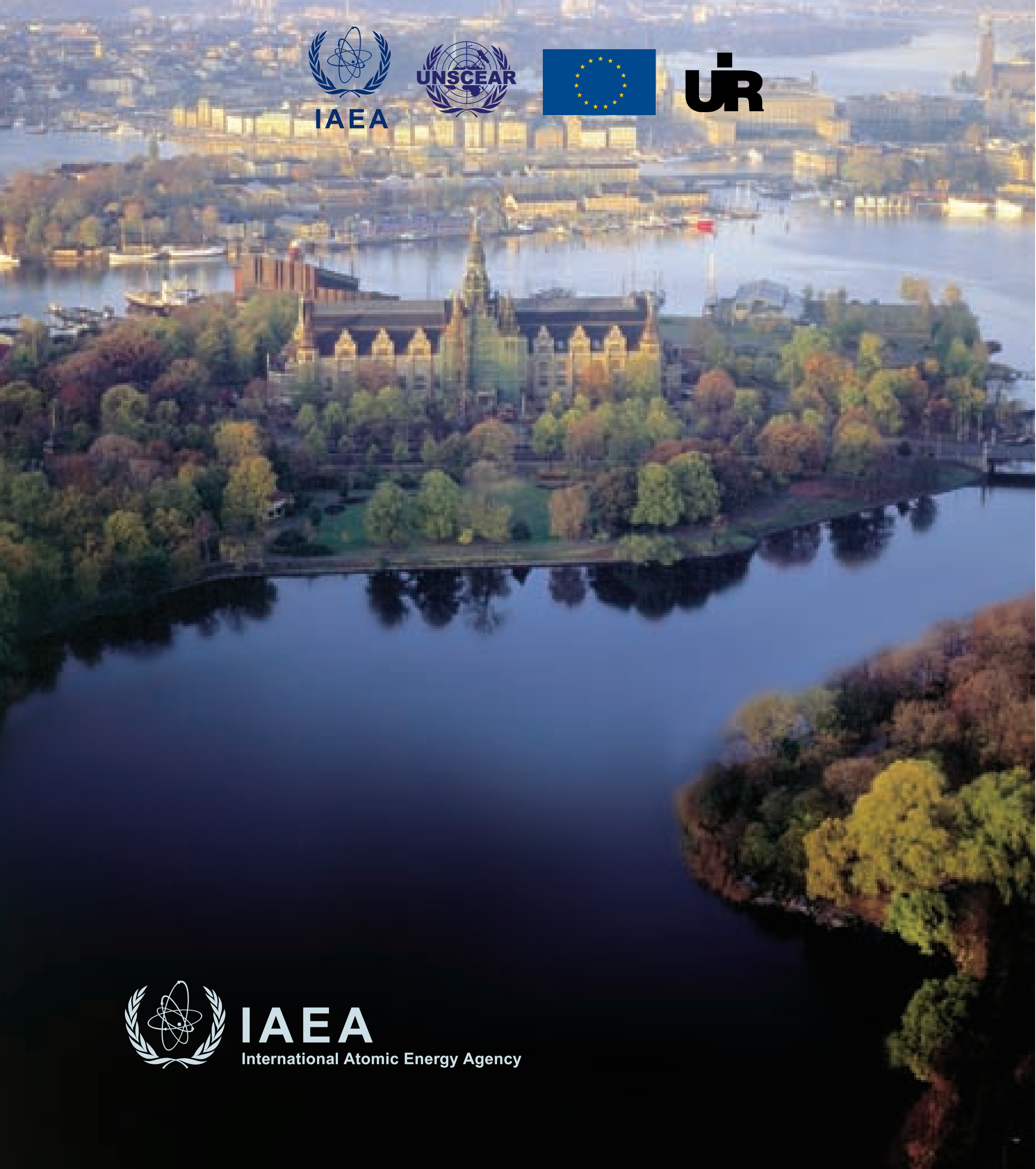
PROTECTION OF THE ENVIRONMENT FROM THE EFFECTS OF IONIZING RADIATION

Proceedings of an International Conference
Stockholm, 6–10 October 2003

IAEA UNSCEAR



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PROTECTION OF THE ENVIRONMENT FROM THE EFFECTS OF IONIZING RADIATION

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IN COOPERATION WITH THE
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ON THE EFFECTS OF ATOMIC RADIATION,
THE EUROPEAN COMMISSION
AND THE INTERNATIONAL UNION OF RADIOECOLOGY,
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FOREWORD

Over the past two decades awareness of environmental issues has increased, prompted by evidence of the harm caused in the environment, inter alia, by industrially derived pollutants. This concern has been reflected in new national and international legal instruments that relate to environmental protection, beginning with the Rio Declaration of 1992. In the context of radioactive materials as environmental pollutants, it has led to a reconsideration of the assumption on which current standards are based, namely that if humans are adequately protected then other species will also be adequately protected.

This subject is now under consideration by all relevant international organizations in the field of radiation protection, including the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Atomic Energy Agency (IAEA).

Starting in 1996, a series of international conferences (Stockholm, 1996, Ottawa, 1999, and Darwin, 2002) has been held to promote information exchange on research and developments in the area of protection of the environment from the effects of ionizing radiation. The conference which is recorded in these proceedings was the latest in this series. The objective of the conference was to review recent scientific and policy developments in this subject area and the implications for further work at the national and international levels. The conference was held in Stockholm from 6 to 10 October 2003. It was attended by some 220 participants from 38 countries and 11 international organizations.

These proceedings contain the summary and overall findings of the conference, the opening addresses, all of the presentations, the topical discussions held during the conference and the summaries of each session. The contributed papers are provided on a CD-ROM that accompanies this volume.

The IAEA gratefully acknowledges the cooperation and support of all organizations and individuals who contributed to the success of the conference. The IAEA wishes to thank especially the Government of Sweden and the Swedish Radiation Protection Authority (SSI) for hosting the conference and providing logistic support.

EDITORIAL NOTE

CONTENTS

BUILDING ON CURRENT KNOWLEDGE
(Topical Session 4)

IMPLICATIONS OF ICRP PROPOSALS FOR INTERNATIONAL SAFETY STANDARDS (Topical Session 5)

EXECUTIVE SUMMARY

Chairperson's Summary

BACKGROUND SESSION

L.-E. Holm,
Sweden*

This session set out to: present the background to the current discussion on environmental issues; review ongoing work within some international organizations; and highlight different views on the subject held by some of the stakeholders.

The chairman of the International Commission on Radiological Protection (ICRP), R.H. Clarke, reviewed the development of the field of radiological protection over the past 75 years. He reminded the audience that ICRP was founded in Stockholm in 1928. ICRP was in those days mainly concerned with the health of personnel involved in medical radiology and radiotherapy. In ICRP Publications 26 and 60, environmental issues were only indirectly addressed. ICRP has now decided to develop a framework for assessing effects of radiation on non-human species and has recently published a report on this subject (Publication 91). ICRP intends:

— To bring environmental radiation protection into harmony with other areas of environmental protection;
— To help regulators in this area;
— To advise on intervention;
— To provide information to different stakeholders;
— To take into account what can be learnt from other fields.

In doing this, ICRP is working towards the formulation of a system for environmental radiation protection that:

— Is harmonized with the system of radiological protection for humans;
— Has a clear set of objectives and principles;
— Uses an agreed set of quantities and units;
— Uses a reference set of dose models.

The International Atomic Energy Agency (IAEA) uses the recommendations from ICRP, as well as the scientific assessments performed by the

* Assisted by C.-M. Larsson (Sweden).

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), as primary inputs to its development of safety standards. A.J. González (IAEA) outlined the work of the IAEA in the environmental area against the background of the IAEA's statutory responsibility to establish standards for *'protection of health and minimization of danger to life and property'*. A number of relevant publications by the IAEA have emerged over the past 25 years, ranging from the technical to the ethical/philosophical. In general, the IAEA believes that environmental radiation protection would be secured under conditions where the IAEA International Basic Safety Standards for Radiation Protection and for the Safety of Radiation Sources are complied with. If the nuclear sector is to maintain its current contribution to the global electricity supply, the IAEA will have to continue evaluating potential and real environmental problems and assist Member States through the further development of guidelines in the environmental field.

The future role of nuclear power was also discussed by J.B. Ritch of the World Nuclear Association (WNA). He suggested that the concern over environmental issues, notably global warming, is one of the principal reasons for maintaining and possibly enlarging the contribution of nuclear power to the world's energy supply. This should be seen against the background of an increased demand for electricity by less developed regions of the world as they develop, at the same time as stabilization of the global warming effect calls for a 50% cut in carbon dioxide emissions. This suggests a need for an expansion of the nuclear industry globally, and the WNA:

— Invites strong ICRP and IAEA leadership in this area;
— Supports the human-oriented protection system;
— Is committed to environmental stewardship;
— Supports the development of criteria for environmental radiation protection.

Also, it is felt that, in cases where environmental radiation protection becomes a scientifically justifiable issue, efforts to protect the environment should focus on populations and species, not individuals.

The position of the WNA was disputed by S. Smith, representing WWF (formerly known as the World Wildlife Fund). In WWF's view there are considerable environmentally based objections against nuclear power, inter alia:

— The existence of an unresolved issue of radioactive waste, where substantial quantities of waste are generated although no solution is at hand for the final management and disposal of such waste;

- That a considerable amount of plutonium is generated through nuclear power production;
- That accidents have caused the contamination and subsequent abandonment of considerable areas of land;
- That the nuclear industry is heavily subsidized;
- That the nuclear industry contributes to the risk of nuclear weapons proliferation.

While WWF shares the industry's concern over global warming, it strongly feels that the solution lies in a vastly increased use of renewable forms of energy and in efforts to reduce energy demand. An ecosystem approach is needed where the long term effects of all impacts on the environment are assessed, and where a precautionary approach is used.

In discussion, the intention to harmonize environmental radiation protection with other areas of environmental protection was clarified. The fact that environmental legislation in many countries focuses on individual organisms, not only on populations and/or species, was recognized. Thus, decisions on protection aims reside with national governments; the experts on radiation protection can, however, contribute by developing an assessment system that permits the quantification of risks at different levels of the biological hierarchy.

Chairperson's Summary

TOPICAL SESSION 1 AND ROUND TABLE 1: STAKEHOLDER VIEWS AND STAKEHOLDER INVOLVEMENT IN ENVIRONMENTAL PROTECTION

L. Keen,
Canada*

Topical Session 1

This session provided the opportunity for representatives of regulators and the nuclear industry, as key stakeholders, to present their views on environmental radiation protection, with the objective of provoking discussion and providing an introduction to the related round table.

A. Oliveira (Argentina) presented a regulator's view of the need for a framework for the protection of non-human species in the context of existing procedures for controlling radionuclide releases to the environment. He outlined the rigorous procedures already in place for regulating the discharge of radionuclides to the environment. He cautioned against an overreaction to the apparent conceptual gap in the present system of radiation protection; he stated that, if applied properly, the present system was protective of the environment and that radiation was not a significant threat to the environment compared to the effects of some other human activities. He stressed that regulations should have a sound scientific basis and be capable of being communicated to the public.

J. Ishida presented an operator's view of the regulation of releases to the environment by outlining the controls placed on the construction and operation of the Tokai Reprocessing Plant (TRP) and the considerations taken into account in setting the values. He stated that environmental monitoring results around the TRP were indistinguishable from background dose rates and that the current protection system had successfully worked to reduce the levels of discharges to the environment over time. He argued that it was important not to place excessive restrictions on the nuclear industry that might reduce the environmental benefits of nuclear energy production. He indicated that environmental protection should be dealt with on a unified basis that allowed the proportionate treatment of different pollutants.

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* Assisted by P.A. Thompson and S. Mihok (Canada).

During discussion the treatment of natural radiation and the availability of information to the public were raised as particular issues.

Round Table 1: stakeholder involvement in environmental protection

The four panellists briefly presented their viewpoints. All panellists agreed in their opening remarks that stakeholder involvement was essential.

Panellists' introductions

T. Carlsson (Sweden) indicated that decision making in stakeholder consultations requires trust and confidence, which can only be developed over time. Stakeholder programmes should be based on hard facts, open and understandable information and dialogue. Resources are required to support stakeholder involvement and to improve the access of stakeholders to independent expertise. Regulators should be independent and competent and should facilitate the process.

A.A. Shpyth (Canada) stressed that the nuclear industry is also a stakeholder. It is knowledgeable and concerned, and it must implement any decisions. The industry is increasingly aware that there is a need for a social as well as a regulatory licence to operate.

J. Sutcliffe (UK) stated that public involvement in decision making processes is a legitimate need and requirement. The Rio Declaration specifically identified the need for the involvement of children, women and aboriginals. Transparency in decision making processes is imperative. Radiation policy has tended to be developed behind closed doors by a self-appointed group; therefore, it has lacked transparency and openness. Policy development needs to be accountable to the public in order to be truly democratic.

D.H. Oughton of the International Union of Radioecology (IUR) noted that there is a growing focus on the legitimacy of stakeholder representation — who should be involved, how are they selected and whose opinion are they representing? Another important consideration is who will represent the interests of future generations.

Summary of discussions

Stakeholder consultation should be incorporated into public policy to balance individual and societal needs. The consultation process should be based on a good governance model, where there is a clear understanding of who will take the decision, the process for arriving at the decision, and how the inputs from consultation will be used in taking decisions.

The process should be knowledge based while recognizing that there are different types and sources of knowledge. Local communities have traditional knowledge that may inform the decision making process. A successful process requires:

— Early public involvement;
— A well defined process and framework that is clear to all participants;
— The facilitation and empowerment of participants;
— Access to resources;
— A balance of representation;
— Recognition of and respect for other points of view;
— A clear understanding of the decision making process.

Chairperson’s Summary

TOPICAL SESSION 2: CASE STUDIES

L.B. Zondo,
South Africa*

Case studies have particular value during the development of any framework for environmental protection. The results from case studies provide a concrete background for the more abstract considerations of principles, standards and methodologies, and are thus necessary in formulating a framework. Case studies can also help develop competence, evaluate and guide the development of assessment tools, and identify uncertainties which can be resolved by further work.

The three studies presented orally during the session spanned a range of site specific scenarios in terms of the types of ecosystem impacted, and the nuclides and radiation types involved. S. Saint-Pierre (France) described a study of the impact of discharges from the nuclear fuel reprocessing plant at Cap de la Hague on the local marine environment, in which fission products proved to be the most significant source of impact; K.A. Higley (USA) described a study of a contaminated area of the Hanford site, in which impacts on the freshwater and riparian ecosystems of the Columbia River were considered and uranium (in the absence of its long lived daughters) proved to be the most significant source of impact; and A. Johnston (Australia) described a study of the impact of the Ranger Uranium Mine on the watershed of the Alligator Rivers Region, Northern Territory, in which the long lived daughters of uranium (especially radium-226) were of greatest significance.

Despite the substantial differences between the three scenarios, there were many common features in the approaches used. All three studies involved stakeholders to some degree, although the level and mode of involvement varied. All three studies were based firmly on a body of existing monitoring data for abiotic and biotic ecosystem components which had been collected, by and large, for purposes other than protection of the environment per se. All three studies considered the actual organisms present in the potentially impacted ecosystems before selecting a range of representative organisms for assessment. All three studies used tools developed over recent years, but based

* Assisted by S.R. Jones and I. Zinger (UK).

on long established approaches to environmental dosimetry, in order to calculate doses to biota on the basis of measured or predicted concentrations of radionuclides in the abiotic and biotic components of the systems studied. All three studies referred, either directly or indirectly, to the dose rate values established by UNSCEAR in 1996 as a basis for judging the likelihood of harm and hence compliance with regulatory requirements.

The three studies showed that existing monitoring data can make substantial contributions to assessments aimed at ensuring protection of the environment. Naturally, one of the values of the studies is the identification of areas where the monitoring programmes for the sites studied could be extended to improve the assessment of radiological impacts on the environment. Specific examples include the uptake of radionuclides by wading birds in the Cap de la Hague study, and the degree of equilibrium between radium-226 and its daughters in freshwater mussels in the Ranger Mine study. The available tools for dosimetric assessment proved adequate for the tasks in hand, although the need for simple, adequately accurate, and flexible tools in this area was emphasized.

Although identifying some gaps in the data, all three studies showed that existing controls applied to past and current operations at the sites studied appear to have adequately protected the ecosystems studied. The Ranger Mine study identified a possible future discharge scenario in which doses to freshwater mussels would approach the UNSCEAR value of 400 μGy/h. In this case, protection of the environment appeared to be more restrictive than protection of humans, the explanation being that the watercourse most heavily impacted was not used as a source of food or water by humans. Even so, the chemical toxicity of uranium to freshwater organisms was more restrictive than criteria based on radiation dose.

L. Moberg (Sweden), as Rapporteur for the Contributed Papers on Regulatory Approaches and Case Studies, drew attention to further case studies by: Twining et al. (Australia), dealing with tritium discharges to the marine environment from a research reactor; Petr and Tsela (South Africa), dealing with discharges of uranium and its long lived daughters to freshwater from a uranium mine; and Steevens et al. (USA), dealing with sediments contaminated by radium-226 and radium-228 as a result of oil exploration and extraction activities. Lessons from these studies were in broad accord with those from the three oral presentations. The paper by Fuma et al. (Japan), which proposed an approach to developing a common index for the ecological impacts for radioactive and non-radioactive contaminants, was also highlighted. Among the relatively few papers on principles and ethics, those of Garnier-Laplace et al. (France) and Oughton (Norway) offered, respectively, a scientific and sociological perspective on dealing with uncertainties in assessments based on current knowledge.

Summary of discussions

The reliance of all three orally presented case studies on the UNSCEAR 1996 dose rate values for assessing the likelihood of harm was raised during discussion; it may be that a review of the existing data on radiation effects, using techniques applied in ecological risk assessment, would produce different results. The contributed paper by Twining et al. (Australia) provides an example of this, and further development using resources such as the FASSET Radiation Effects Database (FRED) produced by the FASSET project appears to present a way forward.

The issue of comparison with natural background radiation was also discussed. It was agreed that this provided valuable context and a secondary approach to judging whether harm from anthropogenic sources of radioactivity would be likely in any particular circumstance. For example, as doses to organisms in the Cap de la Hague study were one to two orders of magnitude lower than those from natural background, no harm would be expected. However, it was also emphasized that, as critical effects on biota are likely to be non-stochastic in nature, radiation doses from natural background must be added to those from anthropogenic inputs in considering the significance of doses against criteria for the likelihood of harm.

Finally, the discussion touched on whether it was possible to identify the most exposed organism, and use that as a ‘reference’. This highlighted the importance of continuing, as at present, to consider a range of representative organism types in an assessment. The organism most highly exposed will depend on the radionuclide “fingerprint” of the emissions and the nature of the receiving environment; further, if relative radiosensitivity is considered, the most heavily exposed organism may not be the most significantly affected. Use of the appropriate range of reference organisms allows these questions to be addressed on a site-by-site basis and also, if necessary, makes it possible to demonstrate that organisms of high perceived conservation value are indeed adequately protected.

Chairperson's Summary

TOPICAL SESSION 3: APPROACHES FOR NON-RADIOACTIVE POLLUTANTS — SEARCHING FOR COHERENCE AND CONSISTENCY

L.B. Zondo,
South Africa*

L. Power (Canada) provided an overview of the Canadian regulatory framework for non-radioactive environmental pollutants, focusing on the legislation at the Federal, Provincial and State levels. The precautionary principle had long been embodied in the Canadian regulatory approach, and had been the subject of Federal guidance published in 2003; the Canadian Environmental Protection Act 1999 (CEPA) placed emphasis on the precautionary principle and the polluter pays principle. The toxicity of chemicals was considered with regard both to the environment and to human health. The regulatory framework included: the use of multiple risk assessment paths; reviews of overseas decisions; the elimination of persistent chemicals; and the application by each industry sector of the Best Available Techniques that are Economically Achievable (BATEA). A National Advisory Committee advised on decisions under CEPA; each State Government was responsible for implementing Canada-wide standards within its jurisdiction. Stakeholder input was incorporated into risk assessments and risk management.

M.E. Clark (USA) compared different approaches adopted for environmental assessment and management. Generally, systems for protecting the environment have developed separately from those for protecting humans. The general approach for environmental radiation protection was based on: a risk paradigm; the precautionary principle; and a continuous process of ecosystem management. Four examples were given of rationales for environmental radiation protection — namely, quantitative risk management using risk limits; an iterative/deliberative approach for decision making; the direct application of the precautionary principle; and the use of a risk assessment/management framework. Common elements in these rationales were identified: ethical concerns have led to the legal basis of regulation; there was stakeholder involvement; the regulatory process was iterative and was more flexible and less linear than processes related to human health; the data on exposures and

* Assisted by N. Gentner (UNSCEAR) and C.R. Williams (UK).

effects were limited; and there were quantitative and qualitative uncertainties. Differences between environmental radiation protection and human health protection included the exposure pathways, the receptors and end points and effects; the focus on populations of organisms rather than individuals; and the availability and quality of data.

Summary of discussions

A number of questions and issues were raised in the discussions:

- How should "potentially significant effect" be interpreted? This depends on the context — if the precautionary principle was adopted, it could be very restrictive, whereas a less restrictive standard could be applied to cleanup.
- It was considered that the principles of justification, optimization and limitation were relevant for environmental protection.
- Difficulties in extrapolating from an individual organism to populations were recognized. Moreover, a pollutant could affect more than one species in the environment. Irrespective of the stressor, there was uncertainty about the stress that was capable of producing a substantial incremental effect on populations; this meant that safety factors had been built into the regulatory approach in some cases.
- In practice, a precautionary approach could not only be based on science, but might also take account of ethical considerations and societal concerns.
- Considering the range of non-radioactive environmental stressors, metals appeared to have most similarities with ionizing radiation. However, there were caveats: for example, some metals had an essential biochemical function, and others were regulated homeostatically by organisms.
- Where radiological assessments related to deterministic effects on organisms, it could be particularly important to include background levels of radiation.

Chairperson's Summary

ROUND TABLE 2: IS CONSISTENCY OF REGULATIONS FOR IONIZING RADIATION AND OTHER POLLUTANTS IMPORTANT?

D. Clein,
Argentina*

Panellists' introductions

The Chairperson pointed out that some years ago it would have been inconceivable to propose consistency in this subject, because the system for protecting humans against the effects of ionizing radiation was so much better developed than that for protecting them against the effects of other pollutants. However, there had subsequently been substantial developments in regulating other pollutants, so that it was now timely to propose consistency.

A. Simcock (OSPAR) referred to the marine environment — in which few humans were found and which covered some 70% of the planet's surface. It was in this environment that the ICRP 60 statement about environmental protection was most under question. OSPAR's Strategies for Hazardous Substances and for Radioactive Substances, both adopted in 1998, have many common features. The European Commission has also put forward a strategy for chemical pollutants, and it would shortly be considering a strategy for radioactive substances. Environmental policy was not based solely on weighing costs and benefits — there were other considerations, such as: the discernibility of pollution in the environment; the principle of inter-generational equity; the "fright factors" which the public associate with particular risks; and media publicity, which could increase the need to manage perceptions of risk.

M. Doi (Japan) agreed that it was important to construct a simple and comprehensive regulatory framework for ionizing radiation, taking account of the frameworks for chemicals. One difference between chemicals and radionuclides was that some chemicals were biodegradable. Ecological systems are inherently robust, and there is a need to consider costs when applying the precautionary principle. In some countries, some policy areas have a greater priority than environmental radiation protection — for example, infant mortality in the developing countries.

* Assisted by N. Gentner (UNSCEAR) and C.R. Williams (UK).

