.g., between genes within the genome, between the genome and its environment in the cell, between the cell and its environment in a tissue, etc., it may cause within the dynamics of the processes underlying the life process.

The analogy with the candle cannot be pushed too far, but it does serve to remind us that it is easy to study the structure of the components of a process but much more difficult to study the interactions or dynamic aspects of the process; if the essence of a process lies in these interactions, the structure may be largely irrelevant. I suggest, therefore, that what is urgently needed is greater emphasis on the processes by which radiation may perturb the dynamic processes in the cell, such as the DNA degradation/repair processes.

The essential point about a new paradigm is that of incommensurability of the languages used for the old and new paradigms (4,5). The new language takes time to learn and understand; it may not even be translatable because it may contain new concepts for which words are not currently available. The value of the new paradigm is that it leads to new questions that under the old paradigm would not be thought of as relevant or simply not thought of at all. Traditional concepts borrowed from physics and chemistry such as equilibrium thermodynamics and transition state theory, etc. are not necessarily appropriate in biology. The concept of dynamic steady states in which counteracting processes (for example, spontaneous DNA degradation and repair) result in a constant residual damage in the genome may be much more relevant than true equilibrium.

Nonequilibrium states, as previously noted, have an entirely different, and usually unrelated, source of stability than equilibrium states—namely, the energy that maintains them far from equilibrium. Eigen and Winkler (9) put this rather succinctly. They distinguish between conservative and dissipative structures. Conservative structures are based on static forces and tend toward equilibrium. Dissipative structures are based on dynamic interactions, that are derived from the energy dissipated to maintain the structure. A spinning top, for example, adopts one of two stable states, on its side while not spinning and upright on its tip while spinning. This latter state is stable because of the rotational kinetic energy being dissipated, the symmetry of the structure and the levelness and smoothness of the surface upon which it is spinning. At equilibrium, i.e., rest, the structure alone determines the stable position. As Eigen and Winkler (9) put it, "in contrast to the conservative model, dissipative form is not determined solely by the interaction taking place between material particles but is decisively [my emphasis] influenced by the boundary conditions and the limitations of the system." In other words, such form (stable dissipative structures) depends on conservative forces and the other properties of the whole within which the stable structure or state exists. A whirlpool, a dissipative structure, cannot exist outside the flowing river and its structural features such as its bed and its banks. Herein lies a weakness of our current paradigm for radiobiology; we constantly assume, often tacitly, that the components of the cell when extracted and studied in the test tube or the component cells of a tissue when extracted and studied in culture will be reliable guides to their behavior in the living cell in its organism. This may not be the case.

The British geneticist CH Waddington gives this example (10), although in a different context. He shows a set of upright glass cylinders connected sequentially at their bases by tubes of varying diameters, as illustrated in Figure 2. When this system contains static water, i.e., it is in equilibrium, we would expect the levels in all cylinders to be equal (except for any differences caused by surface tension). However, if water is flowing, the far-from-equilibrium state, constricted flow of the water can result in differing but stable levels in all the cylinders. This nonequilibrium stable or steady state arises because of the potential energy drop across the sequence of tubes together with the structural features (the constrictions) of the assembly and their interaction through friction with the water. It is a consequence

![Figure 2. Diagram taken from Waddington (10) and shows how in a dynamic system the flow of water can support nonequilibrium but stable states, i.e., differing levels of water in the upright glass tubes connected at their bases.](image-url)
of the interaction and dynamic aspects of the system; it can be understood from a knowledge of the structure and physical properties of the components, but it is not predictable in the sense we usually reserve for that term. It is a simple emergent property, and often that is what we have to deal with in biology.

Emergent properties are not amenable to reductionistic analysis. As stated by Medawar and Medawar (11), “The idea of emergence plays a useful part in the biological sciences by giving a name to that which does not respond to reductionistic analysis.”

The relevance of this aspect of complex biological systems is discussed in detail by Peacocke (12). In his book on the controversial new science of consciousness, Scott (13) simply attributes emergent phenomena as properties of nonlinear systems. Biological systems are certainly this whatever else they are.