U. Fernández Gómez (Cuba) pointed to the need to harmonize regulatory frameworks and to consider how and when particular features of the harmonization process should be addressed. It was important for the nuclear industry and regulators to have a dialogue with environmental experts, so as to develop a system that was simple to use and which could be monitored. An important consideration was the lack of scientific data on the effects of ionizing radiation on biota and on environmental pathways. In addition to scientific considerations, the regulatory approach would have to incorporate other factors, such as perceptions of risk.

R.J. Pentreath (UK) highlighted the question of whom, and what, the stated objective of consistency was intended to target. Consistency was certainly important for the nuclear industry, which discharged not only radioactive pollutants but also chemical pollutants, usually via the same discharge routes. Operators and regulators had to face a range of regulations that could be bewildering. It would be desirable at least to have a single, integrated environmental licence for a particular site. There were various bases for non-radioactive pollution control; some standards related to environmental protection, some to human protection; environmental quality standards for metals were a combination of both. The current developments regarding environmental radiation protection systems would lead to a more consistent overall approach to environmental regulation. It might be a mistake to try internalizing other environmental management aspects within a protection framework — instead, a useful objective would be to develop good science and simplify the legislation.

Summary of discussions

If radionuclides were judged against the criteria used for chemicals — persistence, bioaccumulation, toxicity — what would be the outcome?

- It was noted that some chemicals are judged on other bases — for example, endocrine disruptors (which can be very important for reproduction and hence for populations of organisms). In those cases, there is a reliance on expert judgement.
- Many radionuclides are persistent and bioaccumulative, and many of the associated questions are related to maintaining biodiversity. This is a difficult subject area for chemicals, and a very difficult one for radionuclides. But there is a need to have an environmental management framework for all circumstances, including accidents.

What is the additional burden associated with responding to a perception of risk, compared with responding to a risk?

— It may not be large, because many questions are directed at the scientific level. One issue is that scientists are perceived to disagree amongst themselves. It would be a good start if those involved in this field produced an environmental radiation protection framework, and maintained a dialogue with people involved more broadly in environmental management. The nuclear industry has some catching up to do on approaches to managing the environment, because of its focus on human protection.
— There is a need to publicize "good news" stories. If there is no evidence or expectation of harm, based on sound science, then this can be stated.

How can the impact of human activities, compared with natural variability, be managed within an ecosystem approach?

— The problem is one of resolving exactly what the ecosystem approach means. This issue first came to the fore in the context of fisheries. While it is difficult to integrate all elements of an ecosystem, it is worse to avoid doing so.
— Pollution control has generally been single-substance and single-organism based. The emergence of the ecosystem approach is encouraging, and it has a good future.

Does the public view the risks from different pollutants inconsistently, and do the public's views have an impact on regulation?

— The public acts in a way that is not based solely on weighing risks and benefits. Any political authority has to take account of this aspect. The public may be said to be "logically irrational" in the way it perceives various risks.

Most hazardous substances are discharged to the environment from diffuse sources, whereas radionuclides are discharged by the nuclear industry from point sources. How should the issues associated with point sources be communicated to the general public?

— The general public does not yet recognize the risks and benefits associated with the various means of energy production. Moreover, the consequences in terms of energy supply are not yet apparent. At present, it is not possible to compare the impacts of different forms of energy production on the same terms, but this should be increasingly possible in the future.

- Reference to natural analogues may be useful.
- With regard to the issue of inter-generational equity, radioactive substances can be compared with mercury and other hazardous substances that have been discharged in significant amounts from point sources.

Chairperson's Summary

TOPICAL SESSION 4: BUILDING ON CURRENT KNOWLEDGE

J.-C. Barescut, France, and Y. Sasaki, Japan*

The session began with a review paper, presented by P. Strand as the President of the International Union of Radioecology, which provided an overview of the status of current scientific work and underlined the need for future work to support the development of an international system for radiation protection of the environment. He noted that, while data gaps exist, there is already sufficient information available on which to develop a systematic protection framework. He indicated that there was a need to develop environmental transfer models and biomonitoring techniques to allow impacts to be determined at population and ecosystem levels. Preliminary sensitivity analyses for semi-natural and marine systems demonstrated the importance of a range of radioecological parameters in estimating biota dose rates.

C.-M. Larsson (Sweden) described the development of conceptual and practical approaches to environmental assessment and protection, using the EC-funded FASSET and EPIC projects as particular examples. These projects make use of a generalized ecological risk assessment methodology to as a framework for the assessment of the impact of radiation on biota within representative European ecosystems, with EPIC targeted at the Arctic. The projects used a reference organism approach to provide the starting point for the development of dosimetric models and for pooling information on biological effects of ecological relevance. Both projects included extensive literature surveys on biological effects. The frameworks and results will be published at the end of 2003.

Environmental transfer

S.W. Fowler (IAEA Marine Environment Laboratory) gave a presentation on radionuclide bioaccumulation patterns in marine organisms. Several examples of the way in which radionuclides are concentrated, distributed and

* Assisted by C.A. Robinson (IAEA), M. Doi (Japan), J.E. Brown (Norway) and M. Balonov (IAEA).

retained in marine organism tissues were presented, demonstrating the time-dependence and inhomogeneity of radionuclide distributions in tissues.

B.J. Howard (UK) reviewed the available environmental transfer data for terrestrial biota and the different approaches that have been suggested to compensate for the data gaps. The need for transparency regarding the data origin and in the application methodologies was highlighted.

During discussion, it was recognized that equilibrium transfer factors from environmental media to plants and animals are available for some radionuclide-organism combinations and generic systems, and that the IAEA's default values for the marine environment have recently been revised (IAEA TRS-247, to be published). It was suggested that the collation of site and ecosystem specific research data would be valuable, e.g. for non-temperate systems, and that special attention should be paid to technologically enhanced naturally occurring radioactive material in ecosystems.

Rapporteur's summaries

G. Pröhl (Germany) reported on the contributed papers relating to environmental transfers and dosimetry. The following key findings were identified:

- — Transfer parameters presented for arid or tropical conditions were similar to those obtained for temperate environments;
- — Information on radionuclide speciation is key to understanding radionuclide behaviour in soils;
- — Allometric relationships are valuable, but more experimentation is needed in order to improve their reliability;
- — The weighting factor for alpha radiation is the most sensitive parameter in estimating doses from alpha-emitting radionuclides; agreement on the use of weighting factors for biota is necessary.

S.I. Salomaa (Finland) reported on the contributed papers relating to biological effects and ecosystem studies. A variety of effects on biota were reported in these papers, from which it was clear that humans are not the most sensitive organism for all biological effects considered. The systematic collection of effects data has made it clear that more work is needed in order to understand the effects — including hereditary effects — of radiation at low doses and dose rates on biota. It is generally the case that deterministic end points are ones that principally affect population survival. However, somatic mutations like chromosomal aberrations can be used as indicators of radiation exposure. A systematic review of natural radiation experienced by biota will be necessary in order to interpret environmental effects information and the developing ICRP approach.

Dosimetry

H.-G. Menzel (ICRU) and D.B. Chambers (Canada) reviewed issues related to dosimetric quantities for non-human organisms and radiation weighting factors for biota respectively. The value of absorbed dose as a measure of harm and issues related to averaging doses over time and space, particularly for small short lived organisms, were discussed. The need for weighting factors with which to modify absorbed doses so as to take account of the differences in the effectiveness of different types of radiation in inducing radiation damage was considered. The need for weighting factors that are correctly calculated and relevant for the type of organism and the biological end points of concern was emphasized.

There was a general consensus that absorbed dose and dose rate are the fundamental quantities for biota dosimetry. It was also agreed that radiation weighting factors are an important consideration in assessments under chronic exposure conditions. The available RBE estimates depend upon the reference radiation used and the end points under consideration. For alpha radiation the radiobiological data imply RBE values of around 10, with a possible range of 5–50.

Dosimetric models are available for a number of exposure geometries. It is now possible to develop a robust set of dose conversion factors. Estimates of the dose rate from the natural background are required both as a basis for comparison and also for aggregation with the incremental dose rates from authorized releases.

Biological effects

I. Zinger (UK) explained the known mechanisms of the biological effects of ionizing radiation on individuals, including differences caused by radiation types. Individual level observations have been made on four “umbrella” biological end points: mortality, morbidity, reproductive capacity and observable DNA damage or mutation. A threshold level for minor effects appears to occur at around 100 μGy/h, while effects are clearly shown at dose rates exceeding 1000 μGy/h. The projection of effects on cells to tissues, organs and the whole body can in principle lead to effects at the population and community level. However, it is generally the case that if individuals are well protected community level effects may also be prevented.

There is a need for more information on chronic effects and for a systematic consideration of RBE. In future it will be important to harmonize research and to focus on the selection of reference organisms. The utilization of biomarkers and the development of standards and environmental criteria are also issues for future consideration.

P.A. Thompson (Canada) described three types of interaction of multiple stressors; additive, synergistic and antagonistic. Additivity is the most frequently used model. However, the current information is insufficient to take account of effects of mixtures of radioactive and non-radioactive stressors. Therefore, biological monitoring and individual measurements are important for the consolidation of the information database.

In the discussion which followed, the usefulness of bioassay for biomarkers was pointed out. Hormesis was explained as a phenomenon that is sporadically observed but remains controversial. Some data gaps in the FASSET Radiation Effects Database (FRED) remain.

Population and ecosystem studies

D.S. Woodhead (UK) addressed the question "Can continuous low-level irradiation affect populations?". He described a study of fish populations in the north-east Irish Sea in which a peak dose of 2 μGy/h can be obtained from the frequency graph of individual exposure of aquatic biota. He used a population model that took account of features of the population such as age at maturity, productive lifespan, and life stages sensitive to radiation. He demonstrated that, since populations show non-linear responses, it is possible, even if individuals are well protected, that community level effects may not always be prevented. As a result, it may be necessary to consider both individual and population responses so as to ensure that protection objectives are achieved.

R.M. Alexakhin (Russian Federation) gave a presentation containing numerous data on effects in contaminated areas around the Techa River and following the Chernobyl accident. Estimated radiation doses to various plants and animals, and their subsequent changes, were presented. High dose rate examples included a pine forest (3.1 Gy/a) and soil invertebrates (7.9 Gy/a) in 1986 soon after the Chernobyl accident. These dose rates had decreased to 0.02 Gy/a and 0.06 Gy/a, respectively, in 1991. Based on this observation, it is possible that the critical ecosystem may change with time.

Application of current and future scientific information

R.J. Pentreath (UK) outlined the concept and use of reference animals and plants, proposed as a device to relate exposure to dose and dose to effects, in a manner analogous to the use of reference man in the radiation protection of humans. Conditions for the selection of reference animals and plants include:

(1) Typical fauna and flora of a particular environment;
(2) Relevant information already in existence;
(3) Amenability to further research;
(4) Dosimetry easily modelled;
(5) Dose–effect relationships easily seen.

He outlined the sort of information that would be needed to describe a reference duck and benthic fish. He mentioned genetic diversity, emphasizing that plants are more complicated than animals, and indicated that reference animals and plants approach would provide a reasonably complete set of related information for a few types of organism that are typical of the main types of environment.

During the discussions that followed, the use of data obtained after an accident for reference in normal situations was questioned. Individual effects and population effects were discussed in contrast, and more scientific data on population effects were recognized as important for bridging the information gap between individual level and population level effects.

Chairperson's Summary

ROUND TABLE 3: WHAT ARE THE IMPLICATIONS OF EXISTING KNOWLEDGE ABOUT THE EXPOSURE OF AND EFFECTS OF RADIATION ON NON-HUMAN SPECIES FOR THE PROTECTION OF THE ENVIRONMENT, AND WHAT ARE THE MOST SIGNIFICANT GAPS?

K. Higley,
USA*

Panellists' introductions

K.A. Higley (USA) noted that we need to carefully examine our own inherent prejudices when selecting our starting point for determinations. It is important to review data needs objectively. Also, while we should foster a healthy debate on knowledge gaps, we should not give the public the impression that the environment is in imminent danger.

J. Garnier-Laplace (France) pointed out that there are many knowledge gaps — bioavailability is key, as are the chronic nature of exposure and the geochemical behaviour of radionuclides. The different scales for biological effects (e.g. early to delayed and subcellular to population) also need to be considered.

J.M. Godoy (Brazil) asked what price we will have to pay in order to implement the proposed ICRP approach. If the costs are overly burdensome — and especially if there is no obvious benefit — the proposed methods will not be accepted. Thus, we will need to consider how to streamline these methods. It would be useful to look at existing areas with high background exposure for insight.

R. Avila (Sweden) agreed that the more we learn, the less we seem to know. It is important to identify which data gaps are the more important, but this may be context specific. He questioned the use of equilibrium transfer factors and suggested that parameters that were more amenable to research, and had a more direct physical meaning, might be more appropriate. He also

* On behalf of Y. Zhu (China) with contributions from C.A. Robinson (IAEA).

suggested that standards and assessment methodologies that allow for uncertainties should be developed.

Comments from floor (overview)

The need for more information in order to establish the way in which radiation effects observed at the individual level may be manifested in populations or species was highlighted as a key issue. There is a need to develop a system of protection that allows the uncertainties in the scientific information to be expressed, while being communicable to a wide range of stakeholders. Consistency in the approaches used to regulate radioactive and non-radioactive pollutants was discussed at some length; it was concluded that the present developments in environmental radiation protection would benefit from experience gained from the environmental management of non-radioactive pollutants.

In view of an absence of obvious evidence of harm, the need for basic research was questioned and discussed. It was suggested that there exists a wealth of data from more than 50 years of releases from the nuclear industry (into both the biotic and the abiotic part of the environment). This should be used to develop assessment methods for non-human species further. For example, we are lacking in information on exposures and effects at the level of populations. Quantitative assessments exist, especially for areas around nuclear power facilities, but better analysis is needed.

The detailed application of ICRP's proposed set of reference animals and plants in the light of area specific conditions was discussed. The need for the approach to be communicable to a wide range of stakeholders was again illustrated during the discussions.

Chairperson's Summary

TOPICAL SESSION 5: IMPLICATIONS OF ICRP PROPOSALS FOR INTERNATIONAL SAFETY STANDARDS

Z. Pan,
China*

L.-E. Holm (ICRP) described the current ICRP position with regard to establishing a framework for assessing the impact of ionizing radiation on non-human species. ICRP Publication 91 sets out the recommendations of the ICRP Task Group to the Main Commission, with the Main Commission's response set out in the Foreword.

The new ICRP recommendations expected in 2005 will include a framework for the protection of non-human species derived from ICRP Publication 91. In the meantime, a new Task Group has been formed to refine the framework, and especially to further develop the reference animal and plant approach. The new Task Group is currently considering a list of 11 animals and plants and aims to report to the Main Commission late in 2005.

An important point of focus will be consistency of approach to the protection of humans and of non-human species. With regard to the protection of humans, the 2005 recommendations are likely to include "Levels of Concern" that are related to background dose rates (excluding radon). For animals and plants, ICRP intend to define "Derived Consideration Levels" to represent doses and effects relative to their background dose rates. Mr. S. Mundigl (OECD/NEA) described the role of the OECD Nuclear Energy Agency and its Committee on Radiation Protection and Public Health, which have been involved in a process of stakeholder consultation about the new ICRP recommendations, including the environmental protection framework. In particular, OECD/NEA sponsored a meeting in February 2002 on environmental issues and recently one on the draft ICRP recommendations as a whole. These meetings included participants representing operators, regulators and NGOs.

One of the views that emerged from the meetings was that the reference animal and plant approach is potentially complicated and may be difficult to implement. The approach needs to be consistent with the broad principles of

* Assisted by J. Loy (Australia).

sustainable development and to be simple and cost effective for operators to implement. The relationship of the environmental framework to the human protection system of justification, optimization and limitation needs further elaboration — particularly since there may be times when optimization of human protection affects protection of the environment. C.A. Robinson (IAEA) described current thinking within the IAEA about the development of safety standards for the radiation protection of non-human species. The IAEA has done work on the ethical principles that lie behind environmental radiation protection, concluding that, while there are differing ethical approaches, there is broad agreement on the basic protection principles. The IAEA's role will be to develop guidance for implementation of the higher level advice flowing from ICRP.

The following matters were raised during the discussion:

— The need to expand the process of optimization, with consideration given to the protection both of humans and of non-human species and to the need to take account of the views of stakeholders in this process;
— The need for an IAEA action plan, it being noted that a role of the Conference was to advise the IAEA on areas for future cooperative activities;
— The place of environmental justice and respect for human dignity in the assessment process, it being agreed that this issue was most important at the stage when risk management decisions were being taken;
— The possible need for changes in the membership and approach of ICRP, including the Main Commission, to most effectively advance environmental protection issues;
— Whether domestic animals and agricultural plants need to be considered;
— The relationship between the reference animal and plant approach and existing national approaches;
— The value of continuing stakeholder involvement, including involvement through OECD/NEA;
— Whether there should be consideration of protection of the abiotic environment (ICRP is of the view that ionizing radiation does not cause damage directly to the non-living environment, while accepting that there are strong societal commitments to an overall clean environment).

Chairperson's Summary

ROUND TABLE 4: DO THE ICRP PROPOSALS PROVIDE AN APPROPRIATE WAY FORWARD TO THE DEVELOPMENT OF AN APPROACH TO THE PROTECTION OF NON-HUMAN SPECIES?

J. Loy,
Australia

R.L. Andersen (World Nuclear Association) agreed that the ICRP proposals provided an appropriate way forward. He emphasized that practices within the current framework are protective of the environment, but that the conceptual gap called for a practical and flexible solution. International leadership is required, and it would be valuable to have a "roadmap" of the directions to be taken, the outcomes sought and the roles of the different international organizations.

S. Carroll (Greenpeace) welcomed the fact that the issues dealt with by the Conference were now being addressed. From a Greenpeace point of view, it was important to take a "top down" approach that reflected societal views about environmental protection, rather than a "bottom up" approach driven by scientific numbers. He saw the reference organism approach as useful, but not necessarily sufficient for management decisions, especially decisions by society about the values of different environments that go beyond the protection of biota. The approach could be improved by taking account of approaches to environmental protection against the effects of non-radioactive pollutants — it should at least reflect current best practice.

H. Forsström (EC) spoke from the viewpoint of an organization that funds research. His view was that the ICRP proposals were positive but incomplete as regards a number of matters, and it was not clear how these matters would be addressed. The objectives of the proposed system needed clarification and the whole approach needed to be able to be simply explained. There was a need to cooperate with organizations working with non-radioactive pollutants and to define research priorities.

N. Gentner (UNSCEAR) said that despite data gaps we already knew enough to start setting up a system for the protection of non-human species. The ICRP proposals were very sound. All relevant organizations needed to play a part in ensuring consistency between approaches used to control non-radioactive pollutants and the system for the protection of humans. The issues to be resolved included the use of dose rates (consistent with concentrations of chemicals) and the value of RBEs. Conservatism should be built into the system, but at one clear point, not everywhere.

The following matters were raised during the discussion:

- The meaning of the "top down" approach advocated by S. Carroll (Greenpeace);
- The need for regulators to have specific numbers as a basis for decisions on licences (the ICRP approach will establish an assessment process which will need to be incorporated into national regulatory assessment processes);
- Whether the approach will engender public confidence, and the role of the precautionary principle (it was acknowledged that there was a need to make clear what the proposed system could do and what it could not do, and that even with incomplete information it would engender public confidence if it was clear that an effective start was being made);
- The timescale over which dose rates should be used;
- The tension between having a general framework for assessment on one hand and clear presentation on the other, and the need for public understanding and acceptance;
- The fact that society will take decisions about the degree of protection to be accorded to different environments — some may be kept as near to "pristine" as possible (the ICRP guidance based on reference animals and plants can serve as a tool but cannot be definitive);
- Evidence based decision making in wildlife legislation and the need for further R&D and for the definition of research priorities.

Chairperson's Summary

ROUND TABLE 5: COMMUNICATION WITH THE PUBLIC AND THE ROLE OF THE MEDIA

P. Rickwood,
IAEA*

This round table addressed three main issues: the role of the media (what do journalists do?); what the media communicate (what is a good story?) and risk perception (why is radiation so scary?). Each of these points is considered in turn.

(1) The role of the media: What do journalists do?

The role of journalists is different from that of scientists. Indeed, journalists and scientists can be said to have rather different cultures. Journalists tend to be rather individualistic and to be interested in breaking stories rather than in educating the public — a role that scientists often expect of them. Journalists work under intense time pressures and competition for the inclusion of their stories. Scientists, on the other hand, tend to work in a collaborative manner and often focus on uncertainties (what they do not rather than what they do know).

The differing role of different parts of the media was discussed. It was suggested that the power of the press may be weakened by the advent of the Internet, by allowing the public more direct access to a variety of information sources. The differing coverage of the mass media and the various types of newspaper will also influence the spread of a particular news item. It was suggested that scientists tend to deal with journalists from smaller-circulation 'broadsheet' newspapers that do not reach most people.

(2) What the media communicate: What is a good story?

It was suggested that journalists are generally only interested in bad news stories. In reply, the characteristics of a good story were identified — it should be dramatic and interesting, and have resonance with the audience. The use of

* Assisted by D.H. Oughton (IUR).

nuclear technology to control the tsetse fly was given as an example of a situation when a good science news story received wide coverage, partly as a result of it having been presented by the scientists involved in an appropriately interesting manner.

The need to be able to describe a story in a short and simple manner was emphasized — given the competition for inclusion in the news, a story needs to be able to be explained in 'sound bites' or 'top lines'.

(3) Risk perception: Why is radiation so scary?

There are a number of factors that lead to radiation being of particular concern to the public. The word 'nuclear' has worrying connotations, and was consequently dropped from 'magnetic resonance' when used for medical purposes. This concern is exacerbated by, among other things, the lack of personal control over radiation exposures and an increasing distrust of expert advice — for example, following the BSE crisis. The consequence of uncertainties and the apparent disagreement among scientists does not help in this regard. It is important to remember that trust is a fragile commodity — once lost it is difficult to rebuild.

FINDINGS AND RECOMMENDATIONS[1]

1. INTRODUCTION

The International Conference on the Protection of the Environment from the Effects of Ionizing Radiation (the conference) was held at the Stockholm City Conference Centre — Norra Latin — from 6 to 10 October 2003. It was organized by the IAEA, in cooperation with UNSCEAR, the European Commission (EC) and the IUR. The conference was hosted by the Government of Sweden through the Swedish Radiation Protection Authority (SSI). It was attended by some 220 participants from 38 countries and 11 organizations.

Stockholm has an impressive history as the venue for meetings on radiation and environmental protection. In 1928, the International Commission on Radiological Protection (ICRP) was established in Stockholm. In 1972, the first United Nations Conference on the Human Environment was held there, and in 1996 the first international symposium on ionizing radiation and protection of the natural environment took place in Stockholm. The conference continued this tradition.

The primary objective of the conference was to promote the development of a coherent international policy on the protection of the environment from effects attributable to ionizing radiation exposure. It was the culmination of a series of meetings on the subject organized by, or held in cooperation with, the IAEA. The conference reviewed recent developments and considered their implications for future work on developing guidance at the national and the international level.

The IAEA and the cooperating organizations have interrelated responsibilities with regard to environmental radiation protection. The IAEA has unique statutory responsibilities within the United Nations family for establishing standards of radiation safety — and by implication ones for environmental radiation protection — and for providing for the application of those standards at the request of any State.[2] UNSCEAR's mandate within the UN system is to

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[1] The views and recommendations expressed in this summary are those of the President of the conference and the participants, and do not necessarily represent those of the IAEA.

[2] The IAEA has established a programme for developing standards that specifically address the protection of both humans and other species. The programme includes a number of mechanisms for providing for their application.

estimate sources and effects of exposure to ionizing radiation and to report its estimates to the UN General Assembly. UNSCEAR published a review of the effects of ionizing radiation on the environment in 1996, and it has recently embarked on a new programme of work in this area. For the establishment of its international radiation safety standards, the IAEA relies on the UNSCEAR's estimates and on the ICRP's radiation protection recommendations.

The EC has competence in radiation protection, under the 1957 Euratom Treaty, and issues basic safety standards through Directives that are binding on the Member States of the European Union. In view of the increasing awareness in many European States of the need for a system to demonstrate explicit protection of the environment, the EC has funded and continues to fund scientific research in this area — for example, the FASSET (Framework for Assessment of Environment Impact) and EPIC (Environmental Protection from Ionizing Contaminants in the Arctic) projects, the final results of which were presented at the Conference. The IUR is a non-governmental scientific organization for professional radioecologists that promotes information exchange among scientists involved in environmental research and the management of pollutants.[3]

The World Nuclear Association (WNA), representing the industry engaged in the peaceful applications of nuclear energy, welcomed the leadership shown by the IAEA and the ICRP in addressing how best to deal with the question of protecting non-human species. It underscored the widespread agreement among experts that the current system of radiation protection has in practice been protective of the environment. The WNA furthermore affirmed the nuclear industry's recognition of the supreme importance of environmental stewardship and the industry's continuing commitment to operating in accordance with high environmental standards.

WWF, a non-governmental environmental group, stressed the importance of adopting a long term holistic approach to environmental management — an approach that takes account of cumulative impacts on ecosystems from radiation and other stressors. In the future, the total load of activities in an area or region may become an increasingly important issue in decision making where the key issues for consideration are the conservation of biological diversity and sustainability.

[3] The IUR is involved in recent development work on a framework for environmental radiation protection, has promoted information exchange and has identified relevant research priorities.

2. FINDINGS

2.1 General

Rigorous regulatory mechanisms are already in place to restrict both the release of radionuclides to the environment and their accumulation in the environment. Under the current system, environmental radiation protection is achieved through the restriction of discharges of radioactive substances into the environment. The discharge limits are currently set following a process of constrained optimization of protection. This ensures that members of the public receive radiation doses considerably below internationally established individual dose limits for humans. In setting discharge limits, it is currently assumed that, if human beings are adequately protected, other species will be protected at the population level. There are, however, situations in which this approach is insufficient for the protection of species other than humans, the most obvious example being environments where humans are not present. The explicit consideration of possible impacts on non-human species would therefore strengthen the conceptual basis of radiological protection. Furthermore, it would address the additional requirements arising from nature conservation legislation. These conclusions have led to the establishment of new work programmes by the ICRP and the IAEA, and to the recent issue of ICRP Publication 91.

The main finding of the conference was that the time is ripe for launching a number of international initiatives to consolidate the present approach to controlling radioactive discharges to the environment by taking explicit account of the protection of species other than humans. The process foreseen for achieving this is as follows:

(1) UNSCEAR should continue to provide findings on the sources and effects of ionizing radiation that can be utilized as the authoritative scientific basis for the future international efforts in environmental radiation protection.

(2) The ICRP should continue to issue recommendations on radiation protection, including specific recommendations for the protection of non-human species.

(3) The IAEA should establish the appropriate international undertakings, including international standards and mechanisms for their worldwide application, to restrict releases of radioactive materials into the environment over time, in order that not only humans but also the non-human component of the environment is adequately protected. The

IAEA should continue to foster information exchange by organizing international meetings on this subject.

(4) The involvement of a broad stakeholder community — including intergovernmental organizations such as the OECD Nuclear Energy Agency (OECD/NEA) and non-governmental organizations such as the IUR, the WNA and WWF — is essential for identifying possible gaps in the evolving environmental radiation protection system and for increasing the understanding and acceptance of relevant recommendations.

(5) Regional organizations, such as the EC, and national competent bodies may then wish to incorporate those international undertakings into regional and national regulatory requirements as appropriate.

The conference noted that the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the IAEA system of international safety standards, and the various existing international mechanisms for the application of these instruments provide an appropriate framework for formalizing an international approach to restricting releases of radioactive materials into the environment.

The conference recognized that the elements of such an approach should be practical and simple, avoid undue burdens on regulators and operators, allow for stakeholder involvement, and allow for harmonization of the ICRP's system for the radiological protection of humans with analogous approaches for other pollutants. Moreover, the approach should take account of current national and international initiatives aimed at the conservation of nature in general.

With the above considerations in mind, the conference recommended that, under the aegis of the IAEA, an international action plan on the protection of the environment against the detrimental effects attributable to radiation exposure be prepared and submitted to governments for approval. All relevant international organizations and senior experts from States should be invited to contribute to the preparation of such an action plan.

2.2 Stakeholder involvement

There were differing views about how stakeholders should be involved. The importance of ensuring legitimate stakeholder representation was emphasized. Stakeholder involvement is particularly valuable for taking account of the specificity of local conditions. A successful stakeholder process requires: well-defined procedures that are clear to all participants; a balance of representation; trust and open dialogue between the parties; and access to resources. A greater understanding of the other party's interests and motivations is valuable even when full agreement cannot be reached.

2.3 Case studies

Case studies have particular value during the development of any framework for radiation protection. The results from case studies provide a concrete background for the more abstract consideration of principles, standards and methodologies. Three very different case studies were presented, but they displayed many common features as regards the approaches used: they were based on a body of existing monitoring data for abiotic and biotic ecosystem components; they considered the actual organisms present before selecting a range of representative organisms for assessment; and each referred to the dose rate values established by UNSCEAR in 1996 for comparison purposes. Although identifying some gaps in the data, all three studies showed that the controls being applied to past and current operations at the sites studied in most cases appear to have adequately protected the ecosystems at those sites. In one case, however, a potential discharge scenario for an uranium mine led to a situation in which protection of the environment, and not of humans, would determine the appropriate discharge level.

2.4 Coherence and consistency with approaches for non-radioactive pollutants

Consistency between the approaches applied in regulating radioactive materials with those applied in the case of non-radioactive pollutants is important. The advantages include practicality, for the operator and regulator, and comprehensibility, for the public. The frameworks for the assessment of impacts of radionuclides in the environment that are presently being developed are in many respects similar to those used for non-radioactive contaminants. Examples of regulatory approaches for non-radioactive pollutants were presented that take into account the bioaccumulation, persistence and toxicity of materials. The range of approaches applied in various countries was reviewed and categorized as follows: the risk based approach; application of the precautionary principle; and the ecosystem approach.

2.5 Building on current knowledge

A review of recent scientific research and of its application in the development of an international framework for the protection of the environment from the effects of ionizing radiation suggests a number of priorities for further work:

- The application of existing environmental transfer models and parameters in estimating doses to non-human biota (the application of allometric relationships received particular attention), with the development of a relevant database in a transparent and consistent manner;
- The continued development of appropriate dosimetric quantities and units relating to biota that account for the interaction of ionizing radiation with tissue and for the different effects of different types of radiation for relevant biological end points;
- The development of dosimetric models for a number of exposure geometries applied to reference animals and plants that take into account spatial and temporal averaging, as appropriate;
- The collection of additional information on the biological effects of radiation at environmentally significant chronic dose rates, particular attention being paid to data gaps concerning morbidity, mortality, reduced reproductive success and mutations, in the ICRP-defined reference animals and plants;
- The development of methods that will allow the extrapolation of effects observed in individuals to populations and ecosystems;
- The development of an approach that takes account of the combined effects of radiation and other stressors, building on current knowledge presented in the UNSCEAR 2000 Report;
- The further development of the reference animals and plants approach for assessing the impact of ionizing radiation on biota, so as to underpin the development of practical international radiation safety standards; and
- Investigation of the possibility of defining environmental activity concentration levels, that would take account of both environmental and public protection.

2.6 ICRP proposals and international safety standards

The conference was made aware of the proposals for a framework for assessing the impact of ionizing radiation on non-human species being developed by the ICRP. This work is part of an overall revision of the ICRP's recommendations expected to be completed in 2005. It was agreed that natural background radiation levels provide a valuable basis for comparison.

The conference supported the consultative manner in which the framework for environmental radiation protection and the overall revised recommendations were being developed. The conference was informed about the approaches being considered within the IAEA for an action plan to develop the basis for safety standards specifically addressing radiation protection of the environment.

While accepting that there remain significant gaps in knowledge and that there needs to be continuing research, the conference accepted that there was an adequate knowledge base to proceed and strongly supported the development of a framework for environmental radiation protection. The ICRP and the IAEA have important roles to play, and it is vital that the framework be developed in a consultative and inclusive manner. The conference supported the approach based on the development of reference animals and plants, and it noted that these may also serve as a basis for site specific assessments.

The conference supported the early development of a "road map" that would set out the objectives and expected components of the framework and describe the roles of the different organizations. It was agreed that the framework needs to be based on the best knowledge available at present, be flexible, be applicable in different contexts and be able to accommodate new scientific information. The need to communicate the basis of the system to decision makers and the general public was emphasized.

The conference recognized that, while it was important that there be an internationally consistent overall framework, decisions on the management of risks must be taken nationally and take into account the perceived environmental value of individual ecosystems. It was noted that such decisions may also be influenced by the nature of the environment, and not only by the biota present.

2.7 Communication with the public and the role of the media

The role of the media in communicating with the public and the different interests of scientists and journalists were explored. Scientists are highly specialized and tend to deal with abstract concepts; they explain their work at some length and often seem to focus on what they do not know rather than what they know. Journalists tend to be generalists who are interested in a "good story" that has a direct impact on people; they work under intense time pressures and need to express themselves succinctly. The different priorities of the two groups frequently lead to misunderstandings. From the scientist's perspective the media tend to concentrate on bad rather than good news, but it was demonstrated that it is possible to "sell" good news if the issues are communicated clearly.

The action of “fright factors”, such as the invisibility of ionizing radiation and the involuntary nature of exposures to it, on the public perception of radiation risk was discussed. The openness of communication has a positive influence on public perception and trust.

OPENING SESSION

OPENING ADDRESS

L. Sommestad
Minister of the Environment,
Sweden

Last week we were reminded once again of the after-effects of Chernobyl. Unexpectedly high values of the radioactive substance caesium were found in moose meat from the south of Västerbotten County. A moose cow shot in Ängersjö had 2000 becquerel per kilo meat, and a moose calf had almost 4000 becquerel. The caesium content in Swedish moose has varied after the 1986 reactor breakdown at Chernobyl.

The explanation for this year's unusually high content appears to be that, due to the warm weather, the moose have eaten blueberries which contain more caesium than plants in wood clearings.

Moose meat containing caesium reminds us of the vulnerability of our society. It reminds us that emissions cross borders and that ambitious, long term environmental policies must be adopted at the national but above all at the international level.

Work on environmental objectives is an important component of Swedish efforts to overcome our environmental problems within a generation. In Sweden, our work is based on 15 environmental quality objectives. We have established subgoals, action strategies and follow-up mechanisms. In an international context it is, I venture to say, unique in its systematic structure.

The Swedish Government and Riksdag have laid down that:

— Human health and biological diversity shall be protected against harmful effects of radiation in the outdoor environment.
— By the year 2010, the content in the environment of radioactive substances emitted from all activities and operations shall be so low that human health and biological diversity are protected.
— By the year 2020 the annual number of cases of skin cancer caused by the sun shall not be higher than the figure for the year 2000. The risks involved in electromagnetic fields shall be continuously reviewed and necessary measures taken when such risks are identified.

These objectives describe the quality and conditions for Sweden's environmental, natural and cultural resources that are ecologically sustainable in the long term.

Creating a sustainable future for all is a demanding and essential task for each one of us. It is our responsibility — as politicians and experts, in the public sector and the private sector and as citizens, to focus our efforts on reaching the internationally agreed targets.

I am therefore delighted to welcome you to Stockholm and this conference on the protection of the environment from the effects of ionizing radiation.

The IAEA plays a very important role in the efforts to make the world safe from a nuclear point of view. Experts convene to explore the issue. Documents and reports are produced, missions are performed and our knowledge of the situation in different areas is increasing.

I welcome the work done by the IAEA and the International Commission for Radiation Protection (ICRP) to draw up guidelines and recommendations for radiation protection.

And the Swedish Government appreciates that the environmental issues have been integrated into the IAEA's safety guidelines.

Sweden has a long tradition in the area of environmental protection. The first United Nations Conference on the Human Environment was held here in Stockholm in 1972. This was celebrated last year when the Swedish government organized the conference "Stockholm Thirty Years on: Assessing Environmental Risks and Coping with Uncertainty".

Sweden has taken an active part in efforts to find criteria for the protection of the environment from ionizing radiation. In 1996, the Swedish Radiation Protection Authority, the SSI, hosted the first international conference on this subject. The SSI also plays a prominent role within the ICRP, the IAEA and the OECD/NEA in the development of the scientific foundation for defining these criteria.

I strongly believe in a sustainable development and cohabitation between man and the environment on conditions that will make sure we leave this world to our descendants as we would like to receive it ourselves. The present generation has to take responsibility for the long term consequences of environmental impact in general, and radiation protection in particular.

A passable way of creating a foundation for sustainable decision making is the Environmental Impact Assessment. The EIA process is a cornerstone of Swedish environmental protection legislation.

Ionizing radiation is both beneficial and harmful. Radiation is widely used to the benefit of mankind in medicine, research and industry. But people are also apprehensive about radiation. The nature of radiation is such that we cannot see it, feel and smell or touch it and that scares a lot of people. This is one reason why research is so important and why we politicians should base our decisions on facts.

We politicians need to be trustworthy in our work and you, gathered here to discuss the issue of protection of the environment from the dangerous effects of ionizing radiation, can help us to be so. During this week you will listen to results from research projects, you will hear standpoints made by international organizations and you will discuss issues related to the work of the supervisory authorities.

In my vision, in our common vision, Swedish moose will be able to choose blueberries in the forest without this resulting in high levels of caesium. In my vision, no child will be born with defects caused by radioactive substances. In my vision, people will not need to worry about the possibility of radioactive substances harming their children, the animals or plants.

You play a major role in the efforts to realize our common vision. Through research, knowledge and wise decisions, together we will be able to fulfil our vision of a sustainable society, a society protected against the damaging effects of radiation in the outdoor environment.

It is a great honour for me to be able to welcome you all to this conference, focusing on protection of the environment from radiation. I hope you will have many fruitful discussions and a pleasant stay here in Stockholm.

OPENING ADDRESS

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It is my honour and pleasure to welcome you, on behalf of the Director General of the IAEA, to this International Conference on the Protection of the Environment from the Effects of Ionizing Radiation. Also, I would like to offer sincere thanks to the Government of Sweden, represented here by Minister Sommestad, for hosting this conference and to the Swedish Radiation Protection Authority for its considerable efforts in organizing it.

The nuclear era has spanned little over a half century, and in that comparatively short period we have witnessed dramatic changes in the way in which the public and their politicians view the environment.

Until the 1960s, people were concerned primarily with their own health and prosperity — there was little reason to think that the environment was at risk.

Increasingly, however, as time went on, there was evidence — for the public to see — of the environment being damaged. Emissions from the burning of fossil fuels were causing acid rain, resulting in damage to sensitive ecosystems, and the increased use of chemical fertilisers was resulting in polluted surface waters, upsetting ecological balances and causing more visible evidence of a deteriorating environment. More recently, the threat of global warming and its possible implications for humans and their environment has become a common concern.

Thus, from the 1970s onwards, there was an increasing consciousness that the environment — which depends on a delicate and complex balance of ecosystems — must be cared for and protected. This led to the UN Conference on the Human Environment in 1972 and to the UN Conference on Environment and Development in 1992. The latter conference, called the ‘Earth Summit’, resulted in the Rio Declaration, which, among other things, concluded that “in order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be isolated from it”. This was reinforced in the declaration of the World Summit on Sustainable Development held in Johannesburg last year, where it is stated that there is a "collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development — economic development, social development and environmental protection".

The Rio Declaration has had a significant impact on policy setting at the international, regional and national levels. In the field of nuclear energy, international conventions and safety standards established since adoption of the Rio Declaration contain explicit statements requiring that the environment (as well as humans) be protected. For example, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management has the protection of individuals, society and the environment from harmful effects of ionizing radiation as one of its objectives. At the regional level, there can be no doubt that the call for dramatic reductions in discharges of all pollutants to the environment made in the Sintra Statement of the OSPAR Convention is to some extent a reflection of the 'Rio spirit'.

With the growing interest in improved environmental protection, it was gradually realized that the international standards for radiation protection were insufficient since they focused exclusively on the protection of humans. While there is no evidence of any permanent harm having been caused to the environment by nuclear activities under normal conditions, it is clear that the subject has not been formally addressed in setting safety standards and that there is a gap in our philosophical approach.

This insufficiency was recognized at an international symposium held here in Stockholm in 1996 and the progress towards rectifying the situation has been punctuated by further international meetings — in Ottawa in 1999, in Darwin in 2002 and now back here in Stockholm. I am pleased to say that the IAEA has played an active role in each of these meetings.

In the meantime, the relevant international organizations have been very active in working towards establishing an accepted environmental protection philosophy. The United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR), the International Commission on Radiological Protection (ICRP) and the IAEA have been working, as we shall hear at this conference, in a coordinated manner supported by the OECD Nuclear Energy Agency, by the European Commission and by the International Union of Radioecology.

It is important that the international scientific community be thorough and objective in its work. The subject is complex and there are many aspects to consider, not least the fact that the peoples of the earth view the environment in different ways, as reflected in a broad spectrum of ethical views represented by anthropocentric, ecocentric and biocentric approaches. Therefore, although it is now generally recognized that it is necessary to go beyond a simple anthropocentric approach, it is not possible to define a single ethical framework that uniquely defines the objectives of environmental protection. These issues have been examined in an IAEA publication which will no doubt be referred to later.

The IAEA's aim is to support efforts to improve the environment through the establishment of safety standards which will reflect a global consensus on how the environment can be properly protected from the effects of ionizing radiation. In doing this, the IAEA endeavour to incorporate the conceptual framework, principles and analytical methodology which are now being developed by the ICRP into a practical system that can be used by national regulators and operators.

However, serious concerns have been expressed by some States and their industries with regard to the danger of establishing unreasonably restrictive discharge standards. The nuclear industry is justifiably seen as an environmentally clean industry — there is no apparent evidence of harm, and so we must guard against any tendencies to be unjustifiably restrictive. In particular, there is the issue of resources — these differ from country to country, and we must be conscious of this and not impose standards involving requirements as regards radiation that are too disproportionate in relation to other pollutants and to other risks in life.

And so, in developing our standards, we must keep these concerns in mind while maintaining a sound philosophical basis. The IAEA has an elaborate process for developing international safety standards, with a system of committees containing senior governmental representatives from its Member States. In addition, all IAEA safety standards must be reviewed by national authorities, and the higher level safety standards, such as the Safety Fundamentals and Requirements, must be approved by the IAEA's Board of Governors. Thus, there is a process already in place to ensure that proper consultation takes place. The opportunity will exist for all national and ethical viewpoints to be taken into account in establishing the standards. There will also be scope for step-by-step improvement through feedback from the application of the standards, which the IAEA supports through the provision of a variety of safety services.

This conference represents an important step in the process of establishing an accepted international framework for environmental radiation protection. This has been recognized by the latest General Conference of the IAEA, which has welcomed the steps taken in developing an international framework for the protection of the environment from ionizing radiation and drawn attention to this conference.

Finally, what does the IAEA expect from this conference? The IAEA and the other supporting international organizations expect to receive advice on how they should proceed in establishing an accepted international framework, as a basis for the development of international standards for protection of the environment. This is particularly necessary in view of the new and complex nature of the issues involved. There is a need to develop standards that are scientifically robust and also comprehensible and acceptable to operators and regulators as well as to the public. We therefore need input from a wide variety of international experts with interests in this subject. In this context, I am glad to note the wide-ranging participation in this important conference and look forward to a successful outcome of lasting value.

OPENING ADDRESS

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The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is proud to co-sponsor this conference.

UNSCEAR has the mandate from the United Nations General Assembly to assess sources and effects of ionizing radiation. UNSCEAR assessments form the foundation for international regulations aimed at radiation protection, for example by the IAEA in its International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources. It also contributes to the underpinnings of the recommendations for radiation protection by the ICRP.

UNSCEAR's role is scientific and it does not itself make recommendations. Its mandate on sources and effects includes the environment. It has long evaluated sources that contribute to exposure in the environment. In its 1996 Report on "Effects of Radiation on the Environment", it examined a number of topics and, importantly, came up with dose rate criteria for the protection of lower form biota that have largely stood the test of time.

In the new document cycle, begun at the 50th Session, UNSCEAR is again extending its examination of effects on the environment. This includes radioecology, pathways analyses, radiation weighting factors for non-human biota, and importantly, looking for evidence of impacts at specific sites, to serve as a litmus test — an acid test — for effects on the environment when models that are typically used are applied.

UNSCEAR does not do mere compilations of data. It has a proud history of applying rigorous standards of data analysis and scientific judgements to these end points. One of the things we maintain is similar to one of the Ten Commandments of Biochemistry, "Don't waste clean thinking on dirty data — it can turbidify the field!"

A sign of our commitment is that some half dozen or more members of the UNSCEAR Committee or the Secretariat are here at this Conference, including: our past Chairman: Mr. Holm, who is also President of this Conference; the Chairman-elect, Dr. Sasaki of Japan; and the representative from the UK, who happens to have an evening job as Chairman of ICRP.

We are proud to co-sponsor this Conference. We welcome you to it, and we are listening to the discussions and the deliberations.

Best of luck; progress has been significant and there are elements we hope to be able to wrap up this week.

OPENING ADDRESS

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It is an honour for me to make this opening address on behalf of the European Commission which has cooperated with the International Atomic Energy Agency in organizing this Conference, and in particular on behalf of Hans Forsström from the Directorate-General, Research, who will arrive only later this week.

Protection of the environment is, and will continue to be, an important consideration in the development and application of soundly based radiation protection standards. Current standards rest largely on the premise that, in protecting man, the environment is afforded an adequate level of protection. While this premise is broadly accepted by the radiation protection profession, it has come under increasing challenge in recent years. This challenge has not arisen because of any observable damage to the environment while operating within current standards. Rather, it has different origins including:

— The robustness of the premise that protection of man affords protection of the environment, in particular the extent to which it is based on value judgements as opposed to rigorous scientific argument;
— The more explicit inclusion of protection of the environment into national legislation on radiation protection and the need to demonstrate compliance;
— A desire to achieve greater comparability between radiation and other pollutants.

These trends were recognized by the Commission in the late 1990s and, as a result, the topic of protection of the environment was included as an important element of the European Union's 5th Research Framework Programme. Community support has been given to the FASSET project about which we will hear much during this Conference. This multinational project is providing much of the scientific basis underpinning and informing ongoing discussions on the development of a system of protection for the environment. Much, however, remains to be done to establish a well conceived and practicable system for protection of the environment, in particular one that is likely to find broad international acceptance. In this context, the topic was included as an important element of the Commission's 6th Research Framework Programme with the specific objective of "establishing a robust conceptual and methodological basis for underpinning sound policy and standards for protection of the environment from radiation". A contract is currently being negotiated to this purpose — the ERICA project which is expected to make a major contribution in this area.