One biological example will suffice. DNA in the cell exists in a semisolid state in close structural association with specific proteins, other macromolecules, and water in a nonrandom orientation. Some of the proteins are in a state of chemical interaction repairing damage that spontaneous processes such as oxidation and hydrolysis constantly produce. Such a state, a gross oversimplification in itself, has not been remotely reproduced in the laboratory, especially the potential influence that energy-dissipating processes such as continual repair of DNA might have on living DNA. Yet we try to infer from studies of radiation on DNA solutions or DNA in the solid state, the type and extent of chemical damage caused by radiation. Such information often has served as the basis for constructing models later used for radiation risk estimation.

Thus, in using these paradigms in radiobiology we must recognize that in biology we are dealing with complex systems that are far from being in equilibrium and that derive their stability not only from their structure but also, and often quite independently, from the dissipation of energy through metabolism. For these systems, control or stability is probably an integral emergent property and not something imposed from any particular part of the system.

Therefore, Faraday’s point about the value of the phenomenon of the candle as exhibiting stability through dissipation of energy may still be valid today. Other physical phenomena may provide the stimulus to better understand biological processes.

Psychosocial Aspects
There is little doubt that one of the major, perhaps the dominant, health effect of the Chernobyl accident is the psychosocial effect (14). For example, in a comparative general health survey in Gomel, a heavily exposed region of Belarus, and in Tver, an unexposed region of the Russian Federation, self-reported assessment of general health was significantly worse among residents of the exposed region, but clinically verified disease was not significantly elevated. The prevalence of psychiatric disorders was approximately the same in each region. In the Gomel region van den Bout et al. (15) found that patients and doctors alike regarded the Chernobyl accident as the most important threat to health in the region. Of course, this phenomenon has to be seen against a well-documented real decline in health and longevity over the whole of the former Soviet Union, so the high prevalences observed in both regions clearly have other underlying causes. Nevertheless, perceived illness, illness behavior, and psychological stress are now documented consequences of the Chernobyl accident.

Given the uncertain, and I believe inappropiate, nature of the existing paradigm ruling radiobiology and the inability of the radiological community to reach a consensus on the health consequences from exposure to low doses of radiation, it is hardly surprising that the lay public expresses its concern about exposure through the so-called psychosocial response. There is, I believe, a true incommensurability, as identified by Kuhn (4,5), between the language used by the scientific community and that employed, at a largely unconscious level, by the public. Judging from media reports a curious paradox exists in that some people are relieved that the perceived consequences of the Chernobyl accident are so slight given the magnitude of the accident (28 deaths from radiation sickness among some 200 exposed during firefighting on site, and about 1000 thyroid cancers) whereas others are almost disappointed that there have not been, as predicted by some, hundreds of thousands of casualties. How do we arrive at such disparate viewpoints?

It became clear at this conference that laymen view these accidents in a much wider context than a simple tally of health effects upon which detriment from radiation exposure is assessed by the International Commission on Radiological Protection (ICRP). The accident is seen as an environmental catastrophe having health, psychological, social, and economic consequences that are far reaching. Health effects are important but it is the action of contaminating the environment that is seen as a crime. This may well be because a sound environment is regarded, largely at an unconscious level, as essential to healthy life. It is, therefore, of little use to insist that risks are viewed from the scientific or rational point of view proposed by the ICRP when that view is predicated on premises not accepted or understood by the layman. Few, if any, of us are truly rational in the way we view risks to ourselves and those close to us; thus, it is arrogant to expect lay people to take on trust the assessment of risk simply because it is based on so called scientific principles.

On a number of occasions I have asked audiences of professionals if they would be prepared to trade the annual 1 mSv from low linear energy transfer (LET) natural background radiation for 1 mSv from plutonium-239 annually. Only about 3% have so far agreed to do so in spite of the fact that the Sv is expressly designed to represent risk.