Progress within the ERICA project and initiatives being taken to develop standards in other quarters (e.g. IAEA, ICRP) will determine the need for further supporting RTD. In principle, within the next few years, an adequate scientific basis should be established for underpinning standards, albeit supported by further modest research of a confirmatory nature.

The Commission has, at present, no plans to establish explicit standards for protection of the environment from radiation. You may be aware that we had included in the work programme of DG Environment the establishment of an Environmental Action Programme under the EURATOM Treaty (complementary to the 6th EAP under the EC Treaty). A follow-up to the Stakeholders' Conference on Approaches to the Management of Environmental Radioactivity of December 2002 was foreseen for 2004. However, in view of the preparation of this EURATOM EAP it cannot be guaranteed at the moment. But the Commission will continue to monitor developments in environmental radiation protection, in particular the results of its sponsored research and the activities of ICRP and IAEA. Should the need arise for standards at a European level, the Commission would respond in a timely manner. If and when it does, important considerations will be the adoption of a system that is robust, practicable, cost effective and proportionate to the problem at hand. A proper balance will need to be achieved between science and policy.

I will end my opening remarks with these last thoughts which I hope will be kept in mind throughout the remainder of this conference.

OPENING ADDRESS

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It is encouraging to see so many experts gathered here today to discuss the important issue of environmental protection from ionizing radiation. The International Union of Radioecology (IUR) has collaborated constructively with other international organizations, notably the ICRP, the IAEA, UNSCEAR and the EU, and hope that these close links may be strengthened and developed in the future. Such international cooperation has been conducive to rapid progress on the theme of radiological protection of the environment in recent years.

The IUR, as an independent scientific association, has been fighting to put environmental radioactivity in the same context as other environmental problems within regulatory and political agendas. In the early years, it could be quite embarrassing because there was little support for this initiative, but now it can give us great satisfaction that the topic appears to be receiving the international attention it deserves. However, it is imperative that any advances are built on a foundation of scientific knowledge.

The IUR task group, formed in 1997, took note of a number of initiatives and ideas being developed within the radiological protection community. The IUR was the first international organization to conclude that a systematic approach was required in order to develop a framework within which various initiatives could be accommodated and, in 2000, such a system was presented and promoted. The IUR also highlighted the need to consider the broader socioeconomic context within which these ideas were beginning to evolve.

I would now like to spend a few moments of your time to update you on the IUR's views and activities.

A consensus conference was held in Oslo in 2001, supported by a number of representatives from NGOs, industry, academia and regulators. A surprising degree of agreement was achieved, enabling the drafting of a consensus statement — stating that the environment should receive radiological protection. Members of the IUR have been at the forefront of exploring ethical and legal aspects of protection of the environment. Their work can be seen in recent IAEA and IUR publications as well as participation at the World Summit on Sustainable Development in Johannesburg and contributions made to the ICRP Task Group working on radiological protection of non-human species.

At the IUR-sponsored conference in Monaco, together with other current initiatives and research efforts, the IUR have been able to present the current status of work connected to radiological protection of the environment and have also been able to make recommendations for future work in the field. Foremost amongst these recommendations was the requirement for basic scientific research in order to strengthen our assessment system and increase confidence in our decision making practices.

I can assure you that the IUR will continue in these activities, and I hope that you all enjoy this interesting and useful conference. I would like to finish by expressing my gratitude to the personnel of Swedish Radiation Protection Authority for their great efforts in staging this event.

CONFERENCE PRESIDENT'S ADDRESS

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The objective of the Conference is to promote the development of a coherent international policy on the protection of the environment from the effects of ionizing radiation and to foster information exchange on this subject. The organizers, the IAEA in cooperation with United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the European Commission (EC) and the International Union of Radioecology (IUR), as well as the hosts of the conference, the Government of Sweden through the Swedish Radiation Protection Authority (SSI), are pleased that so nearly 300 delegates from 53 countries have been nominated by their governments to attend this meeting.

I wish to express my gratitude to the members of the Programme Committee and the Conference Secretariat for their input in arranging this conference. It follows on from previous meetings and symposia held by or in cooperation with the Agency, and I should like to introduce the Conference by mentioning some important events that have brought us here today.

Great progress has taken place in environmental protection over the last thirty years. The 1972 United Nations (UN) Conference on the Human Environment in Stockholm was the first international conference to lay down principles for the protection and improvement of the human environment [1]. Already in 1968, the Government of Sweden had proposed a UN conference on environmental protection to focus attention of Member States to the environmental problems. Many UN bodies and other international organizations were at that time already involved in this field, and a need was felt for coordination and for exchange of information and experience between scientists and politicians. There was also a need to define aspects that could only be dealt with by international organizations.

At its 23rd session in 1968, the UN General Assembly decided to convene a Conference on the Human Environment with the main purpose "to serve as a practical means to encourage, and to provide guidelines for, actions by Governments and international organizations designed to protect and improve the human environment, and to remedy and prevent its impairment, by means of international cooperation, bearing in mind the particular importance of enabling developing countries to forestall the occurrence of such problems" [2]. It is therefore a particular pleasure for me to welcome the person who initiated this process, namely the former ambassador of Sweden to the UN, Mr. Sverker Åström. It was Mr. Åström's vision that convinced the Swedish Government about the necessity to work for a UN conference, and he also presented the Swedish view at the UN General Assembly in 1968. Mr. Åström was also instrumental in the planning and implementation of the Stockholm conference. Without his visionary ideas, we might not have been here today.

Following the Stockholm Conference, the General Assembly created the UN Environment Programme (UNEP). The concern for the environment was also expressed in a number of international conventions, dealing with topics such as pollution prevention and protection of endangered species. In 1980, the World Conservation Strategy was published [3]. This strategy is considered to be the first comprehensive policy statement on the link between conservation and sustainable development. Its aim was to help advance the achievement of sustainable development through conservation of living resources. The strategy explained the contribution of living resource conservation to human survival and to sustainable development, and identified the priority conservation issues and the main requirements for dealing with them.

In 1987, the World Commission on Environment and Development alerted the world to the urgency of making development in a sustained manner and without depleting natural resources or harming the environment [4]. The report emphasized the need to preserve biological diversity and defined the concept of sustainability as "the use of biological components of biological diversity in a way and at a rate that does not lead to the long term decline in biological diversity, thereby maintaining its potential to meet the demands of present and future generations". By and large, this or similar definitions have been accepted in other international forums as well as by national authorities.

The 1992 United Nations Conference on Environment and Development in Rio de Janeiro [5] then laid down a number of general principles for environmental protection, e.g. the Rio Declaration, the Convention on Biological Diversity, and the Agenda 21 Programme of Action. The Rio Declaration emphasizes that protection of the environment shall be an integral part of the development process and that development shall be sustainable. The Convention on Biological Diversity stresses the importance of recognizing that all organisms contribute to the structure of the ecosystem. It defines the concept of biodiversity as "the variability among living organisms within terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part". This includes diversity within species, between species, and of ecosystems.

Biological diversity is dynamic and continuously changing, and preservation of biological diversity thus does not mean conservation of a certain state.

Rather, it means protection against harmful effects that would cause diversity to develop in a fashion that would not have been the case had the environmental contaminant/pollutant not been there. There are different approaches to protecting the environment, and they can all be seen as different facets of environmental management [6]:

- **Environmental exploitation**, where the aim is to crop sustainably populations of animals or plants, e.g., fisheries, forestry;
- **Conservation and protection of the natural environment**, which may include the requirement to protect individuals, the local population of particular species, or ecosystems;
- **Pollution control**, where the aim is to safeguard humans, usually by reference to some kind of environmental quality standards, or via some form of toxicity test in order to protect wildlife.

Different ethical views affect the way in which people view the environment, their impacts upon it, and how best to manage the consequences. Such different ethical views have resulted in different social, cultural, religious, and legal differences across the world. A recent IAEA study [7] identified the anthropocentric, biocentric, and ecocentric views about what has moral standing in the world, with a wide range of views within each of the three categories.

Many methodologies and regulations to protect the environment have been developed, over many years, notwithstanding the fact that our understanding of ecology is incomplete, as is our understanding of the impact of environmental pollutants generally. Consideration of these limitations has resulted in the adoption of several operational strategies with the purpose of protecting the environment, including the pollution prevention principle, the precautionary principle, the principle of using best available techniques and technologies, the substitution principle, the polluter pays principle, and the principle of informed consent [8].

These strategies have resulted in regulations for environmental protection that combine minimization of environmental effects based on scientific evidence and pollution prevention to the extent that is achievable based on social and economic considerations. Any framework for environmental protection that is developed for radioactive emissions therefore needs to acknowledge and accommodate these strategies, and needs to be compatible with other environmental protection approaches that will be in place for non-radiological emissions from the same facilities or other industrial practices.

1. RADIATION AND THE ENVIRONMENT

The accident at the Chernobyl nuclear power plant in 1986 is the most serious accident involving radiation exposure. Apart from the effects in human beings, large territories were contaminated and deposition of released radionuclides was measurable in all countries of the Northern Hemisphere, and the accident thus focused attention also to the environmental effects. Over the last decade, protection against radiation effects in the environment has attracted increasing interest, concomitant with the general development of environmental protection. There is today rapid progress in the development of approaches to address assessment of radiation effects in non-human species and protection of the environment, driven to a large extent by the needs of national regulators and legal demands to meet public concerns. The following section briefly outlines some recent developments in selected international bodies dealing with ionizing radiation and radioactive contamination.

1.1. International conventions

Several international conventions emphasize the need for radiological protection of the environment. The Joint Convention on the Safety of Spent Nuclear Fuel Management and on the Safety of Radioactive Waste Management [9] came into force in 2001, and aims at protecting individuals, society and the environment against the harmful effects of radiation.

As part of the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, the strategy with regard to radioactive substances in practice means that by the year 2020, discharges and emission of radioactive substances should be reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero [10].

1.2. United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR

In 1996, UNSCEAR published a report on the effects of radiation on the environment, taking into consideration the specific problems encountered with dosimetry and quality factors for non-human species, experience from experimental studies, observations made in certain environments as a result of routine discharges as well as observations made after accidental releases [11]. The report summarized a large amount of work that had been done on this subject for many decades and serves as a scientific background document to the development of standards and recommendations by regulatory bodies.

1.3. International Commission on Radiological Protection, ICRP

ICRP's recommendations on radiological protection form the basis for codes and regulations issued by other international organizations and by regional and national authorities [12]. ICRP has recently decided to develop a framework for the assessment of radiation effects in non-human species [8]. This decision has not been driven by any particular concern over environmental radiation hazards, but rather to fill a conceptual gap in radiological protection, and to clarify how ICRP can contribute to the attainment of society's goals of environmental protection.

1.4. International Atomic Energy Agency, IAEA

The IAEA has addressed environmental protection on several occasions since the 1970s. The Safety Fundamentals on Radioactive Waste Management [13] state that radioactive waste shall be managed in such a way as to provide an acceptable level of environmental protection. The Agency has published a series of Technical Documents with relevance for radiological protection of the environment and, because of a perceived international need, has recently taken initiatives to develop a document on environmental protection for its Safety Series. The main purpose of this Conference in Stockholm is to foster information exchange as a starting point for an international action plan for the protection of the environment.

1.5. European Community, EC

On the EC level, the Euratom Treaty fulfils the primary requirements relating to radiological protection of man, and there are several EC Directives that relate to environmental protection. In view of the increasing awareness in the European Union of the need for a system to demonstrate protection of the environment and current work on demonstration of protection of biota, the EC is also funding scientific research in this area. The FASSET (Framework for Assessment of Environmental Impact) programme involves 15 organizations in seven European countries, and aims at obtaining a scientific basis for judging the likelihood or not of radiation damage to biota in the context of protecting humans and the environment (see www.fasset.org). This Conference will coincide with the termination of the FASSET, and with another EC project, EPIC (Environmental Protection from Ionizing Contamination in the Arctic).

1.6. International Union of Radioecology, IUR

In 2001, the IUR was one of the organizers of a consensus conference on protection of the environment [14]. A Consensus Statement from that conference included the following guiding principles: "Humans are an integral part of the environment, and whilst it can be argued that it is ethically justified to regard human dignity and needs as privileged, it is also necessary to provide adequate protection of the environment. In addition to science, policy making for environmental protection must include social, philosophical, ethical, political and economic considerations. The development of such policy should be conducted in an open, transparent and participatory manner. The same general principles for protection of the environment should apply to all contaminants."

1.7. Other initiatives

The Nuclear Energy Agency of the OECD recently organized an international forum in 2002 to discuss radiological protection of the environment [15]. Much has also been learned from national programmes with regard to the development of requirements and guidance for the radiological protection of the environment [8].

In the year 1999, the Swedish Parliament adopted 15 national environmental quality objectives for different environmental sectors, describing what quality and state of the environment, as well as the natural and cultural resources, in Sweden are ecologically sustainable in the long term. The purpose with the environmental objectives is that, one generation from now, the major environmental problems currently facing us will have been solved. To guide efforts to achieve these objectives, Parliament has adopted interim targets for each of them, indicating the direction and timescale of the action to be taken. The Environmental Objectives Council coordinates efforts to achieve the goals, and monitors the action being taken.

The national objective for radiation, A Safe Radiation Environment, concerns both ionizing and non-ionizing radiation. SSI has the responsibility for formulating the goals, coordinating the follow-up, and is currently developing a national environmental monitoring programme in order to achieve the objective. The ultimate purpose of this objective is to provide the necessary foundation for determining whether human health and the environment are protected from the harmful effects of radiation. To provide such a foundation, a system including criteria for protecting the environment must be formulated [16].

2. RECENT MEETINGS ON RADIOLOGICAL PROTECTION OF THE ENVIRONMENT

Seven years ago, the first international symposium on ionizing radiation and protection of the natural environment was organized in Stockholm by SSI in cooperation with Atomic Energy Control Board of Canada [17]. The symposium explored the scientific basis for setting criteria and whether there was any movement in the scientific community to go further in the direction towards environmental protection approaches, i.e., the subject of today's conference. The symposium covered topics such as biological and ecological effects of ionizing radiation, behaviour and transport of radionuclides in the natural environment, and criteria for environmental protection.

A second symposium took place in Ottawa in 1999 and was organized by the Canadian Nuclear Safety Commission (CNSC) in cooperation with SSI and the Australian Office of Supervising Scientists [18]. The scope of the second symposium had both widened and deepened with themes such as environmental management, public participation, and multiple stressors. At that meeting, a striking change was noticeable in the attitude towards radiological protection of the environment, and many participants reported on both scientific programmes and on initiatives by authorities.

The third international symposium took place in Darwin in 2002, organized by the Australian Office of Supervising Scientists and the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), in cooperation with IAEA with the support of a number of other agencies [19]. The main focus of the meeting was the development and application of a system of radiological protection for the environment, reflecting the international work to define a framework for the assessment and management of radiation effects in the environment. The three main topics were ionizing radiation and biota; frameworks for environmental protection; and radiation as a stressor to the environment.

This is the historic background to this week's conference in Stockholm. In summary, there has been a shift in society from the long held human focused approach to environmental matters to one that embraces both biotic and abiotic components of the environment. And all of the recent conventions, principles, reports and statements lend support to the now widely held view that there is a need to demonstrate, explicitly, that the environment can and will be protected from the effects of radiation.

3. OBJECTIVES AND AGENDA OF THE CONFERENCE

The main objective of the conference is, as I said initially, to promote the development of a coherent international policy on the protection of the environment from the effects of ionizing radiation and to foster information exchange on this subject. The Conference will provide a timely opportunity to discuss the work of international organizations, and the work under way in a number of Member States.

Another objective is to discuss the implications of the ICRP's proposal for a framework to assess radiation effects in the environment. A framework for radiological protection of the environment must be practical and simple, as should be international standards for discharges into the environment that take account of such an approach. This is a task for the IAEA, in cooperation with other international organizations. This conference therefore provides an opportunity for you to influence the development of both ICRP and IAEA policy in this area.

The background session today will give information on the current situation as well as social and political drivers for change. A number of organizations will provide an insight to the present status of international policies on the radiological protection related to releases to the environment. During the course of the conference, there will be five topical sessions that will cover selected subjects related to protection of the environment, such as stakeholders' views, case studies, approaches for non-radioactive pollutants, the state of current scientific knowledge and, finally, the implications of ICRP proposals for international safety standards.

Keynote speakers will address key issues within each topical session, and a rapporteur will summarize the issues and trends arising from the relevant contributed papers. A total of 72 contributed papers have been accepted for inclusion in the Book of Contributed Papers, available to participants upon registration. The papers will be presented as posters and displayed during poster sessions, as indicated in the programme.

Five round table sessions will address controversial issues and provide an opportunity to discuss issues arising from foregoing topical sessions. Each session addresses a key question that will need to be answered in the further development of environmental radiation protection:

— Is stakeholder involvement an essential element of environmental radiation protection, and how should it be achieved?
— Is consistency of regulations for ionizing radiation and other pollutants important?

— What are the implications of the existing knowledge about the exposure of and effects of radiation on non-human species for the protection of the environment, and what are the most significant data gaps?
— Do the ICRP proposals provide an appropriate way forward to the development of an approach to the protection of non-human species?
— Communication with the public and the role of the media.

The conference will end with a concluding session at which the round table discussions will be summarized and the overall results and conclusions of all topical and round table sessions will be summarized by the President of the conference.

I should like to end by thanking the Swedish Government for its support, and by expressing my appreciation again to UNSCEAR, the European Commission and the International Union of Radioecology for their co-sponsorship and cooperation in organizing the conference. I thank you all for supporting the work of IAEA, and I wish you a successful meeting.

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OPENING ADDRESS

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I have been asked to say a few words about the origins of the United Nations Conference on the Human Environment, held in Stockholm in 1972. That conference can, I think, be regarded as the beginning of organized international discussion on protection of the environment.

In the 1960s, when I was Swedish Ambassador to the United Nations, it was customary for the United Nations to organize each year a major conference on a topic of global importance. There were always two proposals for the topic, between which the representatives of United Nations Member States in New York had to choose. In 1968 the choice of topic for 1972 was between the peaceful uses of atomic energy and protection of the environment.

In the Swedish delegation, we thought that a further major conference on the peaceful uses of atomic energy was not necessary, having concluded that the main purpose of such conferences was to promote United States industrial interests. Moreover, in our view the time was right for a major conference on protection of the environment. The international community was becoming increasingly aware of the harmful environmental effects of rapid industrialization, particularly after the publication of Rachel Carson's book "Silent Spring". So we took the initiative in the autumn of 1968 and succeeded in having protection of the environment chosen as the topic for 1972.

During the preparations for the conference, which was to take place in Stockholm, we faced a formidable array of opponents. Firstly, some industrially advanced countries, such as France and the United Kingdom, thought a strong United Nations focus on environmental protection would lead to constraints on their further industrial development — and they were supported by a number of the United Nations agencies, such as FAO and UNESCO, which thought that they were doing enough about environmental protection within their respective spheres. Secondly — and more importantly — there was opposition in the beginning from developing countries which, led by Brazil, thought that the choice of environmental protection as the topic was a plot of some industrial countries to hinder industrial development in the developing world by creating various obstacles in the form of regulations for the protection of the environment. Their opposition slowly melted away, however, thanks mainly to Maurice Strong, a rare mixture of idealist and pragmatist who became

Secretary General of the conference — and later also of the conference held in 1992 in Rio de Janeiro.

In addition, there was opposition from the Soviet Union, whose representatives said "There are no environmental problems in the Soviet Union. Under Socialism, such problems cannot exist!" However, assistants from academia attached to the Soviet delegation would come and whisper in my ear "Don't believe that official nonsense. The Soviet Union is the worst hit country in the world as regards environmental deterioration. The whole country is a catastrophe!" Ultimately, however, the Soviet Government modified its practical position — if not its ideology — and collaborated, to some extent, in preparing for the conference, and after the conference (in which the Soviet Union did not take part since the Germany Democratic Republic had not been invited to participate) it took part without reservations in the follow-up work.

The conference was to a large extent designed to increase awareness of the problems of environmental protection, since many governments — including the governments of some very important countries — were completely ignorant of and indifferent to such problems. In order to formulate positions regarding the various items on the conference agenda, governments had to get in touch with and seek advice from their scientific institutions, with which there had generally been very few contacts before. The scientific institutions were, of course, delighted to be consulted and to have an opportunity to tell their governments the truth about environmental problems.

The 1972 conference led to the adoption of a number of conventions and, most importantly, to acceptance of the principle that a country is responsible for the effects of its own acts on the environment in another country — a kind of international responsibility which until then had been unheard of. But the most important achievement, in my view, was the fact that, in the years following the conference, environmental legislation was passed and environmental ministries established in about a hundred countries as a direct result of the conference. Governments came to realize that environmental problems were important also from a political point of view.

BACKGROUND SESSION

Chairperson

L.-E. HOLM
Sweden

ENVIRONMENTAL RADIOACTIVITY
The development of the ICRP philosophy

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Abstract

The International Commission on Radiological Protection has existed for 75 years and throughout that time has produced recommendations for the protection of people against the dangers of ionizing radiation. It recognized some 25 years ago that the environment should also be protected, but the policy was to assume that the protection of people was sufficient to protect other species. The Commission thus regarded the environmental transfer of radionuclides as important only for the purposes of evaluating doses to people. In 2000 the ICRP established a Task Group to recommend whether the Commission should be more specific with regard to protection of the environment and, if so, how it should be addressed. This paper traces the development of the ICRP policy for environmental radioactivity to the present time.

1. INTRODUCTION

Roentgen discovered X rays in 1895, and in 1896 the first paper appeared reporting radiation damage to the skin of the hands and fingers of the early experimental investigators. Radium was also used for therapy soon after Becquerel's identification of the phenomenon of radioactivity, also in 1896, and in the next ten years several hundred papers were published on the tissue damage caused by radiation. Several countries were actively reviewing standards for safety by the start of the First World War, but it was not until 1925 that the International Congress of Radiology was formed and first met, in London, to consider establishing protection standards. The second Congress was held in Stockholm in 1928 and established the International X ray and Radium Protection Committee (IXRPC), which evolved in 1950 into the present International Commission on Radiological Protection (ICRP). The ICRP remains one of three Commissions of the International Society for Radiology and the parent body approves the rules by which the Commissions operate.

The early recommendations were concerned with avoiding threshold (deterministic) effects, initially in a qualitative manner, since a system of measurement or dosimetry was needed before protection could be quantified and dose limits could be defined. The roentgen was defined at the second International Congress of Radiology during the Stockholm meeting in 1928 and by 1934 the IXRPC recommendations had been made implying the concept of a safe threshold:

> "Under satisfactory working conditions a person in normal health can tolerate exposure to x-rays to an extent of about 0.2 roentgens per day" [1].

This is about ten times the present annual occupational dose limit. The tolerance idea continued, and in 1951 ICRP made the following statement:

> "The figure of 2 r per week seems very close to the probable threshold for adverse effects."

This led to a proposed limit of 0.3 r per week for low LET radiation [2]. In considering neutrons and alpha particles, it was stated that:

> "Anaemia and bone damage appear to have a threshold at 1 μCi Ra-226."

By 1954 the threshold was rejected so that:

> "Maximum permissible doses were such as to involve a risk which is small compared with other hazards in life", and "Since no radiation level higher than natural background can be regarded as absolutely 'safe', the problem is to choose a practical level that, in the light of present knowledge, involves a negligible risk" [3].

The epidemiological evidence emerging of excess malignancies amongst American radiologists and the first indication of excess leukaemia in the survivors of Hiroshima and Nagasaki brought about the change.

The problem had become one of limiting the probability of harm to humans, and much of what has subsequently developed related to the estimation of that probability of harm and the decision on what level of implied risk is acceptable or, more importantly, unacceptable. The problem arises in both working and public environments.

At that time the Commission concerned itself with establishing principles for environmental monitoring and developed the concepts of the critical nuclide, critical pathway and critical group [4]. This was essentially a methodology for identifying the radionuclide that gave the highest dose, via the highest transfer pathway, to a group of the public representative of those receiving higher doses than the rest of the population. Thus the Commission identified the need for environmental transfer factors but did not assess and recommend their values.

2. THE 1977 RECOMMENDATIONS

In 1977 the Commission first quantified the risks of stochastic effects of radiation and proposed a System of Dose Limitation [5]. The Commission stated in paragraph 6 that:

> "Radiation protection is concerned with the protection of individuals, their progeny and mankind as a whole, while still allowing necessary activities from which radiation exposure might result."

The Commission then went on to say in paragraph 14 that:

> "Although the principal objective of radiation protection is the achievement and maintenance of appropriately safe conditions for activities involving human exposure, the level of safety required for the protection of all human individuals is thought likely to protect other species, although not necessarily individual members of those species. The Commission therefore believes that if man is adequately protected then other living things are also likely to be sufficiently protected."

This was the first occasion on which ICRP had addressed the question of the effects of radiation on species other than mankind, although clearly it was not pursued. The Commission quickly supplemented its Publication 7 with Publication 29 [6] which was concerned with the prediction of the relationship between releases and the appropriate dose quantities before the commencement of operations giving rise to the release of radioactive materials, whereas the earlier Publication 7 was principally concerned with environmental monitoring during and after such releases.

Much of the work of ICRP was concentrated upon the development of human biokinetic data and the assessment of doses both for workers and the public from the ranges of radionuclides likely to be encountered. This included the development of a 'Reference Man' to develop standardized dose intake data. However, another important branch of the programme that influenced, indirectly, protection of the environment followed the introduction of the Optimization principle in the System of Dose Limitation.

The principle was introduced because of the need to find some way of balancing costs and benefits of the introduction of a source involving ionizing radiation or radionuclides. Thus it was stated [5] that:

> "All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account", ICRP 26, paragraph 12 [5].

This criterion was not necessarily sufficient to protect individuals so it was complemented by the dose limits for individuals which were not to be exceeded. As a result of introducing this requirement, doses to non-human species were certainly reduced to some extent in the majority of situations.

3. THE 1990 RECOMMENDATIONS

In 1990 the Commission produced new Recommendations partly because of revisions upward of the estimates of risk from exposure to radiation, and partly to extend its philosophy to a System of Protection, rather than one of dose limitation [7]. The principles of justification, optimization and dose limitation remained, but more stringent requirements were placed on the optimization of protection from sources by restricting maximum doses or risks by constraints so as to limit the inequity that is likely to result from the inherent economic and social judgements.

As far as protection of the environment was concerned, ICRP retained essentially the position that it had in the 1977 Recommendations:

> "The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species. At the present time, the Commission concerns itself with mankind's environment only with regard to the transfer of radionuclides through the environment, since this directly affects the radiological protection of man", ICRP 60, Para. 16 [7].

In more explicit terms, the policy can be stated as follows:

— ICRP's system of protection provides protection for humans. The system is not confined to dose limits.

- The application of the system of protection may sometimes damage or kill individual members of non-human species. The Commission's policy has been to acknowledge this limited consequence.
- Although ecological information is incomplete, the full application of the system of protection is not thought to endanger whole species or to create imbalance between species. If this were not so, the Commission's policy would be to require additional restrictions.

This approach was not clearly set out and has been misinterpreted to mean that ICRP's dose limits alone would be sufficient to protect non-human species. The Commission has not claimed that the dose limits would be sufficient for this purpose. It also follows that the Commission has not dealt explicitly with radiological protection of the environment, although non-human organisms may well have been afforded an indirect measure of protection as a result of the controls on radionuclide concentrations in environmental media established as part of the system of radiological protection of humans.

Although there are currently methods and approaches already available or being developed by individual countries, there are no ICRP recommendations on appropriate assessment philosophies, methodologies or guidelines on how radiological protection of the environment should be carried out. In particular, ICRP has not advised on whether justification or optimization should be considered in the cases of protection of species other than humans, or what dose limits — if any, and under what circumstances — should or could be applied to other organisms.

Society's concern for environmental risks has put pressures on policy makers and regulators to define protection strategies that specifically and explicitly include the environment, as evidenced by a growing number of international and national legal commitments. This reflects both a need to protect the environment so as to maintain a suitable environment in which humans can exist, and a concern for the environment per se. In turn, these concerns reflect worries related to the possible effects of ionizing radiation on the environment, as well as a desire to protect the environment simultaneously from a wide range of harmful influences. To meet the broader concern, strategies for protection of the environment are increasingly required to be applicable to radiation as well as to other pollutants.

4. PROBLEMS IDENTIFIED SINCE THE 1990 RECOMMENDATIONS

The Commission does not include in its objectives the protection of features of mankind's environment such as weather or the availability of materials. The Commission position regarding protection of non-human species (para. 11) has a significant weakness. It is assumed that the protection of a complete species, but not of individuals in the species, would provide an adequate standard. This level of ambition, and the recognition that the standard of protection of humans is more restrictive than that provided by the dose limits alone, is very likely to be true, but the level of ambition is probably too low.

Many contend that the environment is already sufficiently protected from radiation, and that there is therefore no reason to put resources into the development of a system to protect non-human organisms. It is probably true that the human habitat has been afforded a fairly high level of protection through the application of the Commission's system of protection. The problem is to demonstrate convincingly that the environment is, or will be, adequately protected in different circumstances, because there are no explicit sets of agreed assessment approaches, criteria, or guidelines with international authority that can help. This leads to different national approaches and makes international harmonization difficult.

There are also several examples of situations where the Commission's current view is insufficient to protect the environment. For example, environments where humans are not present or have been removed, or situations where other organisms in the environment could receive much higher radiation exposures than humans. Up till now, the Commission has not explicitly stated that the environment should be protected. Consequently, there is little guidance as to how radiological assessment and management of radiation effects in non-human species should be carried out, or why.

Environmental protection has made considerable progress in developing its philosophy and guidance since the Commission's recommendations were published in Publication 60. The increasing public concern over environmental hazards has resulted in many international conventions, and the need to protect the environment in order to safeguard the future well-being of man is one of the cornerstones of the Rio Declaration [8]. Radiological protection of the environment has attracted increasing attention over the last decade, and there is currently a frequently held view that explicit protection from harmful effects of ionizing radiation should also be provided for non-human species and ecosystems.

There has been a shift in society from the long-held anthropocentric approach to protection of the environment to one that embraces both biotic and, sometimes even, abiotic components of the environment. All of the recent conventions, principles, reports and statements lend support to the now widely held view that there is a need to demonstrate, explicitly, that the environment can and will be protected from the effects of radiation.

5. THE PROTECTION OF NON-HUMAN ENVIRONMENTAL SPECIES

In May 2000 the Main Commission of ICRP decided to set up a Task Group to advise it on the development of a policy for the protection of the environment, and to suggest a framework — based on scientific and ethical-philosophical principles — by which it could be achieved. This was new ground for the Commission, because it had previously considered exposures of other organisms to ionizing radiation only in so far as they related to the protection of human beings. And in contrast to the Commission's unique position in relation to human radiological protection, from which it has played a major role in influencing legal frameworks and objectives at international and national levels, the subject of environmental protection is a more complex and multi-faceted one, with many international and national environmental legislative frameworks and objectives already in place.

The current and potential future role of ICRP with respect to protecting the environment, by way of an understanding of the effects of ionizing radiation on animals and plants, has therefore been discussed against this background. It was concluded that the principal contribution that the Commission could make was that of providing broad policy and guidance — as it does for human radiological protection — by way of formulating recommendations and advice, supported by some key data sets and models. Indeed, it was considered essential that ICRP should develop a more comprehensive approach to the study of the effects on, and thus the protection of, all living matter with respect to ionizing radiation; and that it should therefore develop its system of protection to include both humans and other living things generally.

If such an approach were to be taken by ICRP, then it is also clear that it would need to work in consort with other bodies. This includes the relative roles of UNSCEAR, ICRU, IAEA, NEA, IRPA, and the IUR, as well as those of international bodies who have a need for, and would also play a role in, the practical achievement of environmental protection including such bodies as OSPAR, the EU and so on. Such an approach by ICRP would also have to be cast within the current ethical and social views of what constitutes environmental protection generally, and how such different views, and broadly agreed principles, help to define it.

The recent IAEA study [9] was considered to provide a sound basis upon which to proceed, by drawing together the current ethical views of relevance — anthropocentric, biocentric, and ecocentric — plus the 'principles' embodied in UN legislation of sustainable development, conservation of the natural world, and the need to maintain biological diversity. All of these concepts are also supported by the need to provide environmental justice, and to have respect for human dignity. These are all complex and inter-related issues, and they have been variously addressed at international level over the last three decades.

Of particular importance has been the concept of sustainable development, including recognition of the need to protect all living resources. Such concepts have had a large impact globally since the Rio Convention of 1992 [8], and hence since the publication of ICRP's Publication 60 in 1991 [7]. Similarly, approaches to the assessment and management of environmental risks are continually changing, and such changes will inevitably need to be reflected in ICRP's deliberations on its approach to the protection of non-human species.

If the Commission is to develop a more comprehensive approach to the protection of living matter, then it also needs to reconsider existing databases and their interpretation. The majority of the information on the exposure to, and effects of, radiation has been derived in order to serve the needs of human radiological protection. Probably the most important first step to take is that of distinguishing between the manner in which radiation effects are expressed, at the level of the individual, in different types of animals and plants. For humans the main concern has been that of safeguarding health by an understanding of the way in which effects can be characterized as being stochastic or deterministic. But there is insufficient knowledge to enable a similar approach to be considered for non-human species — with the possible exception of some mammals.

It is therefore considered that a more useful approach would be to describe the effects of radiation on individuals in categories that would be relevant in an environmental context, such as causing early mortality (by any means), or some form of morbidity, or a decrease in reproductive success. The extent to which such effects might, in turn, have consequences for populations, communities, or even entire ecosystems would depend on a large number of factors, including not only the numbers of individuals variously exposed to radiation, but also on many other factors unrelated to ionizing radiation.

A considerable challenge for ICRP will clearly be that of integrating any approach to protection of the environment with that of the protection of human beings, bearing in mind that the latter is also the subject of a current, in depth, review. It is therefore of relevance that a number of different initiatives and concepts have been developing recently with respect to protection of the environment in relation to ionizing radiation, both at national and international level. Much progress has been made in the last few years in the development of a variety of means for estimating exposures to a wide variety of animals and plants in different habitats.

There has also been a high degree of cooperation amongst different researchers across many countries, encouraged by the IUR and financially supported in some cases by international bodies such as the EC. A number of national programmes have also been significantly developed, and within at least one country, the USA, a legal basis has been established for applying dose limit values in relation to certain nuclear sites. There is, therefore, already much being done but, although such programmes have many similarities, they also have the potential to diverge considerably and ultimately to be based on different principles, approaches, and scientific interpretation. Nevertheless, a common feature of many of these is, again, the concept of 'reference' models and data sets.

ICRP is therefore recommending the development of a small set of reference fauna and flora, plus their relevant data bases — in a manner similar to that of Reference Man — to serve as a basis for the more fundamental understanding and interpretation of the relationships between exposure and dose, and between dose and certain categories of effect, for a few but clearly defined types of animals and plants. It would also be useful if the magnitude of doses relating to these effects could be set out in a 'banded' fashion, such as the proposed Derived Consideration Levels, in a manner similar to that being considered for human beings. Such a set of information could then serve as a basis from which national bodies could develop, as necessary, more applied and specific numerical approaches to the assessment and management of risks to non-human species as national needs and situations arise.

In this respect, it is also recognized that such assessment and management approaches differ from one situation to another, and each may constitute only a part of larger and existing environmental management programmes. Assessments may therefore be conducted for many different reasons, and situations may be managed in many different ways. And both will necessarily be integrated into other aspects of planning and action that may be expected to differ from one country to another. In many cases, such actions are already framed or constrained by existing legislation.

6. THE CURRENT POSITION OF ICRP

The Commission has recently adopted the Task Group report dealing with environmental protection [10]. This report addresses the role that the Commission could play in this important and developing area, building on the approach that has been developed for human protection and on the specific area of expertise to the Commission, namely radiological protection.

The Commission will now include in its Recommendations a systematic approach for radiological assessment of non-human species to support the management of radiation effects in the environment. This decision has not been driven by any particular concern over environmental radiation hazards. It has rather been developed to fill a conceptual gap in radiological protection and to clarify how the proposed framework can contribute to the attainment of society's goals of environmental protection by developing a protection policy based on scientific and ethical-philosophical principles.

The recommended system is not intended to set regulatory standards. The Commission rather recommends a framework that can be a practical tool to provide high-level advice and guidance and help regulators and operators demonstrate compliance with existing legislation. The system does not preclude the derivation of standards; on the contrary, it provides a basis for such derivation.

At present, there are no internationally agreed criteria or policies that explicitly address protection of the environment from ionizing radiation, although many international agreements and statutes call for protection against pollution generally, including radiation. The Commission's decision to develop an explicit assessment framework will support and provide transparency to the decision making procedure.

A framework for radiological protection of the environment must be practical and simple. The Commission framework will be designed so that it is harmonized with its proposed approach for the protection of human beings. To achieve this, an agreed set of quantities and units, a set of reference dose models, reference doses-per-unit-intake, and effects-analysis will be developed. A limited number of reference fauna and flora will be developed by the Commission to aid assessments, and others can then develop more area and situation specific approaches to assess and manage risks to non-human species. The Commission has a unique position in relation to human radiological protection, from which it has played a major role in influencing legal frameworks and objectives at international and national levels. In contrast, the subject of protection of other species is more complex and multi-faceted, with many international and national environmental legislative frameworks and objectives already in place.

The Commission proposes that the objectives of a common approach to the radiological protection of non-humans organisms are:

> *"…to safeguard the environment by preventing or reducing the frequency of effects likely to cause early mortality or reduced reproductive success in individual fauna and flora to a level where they would have a negligible impact on conservation of species, maintenance of biodiversity, or the health and status of natural habitats or communities."*

The Commission will continue its work identifying the biological end points of interest, the types of reference organisms to be used by ICRP, and defining a set of reference dose models for assessing and managing radiation exposure in non-human species. The Commission's system of protection has evolved over time as new evidence has become available and as the understanding of underlying mechanisms has increased. It is therefore likely that a system designed for the assessment and management of radiation effects in non-human species would also take time to develop, and similarly be subject to revision as new information is obtained and experience gained in putting it into practice.

In conclusion, therefore, it is considered that ICRP can and should play the key role with respect to ionizing radiation, both in advising on a common international approach, and in providing the basic interpretation of existing scientific knowledge in order for such a common approach to be delivered. The Commission will therefore show its commitment to the protection of the environment, by way of protection of non-human species, and for this to be reflected in changes to its structure and work programme at the earliest opportunity.x

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PROTECTING THE ENVIRONMENT FROM RADIATION EXPOSURE
International efforts for restricting discharges of radioactive substances

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1. INTRODUCTION

Let me first of all join the previous speakers in wishing you all a warm "welcome to Stockholm". I express these wishes in the name of everyone at the IAEA who helped organize this Conference. All around the world it is said that Stockholm is the "Venice of the North" but I am told that the Swedish say "Venice is the Stockholm of the South"! However, everyone agrees that this is a most beautiful city and I am sure you will enjoy your week here.

I will first provide some background information, which could serve as a kind of framework for this Conference, by describing the IAEA's historical commitment to the control of radioactive discharges into the environment and, therefore, to protection against the detrimental effects attributable to radiation exposure. I will then attempt to describe the current international situation as far as radiation protection of the environment is concerned, as well as the challenges we may have to face in the future.

2. THE IAEA VIS-À-VIS RADIATION PROTECTION OF THE ENVIRONMENT

2.1. Functions of the IAEA

Since its foundation in the 1950s, the IAEA has shown a special commitment to environmental radiation protection. It is the only organization in the United Nations family that has a statutory function relating specifically to radiation protection. Pursuant to its Statute, the IAEA establishes relevant standards and provides for their application. In relation to the environment, the ultimate purpose of these standards is to limit radioactive discharges.

2.2. Participation of other organizations

In establishing such standards the IAEA benefits from the work of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which provides estimates of global radiation levels and their effects, and that of the International Commission on Radiological Protection (ICRP), which provides radiation protection guidance. In its endeavours, the IAEA also receives cooperation and assistance from relevant organizations in the UN family.

2.3. Protection standards

The process for establishing the IAEA protection standards is complex, involving four standing Committees of experts nominated by IAEA Member States. Two of these Committees are particularly relevant to environmental radiation protection — the Radiation Safety Standards Committee (RASSC) and the Waste Safety Standards Committee (WASSC). The Committees prepare draft standards that are submitted to the Commission on Safety Standards (CSS), the members of which are heads of national regulatory bodies. After endorsement by the CSS, the draft standards containing mandatory requirements are submitted to the IAEA's relevant policy making organ — its Board of Governors — for approval, while the guidance standards are issued under the authority of the IAEA Director General.

2.4. Provisions for applying the standards

The IAEA has in place a number of mechanisms to provide for the application of the standards. It makes technical assistance available to those Member States in need. It fosters information exchange (through, inter alia, events such as this Conference). It promotes education and training in the application of the standards. It coordinates research and development that may be needed to improve the standards. And — particularly important for the future — it organizes *appraisals* whereby countries can ascertain whether they are complying with the approved international standards.

2.5. International undertakings

The IAEA also services relevant international conventions at the request of their State parties. The international conventions which are relevant to environmental radiation protection are: the Convention on Early Notification of a Nuclear Accident (the Early Notification Convention), the Convention on

Assistance in the Case of a Nuclear Accident or Radiological Emergency (the Emergency Assistance Convention) [1], the Convention on Nuclear Safety [2] and — most importantly — the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Joint Convention) [3].

In the Joint Convention, as within the IAEA, the term “radioactive waste” covers “radioactive material in gaseous, liquid or solid form for which no further use is foreseen...”. Therefore, limiting radioactive discharges into the environment is a legally binding obligation under the Joint Convention.

3. A HISTORY OF COMMITMENT

3.1. Early efforts

IAEA commitment to the radiation protection of the environment goes back to 1958 when the United Nations Conference on the Law of the Sea recommended that the IAEA be responsible for promulgating standards for the prevention of marine pollution by radioactive substances. In 1961, the IAEA promulgated what was probably the first international standard for limiting radioactive discharges into the environment — under the title “Radioactive Waste Disposal into the Sea”[1]. One year later, the IAEA promulgated the first international general standards on radiation protection[2], and one year after that the first standards for limiting the discharge of radioactive waste into fresh water[3]. In 1965, it published the first international methodology for monitoring marine radioactivity[4]. In 1967, it revised its international standards on radiation protection of the environment. This prolific decade of commitment to environmental radiation protection would end in 1972 when the IAEA formulated a definition and recommendations in support of the implementation of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the London Convention 1972) [4].

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Radioactive Waste Disposal into the Sea, Safety Series No. 5, IAEA, Vienna (1961) (out of print).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Basic Safety Standards for Radiation Protection, Safety Series No. 9, IAEA, Vienna (1961) (out of print).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Wastes into Fresh Water, Safety Series No. 10, IAEA, Vienna (1963) (out of print).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Methods of Surveying and Monitoring Marine Radioactivity, Safety Series No. 11, IAEA, Vienna (1965) (out of print).

3.2. New initiatives

All developments during the early period of the IAEA's existence were important for environmental radiation protection, but the real trigger for activities in that area was the United Nations Conference on the Human Environment held in Stockholm in 1972. A revolutionary contribution around that time was the "Sievert Lecture" on "Radiation in Man" given by Professor Bo Lindell of Sweden at the Congress of the International Radiation Protection Association (IRPA) in 1973. Prof. Lindell propounded that the main issue was not to limit the current burden on the environment but to limit the full, present and future environmental radiation impact of today's practices. In order to achieve this objective it would be necessary to limit today's radiation *dose commitment* per unit practice. The — at that time — revolutionary concept of "the annual dose commitment attributable to one year of a practice" was introduced. The concept was revolutionary then because people normally controlled radioactive discharges according to the level of dose to be actually incurred, usually around the discharge point, rather than limiting the levels committed to be incurred, over all space and time — also in the future. The control of discharges at that time ignored the possibility that a practice of releasing radioactive substances into the environment might continue over years, and after many years there would be a buildup of radioactive materials in the environment and of the subsequent dose, which — contrary to many conventional pollutants — could reach an equilibrium due to radioactive decay.

Lindell's ideas were implemented in a few countries, notably the Nordic countries in the so-called "Five Flag Document" [5]. The IAEA soon followed these ideas and, in 1978, established the first international standards for limiting discharges into the environment which introduced the concept of dose commitment[5].

In connection with limiting committed impact in jurisdictions outside the 'releasing' country, something that is often forgotten is that in 1985 the IAEA produced, for the first time, guidance material to take account of transboundary commitment of radiation exposure[6]. Until that time, the de facto motto was "protect your environment, and the environment of your

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[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Principles for Establishing Limits for the Release of Radioactive Materials into the Environment, Safety Series No. 45, IAEA, Vienna (1978) (out of print).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Assigning a Value to Transboundary Radiation Exposure, Safety Series No. 67, IAEA, Vienna (1985) (out of print).

neighbours will be protected”, but this was not necessarily the case. This idea of taking account not only of our own environment but also of that of others, inaugurated what one might call the time of international undertakings in environmental protection.

3.3. The time of international undertakings

The year 1992 saw the Rio Declaration, the Convention on Biological Diversity and the Agenda 21 Programme of Action [6]. For the first time, there were general United Nations principles for environmental protection, and all States participating in the Rio gathering specifically recognized the role of the IAEA in environmental radiation protection.

In 1996, a group chaired by Mr. Roger Clarke, current Chairman of ICRP, formulated the first international fundamental radiation protection principles [7]. Also at that time, the first fundamental principles for waste management were adopted [8]. These would serve as the basis for the Joint Convention. Principle 2 reads as follows: *“radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment”.*

Again in 1996 — which can be considered a cornerstone in the history of radiation protection — the IAEA, together with five other international organizations, followed up the latest ICRP recommendations with the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS) [9], which instituted implicit requirements for radiation protection of the environment.

Following the new BSS, the IAEA updated in 2001 the standard for limiting radioactive discharges into the environment [10], with the aim of implementing the relevant requirements outlined in the BSS.

In 1997, a diplomatic conference organized within the framework of the IAEA adopted the Joint Convention. This is currently the only international legal instrument that requires States to protect the environment against detrimental effects attributable to radiation exposure. Article 4 of the Joint Convention requires each Contracting Party to ensure that the environment is adequately protected against radiological hazards — the only formal legal commitment that States have entered into with regard to environmental radiation protection.

3.4. Assuring compliance

The time for action to ensure compliance arrived requiring generic models for appraising compliance in a consistent and coherent manner. In 1982 the IAEA had already issued standards providing guidance on such generic models [11] and in 2001 the IAEA issued updated generic models [12].

Compliance also requires maintaining a sound database on extreme situations of environmental pollution. In 1999, the IAEA published two technical documents describing the inventory of releases and 'losses' of radioactive materials in the sea [13, 14].

Also in 1999 the IAEA tackled, for the first time, what would be the most critical issue in efforts to protect the environment and in 2002 issued a technical document entitled Ethical Considerations in Protecting the Environment from the Effects of Ionizing Radiation [15].