One of the first attempts to systematize the psychosocial effect, the first step in the process of putting the subject on a scientific basis, was made at a World Health Organization (WHO) expert group meeting in 1991 in Kiev (3). Five dimensions of the psychosocial effect were identified. One of particular interest is called the medical sociological dimension and deals with the illness behavior of those who perceive themselves to have been exposed and the diagnostic behavior of their doctors. Patients tend to present themselves to the doctor more readily and for more trivial reasons and express concern that their symptoms are a result of the radiation to which they perceive themselves to have been exposed. Doctors faced with such patients tend to overdiagnose and agree with the attribution. It is easy to see that the result of this situation is an increased awareness in the population of the supposed health effects of the accident and an inflation of the attributed health effects. The result is a vicious spiral of increasing perceived health detriment and increasing concern fueled by any reports of increases, real or imagined, in health effects in the population perceived to have been exposed. Attempts to allay public fears, which are perceived to be bordering on complacency, further exacerbate the situation.
There is here a clear parallel to the situation discussed in the previous section. The psychosocial effect rather than being solely associated with what we might call the conservative and even comparatively well-understood relationship between radiation exposure and health consequence is also dependent on dynamic interactions with a much broader psychosocial environment. The psychosocial consequences are an emergent property of the accident and its association with radiation and the social, psychological, economic, and political environment in which the accident occurred—what Eigen et al. (9) call the boundary conditions and limitations of the whole system, in this case society.

Although it is for the scientific community to sustain the rational approach and prevent this destructive cycle of attribution of effect to radiation from being inappropriately fueled, this alone will not solve the problem. The perception of radiation risk is deeply embedded in many culturally specific factors that are to a large degree below or on the edge of consciousness.

However, it is still worth evaluating those factors that experience shows are influential. One may identify, as above, a major contributing factor in the diagnostic behavior of doctors. One well-proven method of assisting people to cope with trauma is to "take their side" against the perceived threat and this probably is viewed as the most appropriate response to the plight of individual patients by many doctors. Thus, there appears to be a contradiction between the needs of individuals and those of the public in general. Good doctoring is not necessarily good for public health. This theme occurs in other aspects of the response to the accident. Most clean-up workers and those living at the time of the accident in the evacuated zone, and those living in the strictly controlled zones, are on special epidemiologic registers, both for reassurance that their health will be more closely monitored and as a form of compensation. Being on such a register only increases concern for health by constantly reminding the individual of the accident and his or her perceived exposure. Realistic assessment of risk in terms of malignancy clearly indicates that medical surveillance is of little value to health outcome, except in some special cases, for example, for children exposed to the isotopes of iodine, some of the most heavily exposed clean-up workers, and those on site at the time of the accident. We should remember that when, as scientists, we choose to carry out an epidemiologic study on these groups we also reinforce this aspect.

Estimation of dose is also an area of concern. Undue conservatism, which leads to overestimation of dose, increases concern and may even result in unnecessary actions such as relocation of population subgroups for which there may be heavy social and/or economic costs. Such conservatism can be viewed as protecting the individual but frequently has an adverse effect on public health. Here, then, is another paradox. What may be appropriate in addressing a situation for an individual may be counter-productive for the general population.

Understanding, let alone remediating, the psychosocial effects of Chernobyl is in its infancy, but this conference demonstrates that there is much interesting work underway. Ensuring that the same mistakes, with respect to inducing the psychosocial effect, are not made again in the event of future accidents should be as much a priority as the need for intervention to reduce exposure. It appears clear from the persistence of the psychosocial effect in the populations exposed to the Chernobyl fallout that prevention is far preferable to having to cure the effects once they have occurred.

Questions have been raised at this conference about the possibility that psychological effects might result from the effects of radiation on central nervous system tissue. Pursuing this possibility, however, might prove to be a distracting red herring, a judgment on my part that would be almost impossible to prove. The reason is the extent to which unconscious cognitive processes influence behavior. Thus, in almost any experiment that discriminates between psychosocial and physiopathological origins of a behavioral effect there would always remain the possibility that the effect was mediated by an uninvestigated (in that particular protocol) unconscious psychological process. For an evaluation of the mechanisms underlying unconscious cognitive processing, see Orbach (16).