An International Conference on the Safety of Radioactive Waste Management (held in Córdoba, Spain, in March 2000) led to the *first international action plan on the safety of radioactive waste management* under the aegis of the IAEA. It was followed, in December 2002, by an International Conference on Issues and Trends in Radioactive Waste Management, which led to an update of the action plan by adding an action relating to the control of radioactive discharges into the environment. Following an International Conference on Assuring the Safe Termination of Practices involving Radioactive Materials, held in Berlin in October 2002, the IAEA established the first international action plan on the safety of decommissioning of nuclear activities. This action plan will also have important practical implications for radiation protection of the environment.

Developing countries have not been excluded from the various IAEA activities in radiation protection of the environment. For example, in September 2003 the IAEA held, in Rabat, Morocco, an International Conference on National Infrastructures for Radiation Safety: Towards Effective and Sustainable Systems. This Conference — striving to support an IAEA technical cooperation model project in which 83 developing countries participate and which involves actions relating to environmental radiation protection — has resulted in an international action plan for improving national infrastructures of control.

4. LOOKING TOWARDS THE FUTURE

The International Symposium on the Protection of the Environment from Ionising Radiation, held in July 2002 in Darwin, Australia, might be regarded as the precursor to a major new international endeavour aimed at a new international consensus on environmental radiation protection. It was also the immediate antecedent to this Stockholm Conference.

The lesson of the Darwin Conference was that the international community was ready for new initiatives. The time now seemed ripe for taking stock of the achievements made and looking forward to the future.

4.1. A solid scientific basis

A solid scientific basis exists for formulating a sound and sustainable international policy on radiation protection of the environment. In 1976 the IAEA had already issued the first international report on the effects of ionizing radiation on aquatic organisms and ecosystems [16]. In 1988 it issued a report on Assessing the Impact of Deep Sea Disposal of Low Level Radioactive Waste on Living Marine Resources [17]. During the 1980s, international consensus was reached on fundamental transfer factors of radioactivity through the environment, e.g. on K_dS in sediments and on concentration factors in the marine environment [18]. Finally, and conclusively, a report on the effects of ionizing radiation on plants and animals at levels implied by the current radiation protection standards was issued [19]. This report stated that respecting the dose limit of 1 mSv would most probably lead to dose rates to plants and animals in the area of less than 1 mGy/day and that there was no convincing evidence that this level of dose would harm this biota. Meanwhile UNSCEAR was developing a comprehensive database on the environmental impact of radioactive substances — more impressive than any databases on industrial pollutants of the environment.

4.2. The current approach

A sound international approach to environmental radiation protection has evolved over time. As you well know, the current protection approach involves prospective control criteria for new activities and retrospective intervention criteria involving protective actions for de facto situations that have already occurred and the consequences of which are already to be found in the environment.

For prospective situations, control is exercised on expected releases. It is assumed that these releases would lead to doses that in total would exceed the existing background doses. Once an activity is introduced, control is exercised on releases into the environment expected from that activity. The aim is to restrict the expected additional doses to be incurred by **human beings** (and only human beings) via individual-related dose limits and source-related dose constraints. The policy provides for environmental protection through an implicit anthropocentric criterion that is applied in an environment of relatively high background doses, i.e. with a background of average doses of

2.4 mSv per year for people (which may be higher for other organisms), which have typically high values of 10 mSv per year and high values of 100 mSv per year. Such high background doses are a unique reference that very few other pollutants experience. Above this background if a source is introduced, its releases will be controlled with an anthropocentric criterion so that the additional doses to the more exposed human being do not exceed 1 mSv per year.

For interventions in existing situations, the approach is also anthropocentrical and consists of reducing the avertable doses to human beings by a process of optimization of protection. The approach has been tested by many studies, particularly those carried out by the IAEA at nuclear weapons test sites [20–22]. A report on a study relating to depleted uranium in Kuwait was released one week ago [23], and there is an study under way at the moment at an Algerian nuclear weapon test site [24].

Thus, the essence of the current environmental radiation protection policy is to protect individual human beings of present and future generations by controlling current releases in prospective situations or by intervening in existing situations. This control is managed somehow anthropocentrically, i.e. assuming that by protecting humans other species, the 'environment' as a whole, would be automatically protected.

5. THE CHALLENGE

What is the challenge confronting us? The general dispute is that the current approach for protecting the environment from radiation exposure seems to be based solely on anthropocentric considerations. This dispute can be basically formulated as follows: even if each individual human being were well protected against radiation exposure, now and in the future, the environment (a somehow loose and undefined concept) might nevertheless be unprotected. A critical statement in this connection is the presumption on which the BSS are founded, which is based on an ICRP recommendation and contained in the Preface to the BSS: *"it is considered that standards of protection that are adequate for this purpose* [i.e. for the purpose of the protection of human beings] *will also ensure that no other species is threatened as a population, even if individuals of the species may be harmed."* The dispute can be expressed in three basic questions on the main contentious issues: If humans are individually protected, are other species collectively protected? Which ethical approach should be used to protect the environment? Whatever the approach, does it apply to the 'environment' or to the human habitat?

5.1. If humans are individually protected, are other species collectively protected?

The first contentious issue relates to the basic assumption in the BSS: that the assumption reflected in the Preamble has not been formally demonstrated and might not be valid. Furthermore, it might be considered that the assumption is open to misuse. A case presented as an example is the dumping of radioactive waste in the Kara Sea during the Soviet era. The IAEA carried out a study at the dumping site and came to the conclusion that humans seemed to be well protected (because, inter alia, no-one lives in the area) [25]. However, the environment around the dumping site is probably not so well protected, which suggests that the assumption reflected in the Preface to the BSS would have been violated in this case. However, the Kara Sea example is fallacious, because the uncontrolled dumping of large amounts of radioactive material violates the most fundamental BSS requirements. The BSS presumptions are applicable only to situations where there is compliance with the BSS requirements. The BSS do not allow the dumping of a nuclear reactor into the sea, as was done in the case of the Kara Sea — with several nuclear reactors!

5.2. Which ethical approach should be used for protecting the environment?

The second contentious issue relates to the realm of ethics. It may be considered ethically insufficient to protect non-human species only as a whole, i.e. collectively, as stated in the BSS. For instance, people may wish that protection should be afforded to each individual member of each species. Moreover, others may consider that protection should exceed the realm of individual species and cover entire ecosystems.

It is important to recognize that there are different ethical traditions, particularly in relation to the environment and its protection. The anthropological approach, dominant in large parts of the world, is a natural consequence of the globally dominant Jewish-Christian-Moslem traditions. These traditions have lead to deontology as dominant ethics in the Western world for most of our civilized history. As *deontological* ethics aim toward an anthropological approach, in environmental protection terms it leads to *anthropocentrism*.

But the modern world has witnessed the development of a variance in ethical approaches, some very different from each other and with different environmental protection objectives. The liberal ethics of *utilitarianism* and *consequentialism* aim at *biocentrism*, laying particular weight on protection of all biological systems in nature. The more social ethics of *contactarianism* and *communitarianism* (a term probably used in place of "communism", perhaps because "communism" has been misused by the politicians) aim at *ecocentrism* and the 'natural status quos' of the environment as a whole ecosystem.

The existence of different ethical values and therefore different approaches to environmental protection is a fact of life. Then…which approach should be applied internationally? There is no straightforward answer. It depends on the universal ethical values at a given moment in time in historical evolution. Certainly our moral and ethical standpoint on protection has been changing throughout time. In prehistoric times the only concern was to protect the tribes. Civilization was concerned about protecting citizens, i.e. selected individuals of that status. In relatively modern times we have come to consider all human lives equally important to protect. However, in reality we see that although all human individuals are equal some are more equal than others. In the most advanced nations, there is a growing consensus to protect higher mammals at least, as people seem to be averse to killing monkeys as opposed to, say, killing mosquitoes. While humanity seems to be still far from real biocentrism, and even further from ecocentrism, it seems to be moving in that direction.

5.3. Environment or human habitat?

An important basic question that we have to ask ourselves is, regardless of the ethic selected, whether the objective is to protect the 'environment' (whatever our definition of it may be) or, more precisely, the human habitat. It seems to me that even many ecocentrists have a hidden anthropological tendency and when they use the word 'environment', what they really mean is human habitat. In the environmental radiation protection discussions in which I have participated, people appear to be more concerned about the protection of the human habitat than about problems in protecting the deepest troughs of the Pacific Ocean bed.

6. OUTLOOK

According to a recent study by the Massachusetts Institute of Technology, just maintaining the small percentage of global electricity generation accounted for by nuclear power will call for the construction of some several hundred 1000 MW(e) power reactors between now and the year 2050. If that is the case, the accumulation of discharges will be mounting and the limitation of commitments rather than immediate effects will become mandatory rather than an intellectual theory. If we are not able to build up a solid environmental radiation protection framework with international recognized standards for limiting releases of radioactivity into the environment, we will face a world that will be globally polluted with radioactivity. It will not be the first time: nuclear weapons testing during the cold war period caused the most serious man-made contamination of the world with radioactive materials and still today we can detect the fallout it produced globally. We do not wish the same fate for the future of peaceful uses of nuclear energy.

The good news is that ICRP has produced a framework for the future for radiation protection of the environment [26] and has recently created a Committee to address this specific problem. The IAEA is and will continue to respond to the new challenges. The existing international regime on radiation safety needs to be strengthened with legally binding obligations, international standards and provisions for ensuring their application. All these should be targeted at limiting radioactive releases into the environment.

Despite our optimism, we must recognize that there is still a long way to go. The First Review Meeting of the Contracting Parties to the Joint Convention takes place from 3 to 14 November 2003. While the issue is premature for discussion by the Parties, the meeting could offer an initial opportunity for informal discussions. Environmental radiation protection standards have been prepared and the international community can expand on these by benefiting from the IAEA's thirty-year old tradition of preparing standards for regulatory control.

The next challenge will be to appraise compliance with these standards. The IAEA is already carrying out de facto inspections in connection with the application of its standards, e.g. in the area of transport safety and waste safety. It will be relatively straightforward to develop an appraisal service for checking compliance with release control.

We hope these and other important strategic issues will be discussed at this Conference and that — as a result of our discussions — concrete findings, conclusions and recommendations will emerge which will eventually result in an international plan of action. This should lead to firm international commitments by States to restrain discharges of radioactive substances so that human beings and the environment may be adequately protected.

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ENSURING PROTECTION OF NON-HUMAN SPECIES
A nuclear industry perspective

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I welcome the opportunity to address this important conference to offer a nuclear industry perspective on environmental protection from the effects of ionizing radiation.

The World Nuclear Association is the global industrial organization that seeks to promote the peaceful worldwide use of nuclear power as a sustainable energy resource for the coming centuries. Our membership includes some 115 companies, institutes and agencies in 32 countries. Together WNA members represent over 90% of the non-generation side of the world nuclear industry, and over 80% of nuclear electricity generation outside the United States of America.

The WNA is concerned with all aspects of the nuclear fuel cycle, including mining, conversion, enrichment, fuel fabrication, plant manufacture, transport, electricity generation and the safe disposition of spent fuel. Our functions are twofold: to foster unity and technical cooperation within the industry; and to represent the industry in the transnational arena.

One month ago, we acted in partnership with the IAEA, the OECD Nuclear Energy Agency and the World Association of Nuclear Operators to inaugurate the new World Nuclear University. Headquartered in London, the WNU is a network of leading institutions of nuclear education and research in some 25 countries.

The WNU will foster cooperation among these institutions of learning. Its ambitious aim will be to strengthen education in all aspects of nuclear technology and to build a larger and internationally qualified professional workforce to support the expanded use of these valuable technologies worldwide in the challenging century we have just begun.

Guided by that robust outlook concerning the future of nuclear technology, we welcome the deliberative examination now in progress on the question of how best to protect the environment from anthropogenic radiological effects. We see such an examination as both desirable and inevitable in an age of ever-increasing environmental awareness and concern.

Indeed, as to the context in which we now find ourselves, I submit that we should view the opening years of this century as marking the onset of an entirely new era — in which the geopolitical struggles of past decades will be eclipsed by a wholly different form of challenge. If the 20^{th} century was an age of war and cold war, the monumental task we face in the century ahead is to reconcile humankind's ever more intrusive presence on this planet with the preservation of the potentially fragile biospheric conditions that enabled civilization to evolve.

As we shape our national and international strategies, it will clearly not suffice simply to act in the name of environmentalism. We must do so with intellectual and scientific rigour, for our challenge today is one of navigation. We must preserve our planetary environment while struggling to meet the urgent needs of a huge and growing global population.

As we look ahead, it seems no more than a prudent appraisal to say that humankind has never faced a greater challenge than to reconcile the twin global imperatives of human need and biospheric preservation. The magnitude of this challenge is reflected in the simple but daunting statistics that define the problem of climate change.

In the next 50 years, as global population grows from 6 to 9 billion, the rate of world energy consumption will double or even triple. In just this narrow 50-year period alone, humankind will use more energy than in all previous history combined.

Today, despite much rhetoric and diplomacy, the global rate of CO_2 emissions — now 25 billion tonnes a year, or 800 tonnes a second — continues to rise. By mid-century the greenhouse gas concentration is likely to exceed twice the pre-industrial level.

To stabilize greenhouse gases — even at a dangerously higher level — global emissions must be cut, within the next 50 years, by at least 50%.

Developing countries such as China and India, with priority on human needs, will inevitably emit more greenhouse gases. Thus, to avoid climate catastrophe, the already industrialized countries must cut their own emissions by 75% and lead the world in a radical transformation to clean energy technologies.

It is an irony of our age — and it is fast becoming a tragic irony — that so many citizens and organizations most concerned about the clean-energy problem are fixated on myths, dogmas and sheer fantasies regarding the solution.

In fact, nuclear power is the quintessential sustainable development technology because its:

— Fuel will be available for multiple centuries;
— Safety record is superior among major energy sources;

— Consumption causes virtually no pollution;
— Use preserves precious fossil resources for future generations;
— Costs are competitive and declining;
— Waste can be securely managed over the long term.

In the realm of reality, projections by the OECD International Energy Agency (in the public sector) and the World Energy Council (in the private sector) point unambiguously to the same conclusion — that our need for clean energy on a colossal scale cannot conceivably be met without a sharply increased use of nuclear power.

The goal of sustainable development is also served by a wide variety of other nuclear technologies that are crucially important in worldwide efforts to promote agricultural productivity, eradicate virulent pests, protect livestock health, preserve food, develop water resources, enhance human nutrition, improve medical diagnosis and treatment, and advance environmental science.

It is with a strong belief in the constructive — indeed indispensable — role of nuclear technology in the 21st century that we assess the question of protecting the environment from the adverse effects of anthropogenic ionizing radiation. Our posture is simply stated:

— We are confident that the evolution of nuclear technology — and the multiple institutions that now guide and support its use — will enable humankind to draw increasingly upon this asset to meet the challenge of sustainable development.
— We welcome a framework governing the use of nuclear technology that entails strict rules designed to protect both people and the environment and, as a consequence, to inspire public confidence that this technology is being used wisely and well.
— Finally, we view it as a axiomatic that any such framework must be devised with utmost care to ensure that the enormous capability of nuclear technology to contribute to environmentally sound economic development is not compromised by unsound limitations imposed in the name of protecting the environment.

As this conference commences, we offer these messages:

(1) First, we welcome the leadership shown by both the IAEA and the ICRP in addressing how best to deal with the question of protecting non-human species.

As this question is relatively new to the international agenda, we believe it is essential that these respected organizations operate in tandem to ensure a clear and coherent direction for future work and the coordination of relevant scientific activities.

(2) Second, we reiterate and underscore the widespread agreement among radiological experts that the current system of protection — based on the assumption that protecting humans will afford protection to non-human species — has in practice provided sound standards of environmental protection.

We accept that this framework may not be deemed adequate in some specific situations where humans are not present, but we also believe that this gap is more conceptual than real.

A classic case in point concerns the notorious practices of the government of the former Soviet Union, which, over a period of three decades, used the Kara Sea as a dumpsite for nuclear waste that included six nuclear submarine reactors containing spent fuel.

In the 1990s the IAEA conducted a full-scale assessment of the radiological impact of this practice. While the conclusions concerning short and long term radiological effects were far from alarming, the dumping itself certainly was.

Even so, it is by no means obvious that this example of recklessness demonstrates a fundamental flaw in the traditional premise that protecting humans will protect the environment — if that premise is understood correctly.

That premise rests on certain assumptions, among them that even minor exposure to radiation must be justified as a necessary consequence of achieving a sound purpose.

In this case, available means of treating this waste cautiously were simply ignored — at the risk of current environmental damage and potential future human damage — simply for the short term expedient of saving money.

This action clearly fell afoul of the simple common-sense principle — which may perhaps need to be enshrined — that available means of waste management should always be used as an alternative to any action that might damage a non-human population or an ecosystem or that might unnecessarily threaten individual human beings in the distant future.

(3) Our third message is to affirm the nuclear industry's recognition of the supreme importance of environmental stewardship and the industry's continuing commitment to operating in accord with high environmental standards.

This commitment is expressed strongly and unequivocally in the Charter of Ethics of the World Nuclear Association, which you will find prominently displayed on the WNA website. It pledges all of our member companies to abide by the full array international standards and laws designed to render the use of nuclear technology both effective and benign.

As to the radiological impact of the nuclear industry, it is always useful to remind ourselves that about 90% of the radiation people receive comes from nature and about 10% from medical practice. The percentage from nuclear energy and other non-medical nuclear technologies requires the use of a decimal point. In the vicinity of many nuclear sites, and power plants in particular, it is difficult to detect any variation from normal background levels of radioactivity.

Even for sites that historically have had the most significant discharges, experience with the currently available biota dose assessment methodologies indicates that doses are significantly below levels at which any deleterious effects to populations of marine biota might be expected.

Here I refer you to the results of a comprehensive case study assessing marine biota doses arising from the radioactive sea discharges of Cogema's facility at La Hague. Tomorrow morning, my colleague Sylvain Saint-Pierre will present and analyse this study.

(4) Our fourth message concerns the criteria that any future system of protection should fulfil. We submit the following:

(a) It must be capable of simple and practical application;
(b) It should not require blanket application across sites where it is evident that there will be negligible environmental impact;
(c) It should be focused instead on those exceptional situations where there is a high potential environmental impact — typically, those situations where humans are excluded; and finally
(d) It should be designed to protect species, populations and the ecosystem — not single plants or animals — and based on a scientific framework oriented to these goals.

Having offered those four messages, let me reiterate that the nuclear industry intends to engage constructively in any process designed to ensure and to enhance genuine environmental protection.

Recognizing that the shaping of any sound system must be science based, we will do all possible to bring to bear both valuable expertise and relevant data.

Meanwhile, we will contribute to the ongoing global environmental debate in all of its aspects.

The essence of that debate concerns the best means of achieving global sustainable development. We believe that nuclear technology must be seen and supported as a central instrument of any sound strategy for the successful pursuit of this goal.

With each passing day, the industry is continuing to build on its 11 000 reactor-years of experience — and on a superb record of operational safety and of human and environmental protection.

We are pleased to participate in any process that joins good science and good judgment to strengthen that protection and the public's confidence in it.

ENVIRONMENTAL RADIATION PROTECTION
Views of the WWF

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Good afternoon, ladies and gentlemen. I would like to thank our hosts for making it possible for me to speak to you today. It is an honour to address an audience of experts such as yourselves, and I would like to make it clear at the outset that I am not an expert on radioactivity. At the same time, I do spend most of my time working on energy policy, the effects and management of contaminants, and environmental assessment and decision making.

These topics are, I think, quite relevant for the main subject of this conference — development of a framework for assessing and managing environmental impacts of radioactive substances. My main point today is that existing principles and frameworks for environmental decision making should be applied to decisions regarding radioactive substances. So today I will start off by explaining a bit about the Worldwide Fund for Nature (WWF) and its approach to questions involving radioactive substances, including nuclear power. Then I'll discuss radioactivity in the context of traditional environmental decision making, drawing on experiences from non-radioactive contaminants and the ecosystem approach.

1. WWF, THE WORLDWIDE FUND FOR NATURE

WWF is the world's largest independent conservation organization, with over five million members worldwide. We are present in more than 100 countries around the world. We prioritize our work thematically, with six global programmes, and geographically, with 200 or so priority ecoregions or important areas around the world.

2. WWF'S POSITION ON NUCLEAR POWER

WWF will never support nuclear power as a solution to climate change or for any other reason. WWF opposes nuclear power because it is environmentally, economically and socially unsustainable. It produces 10 000 tonnes of highly radioactive and toxic material each year; creates 80 000 kg of plutonium each year; requires safe storage of waste for some 20 thousand to 15 million years; and, in the Chernobyl accident, contaminated an area of 150 000 km^2. It receives tremendous subsidies from government and these do not even reflect the real, long term costs of waste storage. It is a highly technical, capital investment intensive form of power generation that requires a high level of technical competence and safeguards in order to perform safely. It is therefore not an appropriate form of energy generation for regions that do not have the capital, technical capacity or regulatory system that can ensure adherence to safety standards. It presents as well a proliferation risk for us all, as we see only too clearly in the Islamic Republic of Iran and the Democratic People's Republic of Korea at the moment.

While campaigning on nuclear issues is not a major focus of our work, nuclear issues are quite important for us in two respects: climate change and our work in specific areas such as the Barents region. Over the last few years, the nuclear power industry and some governments have argued that nuclear power provides a way — even the only way — to meet growing energy demands while dramatically cutting greenhouse gas emissions. We oppose this view, as we believe it results in the substitution of one huge waste problem — radioactive materials — for another — greenhouse gases. Our vision for world energy markets is based on vastly increased use of renewables, such as sustainable biomass and hydropower, and wind, increased efficiency in energy production and use, and thus sharply reduced energy demands.

My office has another, particular concern with questions involving radioactive waste. We are developing a large, transboundary project in the Barents Sea and opening an office in Murmansk next year. Scientific assessment of threats to the region's biodiversity shows that the risk of radioactive contamination — from stored radioactive waste and fresh and spent fuel, from reactors in nuclear submarines and power plants — is high. As we work in this region we will necessarily have to engage in these issues, most likely through awareness-raising and advocacy.

3. RADIOACTIVITY AND ENVIRONMENTAL DECISION MAKING

Human safety and health have been the main objectives for decision making about radioactive substances. As a practical and scientific matter, it is increasingly clear that protection of human beings is not, in this context, the same as protection of the environment. We see this quite clearly in the Arctic, for example in the Russian Arctic where it has been proposed to store spent nuclear fuel. This is an area with relatively little human habitation but quite high conservation values — thus the potential for undesirable environmental impacts is high, while the danger to human health might be relatively small.

Thus consideration of environmental impacts of radioactivity is relatively new, and not yet a large part of the decision making process for the nuclear power industry, for waste transport and storage, etc. A first question is whether there is something about nuclear power and radioactive substances that warrants developing a new framework for these decisions, or to use those that already exist for other environmental questions.

My starting point is that we already have very well-developed frameworks for assessing and managing environmental impacts. Indeed, the most important of these frameworks — the ecosystem approach — requires consideration of all human impacts under one management system, and as I will explain there is no principal reason to exclude radioactive substances from this approach.

4. THE ECOSYSTEM APPROACH

An ecosystem is a dynamic natural system composed of the interactions between living biological resources, and between these resources and their environment. An example of an ecosystem would be the Barents Sea, or the Swedish alpine ecosystem, both of which can be defined by biological and non-biological parameters.

WWF advocates the use of the ecosystem approach, which is "the comprehensive integrated management of human activities based on best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of the ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity" (WSSD). Basically, this is adjusting human impacts on nature, rather than trying to adjust natural processes.

An ecosystem approach implies a number of elements. First, one must have a long term approach. Effects on ecosystems are often not visible in short time spans, such as three to five years — in part because of the longer reproductive cycles of higher trophic levels, and in part because effects at one level of an ecosystem take time to work their way through other levels. We advocate a 25 year perspective for management decisions. This means setting long term goals for environmental quality and function.

Second, an ecosystem approach requires consideration of all human impacts. Environmental quality and function over the long term are the result of natural processes and the sum of human impacts on these processes. To determine the end point for cod stocks in the Barents Sea, for example, one cannot look only at the impacts of commercial fisheries — one must also look at longer term effects of contaminants on reproduction, or at the risk from oil and gas development.

5. CUMULATIVE IMPACTS ASSESSMENT

This brings me to a very important and third element, cumulative impacts analysis. The principle behind this type of analysis is that one cannot make good environmental decisions about a specific activity without looking at its impacts over time and in combination with other existing or projected impacts.

Cumulative impacts assessment is a methodology for assessing the total impacts over time of human activities on an ecosystem, population or region. It is very frequently used in Canadian nature management and is as well an important tool for questions about regional development and landscape level planning. Part of cumulative impacts analysis requires looking at global change or long range effects. For example, in a cumulative impacts analysis of a terrestrial arctic ecosystem one would look at background levels of pollution, at local sources of pollution, at long range transported pollution, at the effects of agricultural and animal husbandry such as reindeer herding, at climate change, at habitat loss and fragmentation due to building of pipelines or roads — in short, all impacts in order to sort out what the state of the ecosystem is, how much of it is due to human activity, and what the ecosystem will look like in 20 years if these impacts continue.

In order to perform effective cumulative impact assessment, methodologies for assessing different impacts must produce comparable results. This is highly relevant for assessment of the effects of radioactivity, and a strong argument for choosing an assessment and management framework that is harmonized with relevant frameworks, such as those for other kinds of contaminants.

6. CONSERVATION OF BIODIVERSITY

Biodiversity exists on the ecosystem, species and genetic levels, or within species, between species and of ecosystems, to quote the Convention on Biodiversity. Biodiversity conservation is based on the idea that these differences — diversity — are essential to long term conservation of our natural world. If we think of biological systems as constantly shifting and dynamic processes, reacting and adapting to changes in the geophysical environment and changes within systems, then it is easy to see that the ability to adapt is key to nature conservation. The wider the range of conditions to which a species can adapt, the more likely it is to survive over the long term. Biodiversity provides the foundation for the adaptive capacity, including evolutionary capacity, of living things, as well as nature's ability to produce essential goods and services such as production, nutrient cycling, clean water, etc.

One major goal of environmental decision making is therefore conservation of biodiversity. This goal is embodied in the Convention on Biodiversity, in the commitments from the World Summit on Sustainable Development, and so forth. It is important to add that human beings are a part of the natural world and therefore a part of biodiversity.

Thus a first step in decision making about radioactive substances is whether the proposed action — transport, storage methods, etc. — presents a risk to biodiversity and how big those risks are. Risk should be analysed on three levels — to the ecosystem; to species; and to genetic diversity within species.

I would like to focus on genetic diversity since it is particularly relevant for this class of substances. Genetic diversity is poorly studied but critical to biodiversity conservation. There is nonetheless plenty of evidence that lack of genetic diversity, or loss of adaptive traits, over a longer period leads to population declines and even local extinctions. A specific example would be Atlantic salmon, which in the wild consist of a number of genetically distinct populations, in many cases uniquely adapted to their "home" rivers. An increasing threat to genetic diversity in wild salmon, and to populations, is fish farming. Farmed fish are genetically homogenous and in some areas escape in large numbers and mix with wild salmon. The result over time has been salmon that are less genetically diverse and well adapted to their environments. It is thought that this is one cause of the current drastic population declines in Atlantic salmon.

The point here is that genetic diversity is important but its effects on populations — as they interact with and attempt to adapt to the physical environment — can take time to play out, usually generations. Thus, it is possible that we do not yet know what the real environmental effects are of radiation induced changes in genetic diversity. The fact that we generally do not yet see population-level or ecosystem-level changes is not determinative. Moreover, if we apply the principle of conserving genetic diversity to decision making about radioactivity, then we will say that we must take a very conservative approach indeed to protecting the environment from substances that are known to have genetic effects, and that acceptable levels must be below those that cause genetic changes in individuals from the species that may be exposed.

7. PRECAUTIONARY PRINCIPLE

This brings me to another important principle, the precautionary principle. This is essentially, that where we do not have adequate scientific knowledge about the consequences of an action, the appropriate action is no action. It is the basis of EU environmental policy and of a number of international conventions, where it is often watered down to a "precautionary approach". I like to refer to the precautionary principle as the law of unintended consequences, as human interactions with the environment frequently produce long term, very negative results that were not foreseen or intended.

In the context of radioactive substances, WWF believes that not enough is known about their long term effects on biodiversity. There is evidence that these substances are persistent, toxic and bioaccumulative and that they have genetic and carcinogenic effects depending on dose. We know a little about the effects in some individual organisms of acute doses of some types of radioactive substances, but really almost nothing about the long term effects in individuals, in populations and particularly in ecosystems of chronic doses — which, over long exposure periods, can accumulate to become the effective equivalents of chronic doses. Decision making must, therefore, be highly precautionary — that is to say, it should produce outcomes that pose very little and if possible no risk. The case of radioactivity and environment is a clear-cut example of when to apply the precautionary principle, that is to act to minimize or eliminate risk. Taken to its end point, this means limiting the generation of radioactive substances, such as nuclear fuel and waste, to the absolute minimum that is necessary to meet human needs.

8. SUBTLE AND LONG TERM EFFECTS

To support this point, we need only to look at what we have learned from non-radioactive, persistent, toxic substances such as PCBs and DDT. These were widely used and quite useful substances that were initially thought to be safe, that were later regulated, and that are now wholly or partly banned. Though we knew they were persistent and could be toxic, governments and industry did not apply a precautionary approach to their production and regulation.

Just to take PCBs as an example, they were invented in the 1930s but it was not until the early 1990s that they were banned on a broad scale. They accumulate in the arctic region and now pose a huge problem for arctic ecosystems and human communities. They are persistent, toxic and bioaccumulative, as well as carcinogenic, and can affect the nervous system.

There is an emerging body of evidence from the Arctic that chronic exposure to PCBs can have subtle effects on human development — affecting the ability to learn and concentrate — and on immune system function as well. Researchers agree, however, that we still know very little about the subtle effects of PCBs on human beings, nor do we know what synergistic effects it is has with other contaminants that are common in the Arctic, such as organic mercury.

We know even less about the subtle effects of PCBs on animals. What we know so far is that the ability to break down PCBs varies between arctic species, that polar bears are particularly vulnerable to the effects of PCBs because they are unable to break them down, and that high PCB loads in polar bears are strongly linked to reduced immune system function, and we believe as well to reproductive capacity, cub mortality and potentially also population dynamics. We have no idea whether PCBs have effects on polar bear behaviour that is essential to survival of individuals and populations, such as predation and mating, nor do we have effective ways of studying this. Nor do we know what effects PCBs may be having on interactions between polar bears and other, linked parts of their ecosystem, such as ivory gulls and arctic foxes, both of which scavenge on the leavings of polar bear predation. Yet this information is essential, not only to help us judge how much effort we should put into cleaning up PCB sources, but also to understand what the long term outlook for this polar bear population is and whether we need to take action now to reduce other stresses on the population.

For the management of radioactivity, there are a few learning points from our less-than-precautionary approach to PCBs and other persistent toxic substances. A key one is that chronic, low dose exposures in some species and environments, for example arctic marine mammals and the people who eat them, can build up to become high and very dangerous loads. Another is that exposures will vary dramatically depending on where in the food chain you are looking. A third is that long term and subtle effects on individuals take time to become apparent and, while serious, are difficult to research. And finally, we also learned that the concept of a “safe” dose can be meaningless with persistent, toxic and bioaccumulative substances, as a) different species absorb contaminants in different ways, b) different species have different responses to the same contaminant load, c) chronic exposure over time to “safe” levels of persistent substances can result in the biological equivalent of an unsafe, acute dose, and d) doses cannot be considered in isolation from the effects of other contaminant loads and environmental factors.

9. CONCLUSION

In short, there are a number of compelling reasons why radioactivity should be assessed and managed from an environmental perspective. I would even go so far as to say that we cannot effectively manage nature in the parts of the world without doing so. Nor can we be sure that the current framework, focusing on human health, also protects the environment. In some areas, for example where there is little human habitation, this is demonstrably not the case.

DISCUSSION

U. KAUTSKY (Sweden): Has any thought been given to treating ionizing radiation like any other environmental pollutant and developing a common framework for the study of all pollutants?

R.H. CLARKE (ICRP): In the development of the ICRP philosophy regarding environmental radioactivity, we are taking account of the lessons learned and procedures applied in other fields.

Our view is that the time has come when ionizing radiation should no longer be treated differently from other pollutants — that there should be a more holistic approach to environmental protection.

A.J. GONZÁLEZ (IAEA): The idea of treating ionizing radiation like any other pollutant is attractive, but there is a major problem in that connection to which I should like to draw attention.

The integral of the commitment of the impact from radioactive releases (such as those from the nuclear industry) converges with time, whereas the integral of the commitment of the impact from non-radioactive releases (such as those from the coal industry and the oil and gas industry) diverges with time. You can see this divergence in Europe, where there has been a divergent build-up of non-radioactive pollution due to the use of coal, oil and gas, and this divergent buildup will continue as long as the activities causing it continue.

C.R. WILLIAMS (United Kingdom): There is a widespread view that in the protection of non-human species the focus should be on the protection of the species as a whole or of populations rather than on the protection of individual members of the species. In the United Kingdom and some other countries, however, there are some hundreds of animals and plants that are protected at the individual level — and they do not all belong to endangered species.

L.-E. HOLM (Sweden, Chairperson): That is why ICRP has opted for the reference animal and plant approach.

A.J. GONZÁLEZ (IAEA): I can understand the logic of legislation for protecting individual members of an endangered species, so as to protect the species as a whole, but not the logic of legislation for protecting individual members of a species that is not endangered.

L.-E. HOLM (Sweden, Chairperson): I do not think that it is for ICRP and other radiation protection experts to decide what level of protection should be accorded to different non-human species. Their job is to develop a tool that will provide guidance for complying with present and future legislation.

STAKEHOLDER VIEWS

(Topical Session 1)

Chairperson

L. KEEN
Canada

REGULATORY CONTROL OF DISCHARGES OF RADIOACTIVE MATERIAL TO THE ENVIRONMENT
A regulator's view

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1. INTRODUCTION

Since 1950, the most relevant nuclear activities in Argentina were carried on by the former National Atomic Energy Commission (CNEA). In August 1994, the National Atomic Energy Commission was divided into three independent organizations: one of them retained the original name, National Atomic Energy Commission; it remains within the public sector and its current activities are related to research and development, fuel cycle, radioisotopes and radiation sources, and specialized training in nuclear subjects.

The second organization, named Nucleoeléctrica Argentina S.A. (NASA), is in charge of the operation of the nuclear power plants, while the third one, originally named National Board of Nuclear Regulation (ENREN) and afterwards Nuclear Regulatory Authority (ARN) by means of the Act Number 24804, 1997, is constituted by the regulatory branch of the former National Atomic Energy Commission. This branch started the regulatory activities in 1958. The Regulatory Authority is a completely independent organization, entrusted with all the regulatory functions.

2. NATIONAL POLICY IN THE NUCLEAR FIELD

Due to its special characteristics, the activities related to the use of nuclear energy for peaceful purposes needs to be subject to national (or federal) jurisdiction and regulated as an organic and indivisible system. For this reason the National Congress is empowered to establish the laws concerning the subject, through Section 75 paragraphs 18 and 32 of the Constitution.

Within this context, Act Number 24804, 1997 or "National Law of the Nuclear Activity", is the legal framework for the peaceful uses of nuclear energy.

Article 1st of the Act Number 24804, 1997, establishes that, in regard to nuclear matters, the State will establish the policy and perform the functions of research and development and of regulation and control, through the National Atomic Energy Commission and the Nuclear Regulatory Authority.

Moreover, the mentioned law sets that any nuclear activity either productive or concerning research and development, that could be commercially organized, can be carried out both by the State and the private sector.

3. REGULATORY BODY

3.1. Functions and competence of the regulatory body

Since the initial operation of Argentina's first research reactor in 1958, a sustained nuclear development has been carried out in the country, which required the qualification of specialists in several subjects. During the first years, this aim was accomplished by training the professionals abroad, but the country was soon able to satisfy its main needs. The National Atomic Energy Commission (CNEA) had already reached a reasonable degree of development in the nuclear field and a suitable technical-scientific capability to face the development of each of the nuclear fuel cycle stages, including the corresponding radiological and nuclear safety, safeguards and physical protection aspects.

Act Number 24804, 1997 or "National Law of Nuclear Activity", sets that the Nuclear Regulatory Authority (ARN) is in charge of the regulation and surveillance of nuclear activity concerning radiological and nuclear safety, physical protection and safeguards. It also establishes that the Nuclear Regulatory Authority has autarchy and complete legal capability to act in the field of private and public rights, under the jurisdiction of the Presidency of the Nation. Its resources are basically integrated with regulatory fees and with State support.

The main functions of the Regulatory Authority are concentrated in the following basic aspects:

- Issue of the corresponding standards;
- Execution of regulatory inspections and audits to verify the compliance with granted licenses and authorizations;
- Independent execution of analyses and studies for the licensing process of nuclear installations;
- Development of technical and scientific aspects associated to radiological and nuclear safety, safeguards and physical protection;

— Training of personnel, either belonging to the Regulatory Authority or those working in installations, which perform practices under regulatory control.

The staff of the Regulatory Authority comprises 200 persons, 90% of whom perform technical tasks specialized in areas of their competence and 10% perform administrative activities. It should also be mentioned that 90% of the personnel holding high level positions or functions have a specialized training of about 20 years working in regulatory activities.

On the other hand, the Regulatory Authority is independent from other organizations related to the operation, distribution, or promotion of power generation. It should be noticed that the Regulatory Authority annually reports its activities to the Executive Power as well as to the National Congress.

4. NORMATIVE FRAMEWORK

Act Number 24804, 1997 empowers the Regulatory Authority to issue and establish the standards, which regulate and control nuclear activities, of compulsory application along the whole national territory.

The regulatory standards are based on a set of fundamental concepts, which are part of the performance approach philosophy sustained by the regulatory system concerning radiological and nuclear safety, safeguards and physical protection.

4.1. Standards related to radiological protection of members of the public

The Basic Radiological Safety Standard (AR 10.1.1) establishes the general guidelines required to reach a proper level of protection against the harmful effects of ionizing radiation and of the radiological safety of the installations or practices involved.

Standard AR 3.1.2 refers to the limitation of radioactive effluent discharge to the environment, establishing the total effective dose to the critical group and the collective effective dose constraints.

Regarding potential exposures, the Regulatory Authority has developed a probabilistic criterion with the purpose of limiting individual risk to members of the public. For each installation, the individual risk associated to a given accidental sequence should have at most the same value as that associated to normal situations at such installation. This design criterion has been applied in Argentina during the last 15 years.

4.2. Responsibility for safety

The regulatory system considers that the organization operating relevant nuclear or radioactive installations, known as the Responsible Organization, is fully responsible for the radiological and nuclear safety of the installation. The mere compliance with the regulatory standards does not exempt the organization from the mentioned responsibility. For this reason the regulatory standards are not prescriptive but, on the contrary, they are "performance-based" standards, that is to say, they establish the fulfilment of safety objectives; the way of reaching these objectives is based on engineering experience, on the qualification of designers, constructors and operators and on suitable decisions taken by the Responsible Organization itself. Therefore the Responsible Organization must demonstrate and convince the Regulatory Authority that the installation is safe.

5. RADIOLOGICAL PROTECTION

5.1. General criteria

The basic criteria in which radiological and nuclear safety is supported have been applied for a long time and they are coherent with the ICRP recommendations.

On the other hand the Regulatory Authority has contributed to formulate recommendations issued by international bodies (such as IAEA and ICRP), so that it is usual to find, in its own standards, concepts dealing with radiological and nuclear safety that appear in such recommendations.

The radiological protection basic criteria applied in the country establish that:

- Practices using ionizing radiation shall be justified;
- Radiological protection shall be optimized;
- Limits and established dose restrictions shall not be exceeded;
- Accidents shall be properly prevented and mitigate their radiological consequences if they occurred.

The justification criterion determines that any practice that implies, or could imply, personnel exposure to ionizing radiation will only be justified if it originates a net positive benefit to the society.

As regards the optimization of radiological protection systems, it is the policy of the Regulatory Authority to require that exposures due to a justified practice be kept as low as reasonably possible, taking into account social and economical factors (ALARA). In order to achieve optimization, the Regulatory Authority requires that the technically available options and the collective dose reduction be detailed as well as the cost associated with each option.

The effective dose limit for members of the public is 1 mSv in a year. In order to consider the contribution to the dose received by the critical group due to practices carried out at regional and global levels, and to count on a proper margin for future practices, the Regulatory Authority has established dose restrictions (dose constraints) for a particular installation, not only on the effective dose but also on the collective effective dose per unit of practice.

— The effective dose to the critical group shall not exceed 0.3 mSv in a year (0.1 mSv in a year if optimization of protection systems is not performed).
— The collective effective dose shall not exceed 15 man Sv $(GW_{(e)}\ y)^{-1}$ of generated electric energy.

In order to apply these restrictions and not to exceed dose constraints, the Regulatory Authority limits the authorized discharges into the environment (discharge limits).

6. CONTROL OF RADIOACTIVE DISCHARGES TO THE ENVIRONMENT

For relevant facilities, with authorized routine radioactive releases (main nuclear fuel cycle and radioisotope production facilities), the authorized discharge limits are included in the operating licence.

The release limits are set as annual and short term limits for airborne and/or liquid radioactive effluents and for the significant individual radionuclides.

In order to demonstrate that discharges are in compliance with the discharge limits, the licensee must perform the effluent monitoring at the discharge point.

ARN has a national database with the routine radioactive releases of relevant facilities, which is being continuously updated. It is used to evaluate trends, to update authorized release limits and for inspectors regulatory control activities. Population dose assessments are performed in order to control population exposure due to relevant facilities operation.

The radioactive release data of the two nuclear power plants has been sent periodically to UNSCEAR by ARN, and they are published in the Annual

Report of ARN, with the population exposures committed by these discharges. ARN Annual Report is published in ARN web page (www.arn.gov.ar)

ARN verifies by means of regulatory inspections and audits the compliance with the authorized release limits and with the provisions of the operating license.

For medical, research and industrial uses of unsealed sources, only the radionuclides and the maximum activity allowed to be used are set in the operating license. There are no requirements on effluent monitoring and simple checks on discharge levels are made, for example, on the base of activity balance.

7. CONDITIONS FOR THE DISCHARGE OF RADIOACTIVE MATERIAL TO THE ENVIRONMENT

According to regulatory standards, the radioactive effluent retention systems shall be optimized. The different alternatives considered for effluent treatment should be satisfactorily detailed to the Regulatory Authority, as well as the costs of each alternative and the collective effective dose reduction achieved in each case. The selection of the best option is carried out according to usual procedures.

When the optimization is performed by means of a cost-benefit analysis, a value of the proportionality coefficient between the social cost and the collective dose of $10 000 per man Sievert is used.

The dose constraints to the population for a particular practice are consistent with those proposed by IAEA, but they are more conservative because of the condition applied both to the individual and to the collective dose.

The operating licences issued by the Regulatory Authority establish that the dose to the critical groups due to the discharge of radioactive effluents to the environment should be as low as reasonably possible and shall not exceed the constraint given in terms of the following expression:

$$\sum_i \frac{A_i}{K_i} < L$$

where:

A_i is nuclide *i* activity released to the environment in the period considered;

K_i is a constant activity value, stipulated for the nuclide *i*, for a given installation;

L is the limit for this sum of fractions, with different values for the different periods considered; $L=10^{-2}$ in a day, $L=3\times10^{-1}$ in three months and L=1 in a year.

The value of K_i is calculated for each installation, radionuclide and type of discharge (liquid and gaseous) using specific models to estimate the dose to the critical group, taking into account the site characteristics and the critical group location.

This kind of evaluation ensures that if this inequality is satisfied, the dose constraint for people will be not be exceeded.

The release of gaseous and liquid effluents occurring during normal operation of nuclear installations is continuously monitored and controlled. In case of detecting significant deviations from historical averages or growing annually discharged activity trends, they shall be carefully analysed and justified.

Besides monitoring effluent discharges, the Regulatory Authority requires the implementation of an environmental monitoring programme in the installation surroundings, including measurement of activity in water samples, sediments, biota, milk and other representative samples of the surrounding biosphere.

In addition to the environmental monitoring plan carried out by the licensees, the Regulatory Authority independently performs environmental measurements in the surroundings of nuclear installations or nearby zones with its own labs and specialists.

7.1. Radioactive releases

A general overview of the situation in Argentina will be shown dividing the facilities and practices with authorized radioactive discharges to the environment into two groups, according to the associated radiological risk involved and the regulatory requirement for the control of the routine radioactive releases to the environment [1]:

(1) Facilities of the nuclear fuel cycle and radioisotope production (relevant facilities) are shown in Tables 1 and 2.

(2) Medical, research and industrial uses of unsealed radionuclides, are shown in Table 3.

A summary description of their main characteristics is shown in the following tables.

Relevant facilities

TABLE 1. NUCLEAR FUEL CYCLE FACILITIES, URANIUM MILLING, CONVERSION AND FUEL FABRICATION

Purpose	Milling	Conversion to UO_2	Fuel fabrication
Location (province)	Mendoza	Córdoba	Buenos Aires
Airborne effluents	Yes	Yes	Yes
Liquid effluents and surface water body	No	Sewage system	Stream
Main radionuclide	Natural uranium	Natural uranium	Natural uranium
Typical annual releases (MBq)	1	1×10^3	20

TABLE 2. NUCLEAR FUEL CYCLE FACILITIES, NUCLEAR POWER PLANT (PHWR)

Name	Atucha I	Embalse
Capacity	0.360 GW(e)	0.600 GW(e)
Location (province)	Buenos Aires	Córdoba
Airborne effluents	Yes	Yes
Surface water body	Paraná river	Embalse lake
Main radionuclide	Tritium	Tritium

Research and development

Four facilities are included in this group: 2 Research Reactors and 2 small research and development laboratories.

They are situated in the Atomic Centres and their discharges to the environment are very low and have no radiological significance.

Radioisotope production facilities

The Research and Radioisotopes Production Reactor (5 MW), the Radioisotopes Production Plant, the Mo-99 Production Plant and the Sealed Sources Production Plant are situated at the Ezeiza Atomic Centre (Buenos Aires Province). The liquid effluents are discharged to the Aguirre stream. Their main characteristics are shown in Table 3.