**Thyroid Cancer**

The history of the disclosure that populations living in the vicinity of the track of the initial fallout cloud from Chernobyl showed an increased incidence of thyroid cancer in children is related in full by Baverstock and Cardis (17). Briefly, initial claims were made by Belarusian doctors in late 1991. Further investigation by a small mission from WHO confirmed an abnormally high number of cancers in Belarus, predominantly from the Gomel region, which lies to the north and northwest of Chernobyl. Since that initial report (18), several sources have confirmed and elaborated on the distribution of cases geographically and by reconstructed dose, age, and sex. There now can be little doubt that populations in all three countries closest to the accident are to some degree (19) affected and that the isotopes of iodine are the causal agent. Much work related to this increase has been presented at this conference.

The rarity of thyroid cancer in children, which occurs spontaneously at the rate of about 1 case in 2 million children per year, the high tissue doses that result from exposure in young children, even at several hundreds of kilometers distant from the source, and the high sensitivity of the infant and child thyroid to the carcinogenic effects of radiation, have combined to produce a relative increase of one hundred or more times the spontaneous rate. It must also be true that the increase has attracted unprecedented research interest.

It is now well accepted that the then prevailing view and reason for much of the skepticism initially voiced about the increase in this disease, namely that I-131 does not cause thyroid cancer, were incorrect. This is because it was not fully realized at the time how steep was the gradient in sensitivity of the thyroid to cancer induction with increasing age. A subsequent combined analysis of five studies showed there to be about a 20-fold difference in sensitivity to exposure between 0 to 5 years of age and adults (20). Also a factor was the paucity of data from diagnostic exposure of children to I-131. It now seems probable that I-131 is as carcinogenic for any given age as externally generated X-rays. However, the shorter lived isotopes of iodine were a significant component of the fallout in the first few days after the accident and their role must be investigated. Because these isotopes contribute primarily to dose through inhalation, and little through the food chain, their contribution to total dose is estimated to be less than 15% except in those people evacuated shortly after the accident. If these isotopes are primarily responsible for the increased incidence of thyroid cancer in children (and I-131 is assumed to be relatively harmless), their risk factor must be considerably higher in relation to absorbed dose than that for X-rays.
Dose reconstruction is an important issue. Although there can be little doubt that the current increase in thyroid cancer is associated with the Chernobyl accident and exposure to the radioisotopes of iodine, if we are to learn more about the extent of risk in future accidents, accurate knowledge of dose on an individual basis is absolutely necessary (21). Direct measurements made in the 3 months after the Chernobyl accident (22,23) and also reported at this conference are revealing. For individuals of the same age living in the same settlement, dose estimates ranged over two orders of magnitude. While some of the dispersion could be attributable to measurement error (not more than 10% according to Dr. Voigt (22)), this suggests that behavior is, in practice, a very significant determinant of dose. This has important and obvious implications for dose reconstruction for individuals, especially considering the length of time that has elapsed since the accident and the need for accurate recall of the details of behavior in the few weeks after the accident. On the other hand, in the event of future accidents, there is clearly much benefit to be gained from informing the public so that they can modify their behavior accordingly to reduce exposure. This would be particularly important in the first few hours after a release while other countermeasures, e.g., the distribution of stable iodine tablets, were being implemented.

Iodine deficiency is endemic in the areas most affected by the fallout. Stable iodine is an important micronutrient, a deficit of which causes goiter and in children a slowing in cognitive development. There are therefore good public health reasons to advocate correction of such a deficiency. In the fallout-affected areas there are additional considerations. The deficient thyroid has under some circumstances a greater uptake of iodine, and it expresses thyroid-stimulating hormone at higher levels, thus raising the possibility of accelerating the development of any lesion initiated by the radiation. However, there is a third factor that is equally important. The public awareness of the increase in thyroid cancer among children is activating the medical sociological effect I mentioned in the last section and the demand for and provision of medical intervention for goiter has significantly increased. From an epidemiologic point of view, it appears as though radiation has caused goiter. In reality public concern has increased case ascertainment. If we are to retain an objective perception of the effects of radiation (as opposed to those psychosocially mediated), we must be much more aware of potential interactions between psychosocial and physiopathological effects.

Finally I want to address the issue of whether the increase in thyroid cancer observed is within our expectations (given the numbers of people exposed and the doses received) based on the risk factors determined from other sources of epidemiologic experience, for example, infants and children irradiated for non-thyroid-related reasons (20). On the basis of the relative risk model, the answer has to be "no." Relative risks previously observed in radiation-exposed populations rarely exceed single figures for absorbed tissue doses of the order of 1 Gy. Thus, a relative risk of 100 or more is outside our experience and would indicate an unforeseen risk. On the other hand, with the absolute risk model there is a high degree of consistency between what is now being observed and what is known from previous experience. Indeed, I maintain there is no conflict at all (24). Relative and absolute risks are competing models with which we try to predict the whole-life outcome of exposure from partial experience. Both models have been in and out of scientific favor over the years as evidence has accrued from epidemiology. There is a definite inclination on the part of epidemiologists to favor relative risk and they often turn to radiobiological models to support their arguments. But these radiobiological models are themselves based on other paradigms. Let us be pragmatic, apply Occum’s razor, and turn the problem around. These childhood cancers are caused by radiation and given the dosimetric information we have we are entirely consistent with radiation-induced disease being added to a low spontaneous incidence. In this way we make a step forward in our understanding of radiobiology. This increase is evidence for the absolute or additive model.

Conclusions
I have tried to place the developments I perceive as emerging from this conference into the broader framework of radiation and health. As I warned at the outset, my comments are biased by my own scientific interests. In 1988 in trying to distil, from a meeting in Oxford on the biologic bases of the effects of low doses, a colleague and I concluded the following: "That so many fundamental questions cannot be answered unequivocally, and that so much empiricism is still necessary in risk assessment, points to difficulties with the underlying theoretical basis" (25).

Eight years have passed since that meeting and not much has improved. Empiricism still rules and it is now clear that even this has failed very badly in the case of the increased incidence of thyroid disease after Chernobyl. What I have tried to convey is the importance of having secure frameworks within which to develop a view about the health risks from radiation that not only allows specialists to improve their understanding but also facilitates communication with the lay public, including understanding its reactions to being irradiated. I hope I have been convincing in pointing out that it is the scientific community not the lay public that must take this latter initiative. The more this challenge is resisted, the less trust the public will have that radiation can be used safely.

Two paradigms or frameworks are required, one that enables radiobiologists to understand the radiopathological effects of radiation and one shared with the lay public within which there can be two-way communication to assuage the fears and apprehensions of the public regarding the hazards of radiation. I have tried to show that both paradigms share a common feature (so far mostly lacking), namely, the need to consider the object of study in its environmental setting, e.g., the DNA in the cell, the cell in the tissue, etc., and the psychosocial response in its social and economic environment, i.e., society. This is the domain of the science of complex systems, a fast-growing speciality with much to offer but at the expense of learning a new language.

Health, according to WHO, is an all-encompassing entity, and as such includes the psychological and social factors that contribute to well-being. Illness behavior, without organic disease, is a form of health detriment. The psychosocial dimension of detriment is not acknowledged by the ICRP within the framework for protection of the worker and the public. With the realization of the possible importance of domestic radon exposure and in the light of the Chernobyl accident, it seems likely that protection of the public from radiation is
now more important than protection of the worker. Yet the highly developed framework for occupational exposure remains the basis for radiological protection, with the public dimension appearing to be something of an afterthought. One practical development would be to consider risks to the public from environmental radiation not in the context of other exposed populations but in the context of other population exposures such as chemical pesticides, airborne and waterborne pollution, etc. In other words, the framework for the justification and control of public exposure would be separate from, but would overlap with that for workers, as illustrated in Figure 3.

I am aware I have raised more questions than I have answered and that the questions raised are fundamental to radiological protection. The tendency to work within the existing framework or paradigm unquestioningly is universal throughout science, partly, as pointed out by Himsworth (26), because observation has been largely lost as a scientific pursuit. Faraday was the supreme observer. In the humble candle he observed a principle, namely that an evolved system can derive stability though a combination of dynamic interactions and structural properties, neither being sufficient in themselves. If living systems, as well as candles, adhere to this principle, the impact of radiation and that of the perception of being irradiated, on the dynamic interactions within the living system and within societies, respectively, hold the key to future progress in the field of radiation and health.

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