TABLE 3. MEDICAL RESEARCH AND INDUSTRIAL USES OF UNSEALED SOURCES OF RADIONUCLIDES

Purpose	Research reactor	Radioisotopes production plant	Mo-99 production plant	Sealed sources production plant
Airborne effluents	Yes	Yes	Yes	Yes
Liquid effluents	Yes	Yes	No	No
Main radionuclides	Fission products	Iodine in gaseous forms	Noble gases	Co-60
Typical annual releases (MBq)	2×10^2	4×10^3	3×10^6	< 1

8. ENVIRONMENTAL IMPACT

8.1. Population dose assessment due to radioactive releases of nuclear power plants

With the purpose of evaluating the environmental impact due to the nuclear power plants operation, several studies were carried out in the sites. Some of these studies included data obtained prior to the beginning of the commercial operation and some others were developed during operation. These studies aimed at comparing the evolution of significant parameters on the environment before and during nuclear power plants operation. Studies of climatologic, hydrologic and seismologic characteristics of the region, distribution and population characteristics, dwelling, human activities and agricultural-cattle breeding characteristics as well as eating habits in the zone, should be mentioned.

Besides, dilution factors were calculated in order to evaluate the theoretical radionuclide distribution in the environmental compartments of the man nutrition chain. Moreover, radio-ecological evaluations were performed on vegetable specimens, wild animals, sediments and other components of the ecosystem.

The assessment of critical group doses is carried out following a methodology which consists in an iterative screening approach which starts with a simple assessment based on very conservative assumptions and is refined by each iteration. In a site specific dose assessment model, site specific parameters for atmospheric and aquatic dispersion, actual habits of the population and consumer rates of local products are used. Site specific information about the actual population distribution is needed to identify the critical group, and the conservative criteria for dose assessment is based on the assumption that the critical group only consumes locally produced foodstuffs.

In situations where no critical group as such can be identified, e.g. in an environment with essentially no human habitation, doses to a hypothetical critical group are assessed in order to demonstrate conformity with the operating licence conditions. For example, for discharges to the atmosphere, it is assumed that the hypothetical critical group is located at the boundary of the facility, or at a distance corresponding to the highest predicted concentrations of the radionuclides in air. For aquatic discharges, similar conservative assumptions are made.

In Figures 1 and 2, a summary of the corresponding results of the environmental radioactive releases control and the population dose assessments due to such releases in the Atucha I and Embalse NPPs in the period 1990–2002 are shown.

The 81% of the total average discharge from CNA-I to the environment corresponded to tritium. Comparing these discharges with the respective annual authorized discharge limit, it is observed that they were less than 6% of such limit.

The 40% of the total average discharge from CNE to the environment corresponded to tritium, and 60% to noble gases. Comparing these discharges with their annual authorized discharge limit, they were less than 10% of such limit.

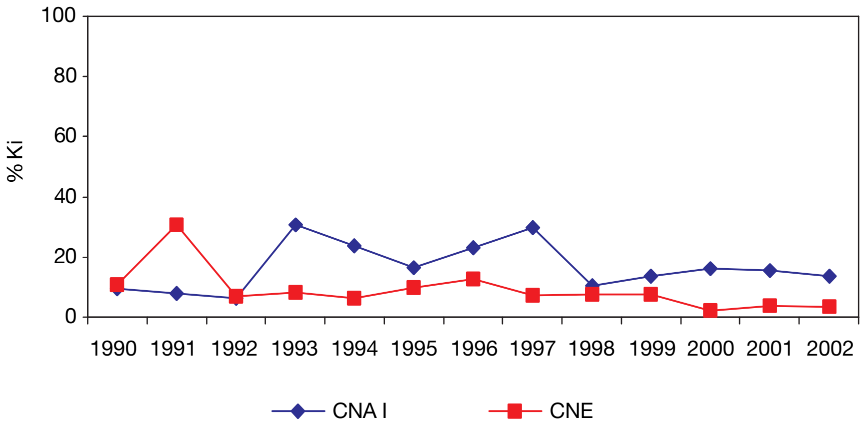

FIG. 1. Environmental releases (% Ki = percentage of the authorized annual limit for radionuclide — in this case tritium).

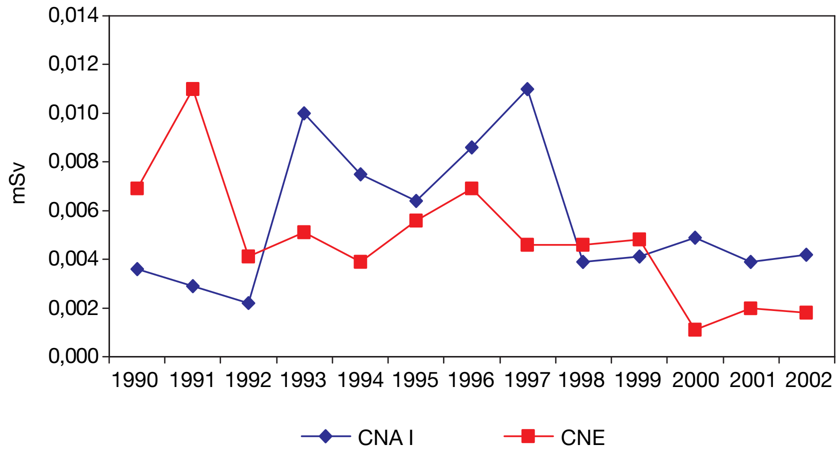

FIG. 2. Doses in critical groups (mSv).

The annual average dose to the critical group due to CNA-I and CNE operation, was lower than 5% of the established individual dose constraint. Gaseous discharges were the main contributor for CNA I, while liquid discharges prevailed at CNE.

9. CURRENT REGULATORY APPROACH AND RECENT CONCERN FOR ENVIRONMENTAL PROTECTION

The concern for the environment protection, particularly with relation to the impact of ionizing radiation on other species than man, has been widely described in recent documents, meetings and publications [2–11]. The main feature of this concern seems to be the shifting of the scientific thinking on environmental radiation protection from the so called “anthropocentric approach” to an “ecocentric approach”. Consequently, the extension of the current system of radiological protection to explicitly include protection of the environment is being considered. Nevertheless, an overreaction to this apparent conceptual gap is not justified when comparing potential impacts of ionizing radiation on the environment with those arising from other human activities [12, 13].

While some human activities are perceived as new threats to the environment, such as the dumping of nuclear waste, decommissioned reactors and nuclear vessels in the Arctic, as well as the establishment of nuclear installations in uninhabited regions, it should be recognized that these activities can be dealt with by properly applying principles of the current system of radiation protection like justification of practices or by using the concept of hypothetical critical groups.

On the other hand, the present system of radiation protection of humans assumes the protection of other species as a result of them being much more resistant to acute exposure to radiation, although there is little or no evidence for chronic exposures. Nevertheless, any severe impact of ionizing radiation on biota has not been demonstrated and this fact should be clearly emphasized.

Guideline dose limits for biota have been recommended by international organizations such as NCRP (1991), IAEA (1992) and UNSCEAR (1996), below which significant effects are unlikely [14–16]. A number of countries such as Canada and the USA have also suggested dose limits for biota [17, 18], while the more recent studies provide further evidence that these values remain appropriate [19, 20]. Moreover, these studies present an estimation of the dose rates to biota resulting from controlled discharges to the environment which imply an annual dose to the most exposed people (critical group) of 1 mSv. Comparing these values with the resulting annual doses to most exposed people (critical groups) from the regulated operation of nuclear power plants in Argentina (and practically elsewhere, accordingly to UNSCEAR reports), it is evident that the estimated dose rates to organisms from controlled discharges of radionuclides to the environment are several orders of magnitude below the recommended values. Furthermore, such values of dose rates are indeed well below the corresponding dose rates to biota due to natural radionuclides in the biosphere.

The above presented lines of evidence clearly support that this current regulatory programme based on the protection of human beings is also adequately protecting the environment (non-human species).

10. CONCLUSIONS

It is recognized that a regulatory body is effective, among other actions, when it performs its regulatory functions in an efficient manner with high quality and without unnecessary costs to licensees and society in general, a manner that ensures the confidence of the operating organizations, the general public and the government.

The present challenge to the well established statement that protecting man automatically implies protection of the environment should be carefully defined in order not to produce a negative effect on public confidence on regulatory authorities. It has been argued that by creating pressures and questioning their institutions people are often strengthening them; unfortunately, often this task is left to unrepresentative pressure groups and not to responsible guardians of societal interests. In such a case, suspicion and mistrust dominates the situation [21].

As expressed by G.J. Dicus [22], the decision making process implicit in regulations also includes political and socioeconomic features which, sometimes, take precedence over science. It is, therefore, particularly important that those involved in scientific work give to those involved in regulatory policy the best foundation possible to balance the equation giving science a very strong voice. Therefore, the need of regulations on radiological safety to be based on the best available scientific evidence must be emphasized and clearly communicated to the public and relevant stakeholders.

J.L. Borges wrote "Doubt is a way of naming intelligence". The message of this presentation can be summarized by slightly changing his words: "Reasonable doubt is a way of naming intelligence".

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REGULATORY CONTROL OF DISCHARGES TO THE ENVIRONMENT
An operator's view

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Abstract

The paper discusses the regulatory control of discharges to the environment based on the experiences at Japan Nuclear Cycle Development Institute (JNC), whose key projects are to form the basis of the nuclear fuel cycle, such as the the fast breeder reactor (FBR), advanced reprocessing, plutonium fuel fabrication and disposal of high level radioactive waste.

1. INTRODUCTION

When we design, construct and operate nuclear facilities, our basic frameworks of radiation protection have been focused on the protection of man, which is based on the statement of the ICRP, "if man is adequately protected then other living things are also likely to be sufficiently protected (Publ. 26)" [1].

In regard to the discharge of radioactivity to the environment, a reprocessing facility is a noteworthy example. Therefore effluent and environmental monitoring at the Tokai Reprocessing Plant (TRP) is introduced at first, and then our efforts to reduce radioactivity into the environment from the TRP and considerations for proper effluent control are shown.

2. TOKAI REPROCESSING PLANT (TRP)

The TRP started its active test in September 1977, and the operational license was given at the end of 1980. By design base specifications, plant capacity is about 0.7 tons of uranium a day. And spent fuels specifications are; the initial enrichment is 4% at the maximum, the burnup is 35 000 MWD/t at the maximum, and the cooling time is 180 days at the minimum [2].

Figure 1 shows the reprocessed amount of fuels at the TRP. About 1010 tons of uranium has been reprocessed since 1977. This figure also shows the amount of fuels reprocessed each year since 1977, which depends on the operational conditions of the TRP. So far the TRP has been shut down to make modifications and improvements with the aim of steady and stable operation.

3. EFFLUENT MONITORING AND ENVIRONMENTAL MONITORING

3.1. Results of monitoring

The effluent and environmental monitoring at the TRP is shown as an example from the view point of regulatory control [3]. In the normal operation of the TRP, low levels of radioactive effluent are discharged to the atmosphere and to the ocean under control measures. There are three stacks whose height

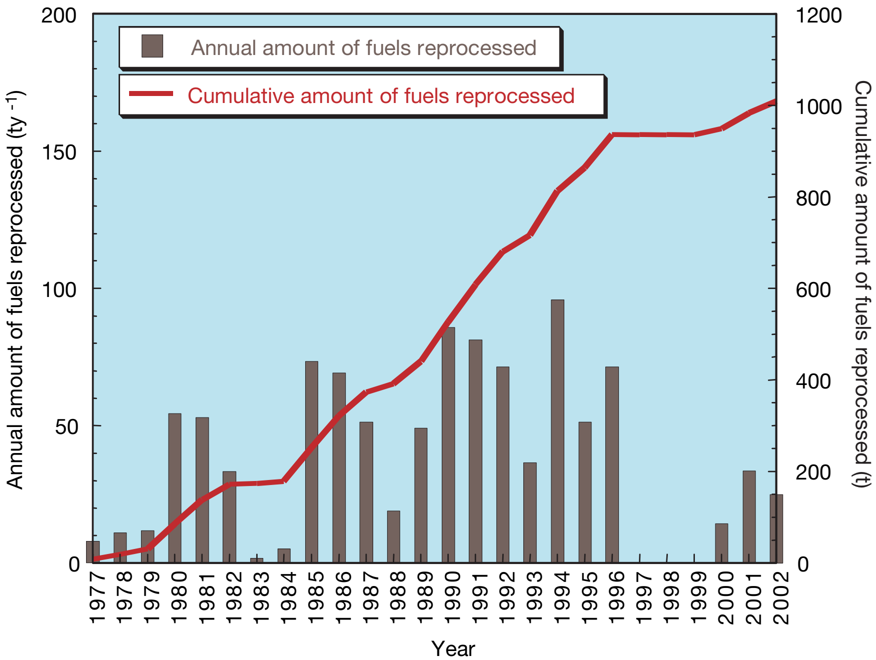

FIG. 1. Amount of fuels reprocessed at the TRP.

are about 90 metres above sea level, and one liquid discharge pipeline whose head is located at about 3.7 km offshore.

Figures 2 and 3 show annual discharged radionuclides in airborne/liquid effluents from the TRP. The discharged amount of each nuclide is sufficiently lower than the annual discharge limits defined in the Safety Prevention Rules.

In order to complement the effluent control measures, environmental monitoring has been planned and carried out. Environmental monitoring items in terrestrial and marine regions are decided from the view points of ‘the exposure pathways to man’ and ‘an indicator of radioactive accumulation’. Many kinds of samples have been collected and analyzed such as air absorbed doses (rates), airborne radionuclides, agricultural products (rice grain, leafy vegetables, milk), water (tap water, river water) and soil (surface soil, riverbed sediments) in terrestrial region, and sea water, seabed sediments, beach sand, marine foods (fish, shellfish, seaweed) and dose rates (boat deck, fishing net) in marine region.

A summary of our environmental monitoring is (1) the levels of environmental radiation/radioactivity have shown no significant increase or accumulation, (2) the monitoring data are almost the same as the background

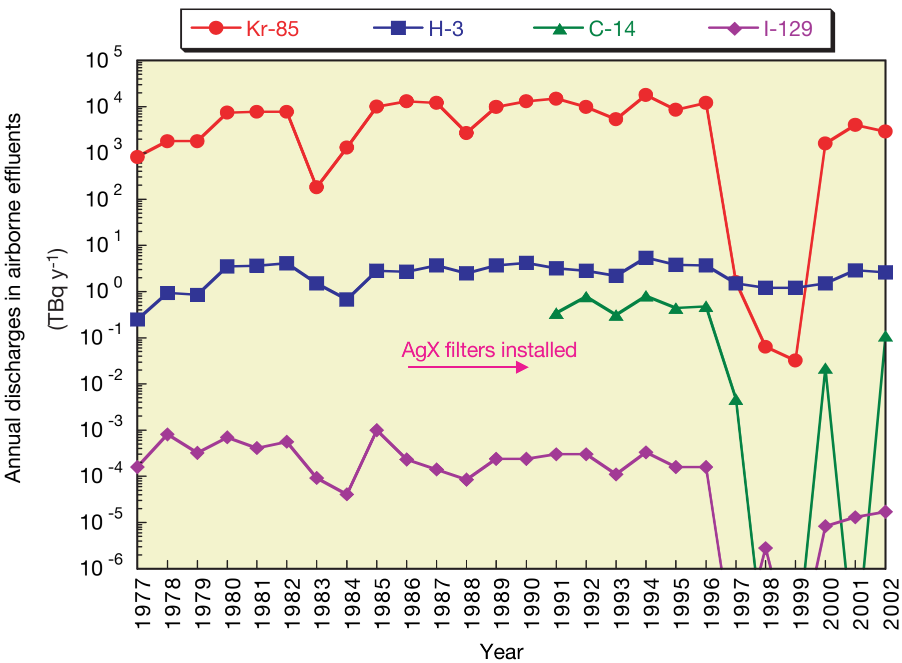

FIG. 2. Annual discharges of radionuclides in airborne effluents from the TRP.

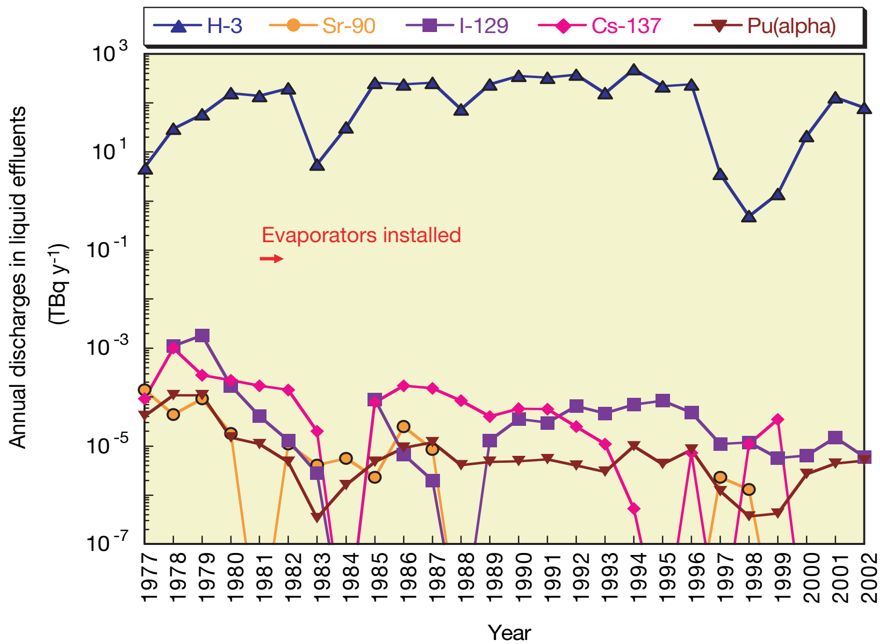

FIG. 3. Annual discharges of radionuclides in liquid effluents from the TRP.

level and (3) there is still no evidence of harm, nor any expectation of harm on the basis of current scientific understanding. So we can conclude that there have been no significant radiological effects to the regional environment due to the operation of the TRP for the last 25 years.

3.2. Results of annual effective doses

Table 1 shows estimated public doses in the latest governmental safety assessment. These doses are calculated based on the annual discharge limits of airborne/liquid effluents which are described in our Safety Prevention Rules. Annual effective dose under design base conditions is 18 μSv/year, which is 2% of the public dose limit recommended by the ICRP. Compared with the earliest assessment, this dose has decreased by much more than an order of magnitude.

Figure 4 shows annual effective doses from radionuclides discharged from the TRP. The environmental monitoring data are almost the same as the background level, so it is difficult to determine the public doses based on them. Therefore annual effective doses are estimated by mathematical models based on discharge data. C-14 has been monitored since 1992 after confirmation of

TABLE 1. ESTIMATED PUBLIC DOSE BASED ON THE ANNUAL DISCHARGE LIMITS

Airborne effluent	External exposure to gamma-ray from Kr-85	5.1 μSv/y
	External exposure to radionuclides deposited on surface soil	1.4 μSv/y
	Internal exposure through inhalation	0.8 μSv/y
	Internal exposure through ingestion	5.7 μSv/y
Liquid effluent	External exposure to absorbed on fishing nets, fishing boats, etc.	1.9 μSv/y
	Internal exposure through ingestion	3.6 μSv/y
Annual effective dose at design base		18 μSv/y

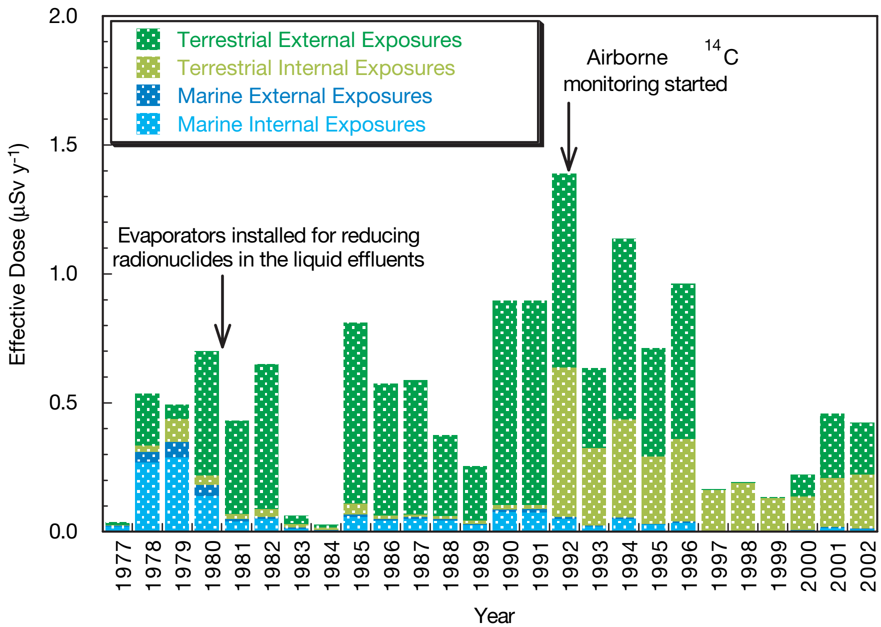

FIG. 4. Annual effective doses from radionuclides discharged from the TRP.

the monitoring technique. The contribution via marine pathways represented half of the total exposure doses before 1981, but it became negligibly small compared with other pathways' contribution after the construction of the 2nd/3rd evaporators shown in section 4. The estimated doses are around 1 μSv/year; only 0.1% of the public dose limit. It is concluded that the effluents into the environment have been well controlled.

3.3. Challenge to dose estimation and environmental monitoring

Radiation exposures to the public around the TRP have been estimated for the potential pathways with site specific parameters such as food consumption, concentration factors of marine organisms, and meteorological conditions etc. Figure 5 shows the exposure pathways to man in the terrestrial environment around the TRP. Discharged radionuclides/radiation reaches man via inhalation pathways, ingestion pathways, and external pathways. Key nuclides are Kr-85, C-14, H-3 and I-129. Figure 6 shows the exposure pathways to man in the marine environment. Discharged radionuclides/radiation reaches man via ingestion pathways and external pathways. There are many kinds of key nuclides in the marine environment.

Exposure pathways in terrestrial and marine environments both result in exposure to man. A very broad environmental monitoring programme has been carried out, but non-human species outside the food chain have not been monitored in the present monitoring programme, except several samples chosen as a good indicator of radioactive accumulation. This may be where we need to offer more consideration for the protection of the whole environment.

When we think about new monitoring samples, some evaluation items should be examined closely:

(1) appropriateness of the samples; (2) evaluation standard (e.g.; rate scale of hazard/effect, species preservation, etc.); (3) exposure pathways; (4) evaluation period, etc.

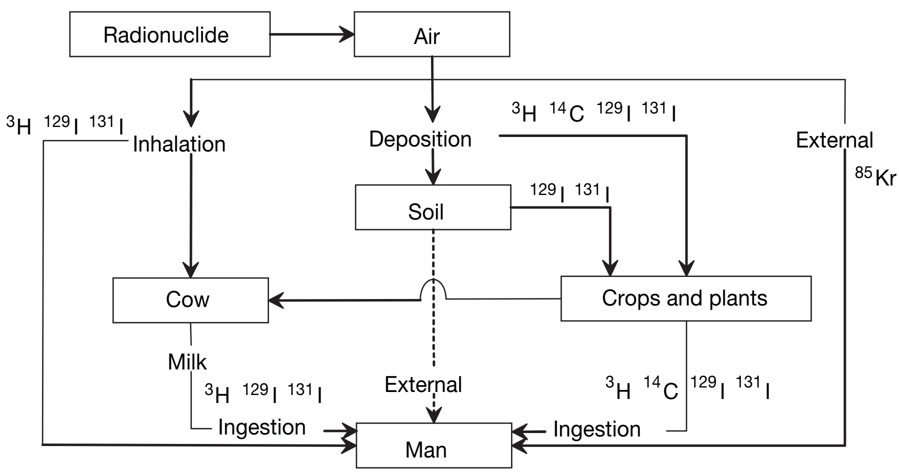

FIG. 5. Exposure pathways to man in the terrestrial environment.

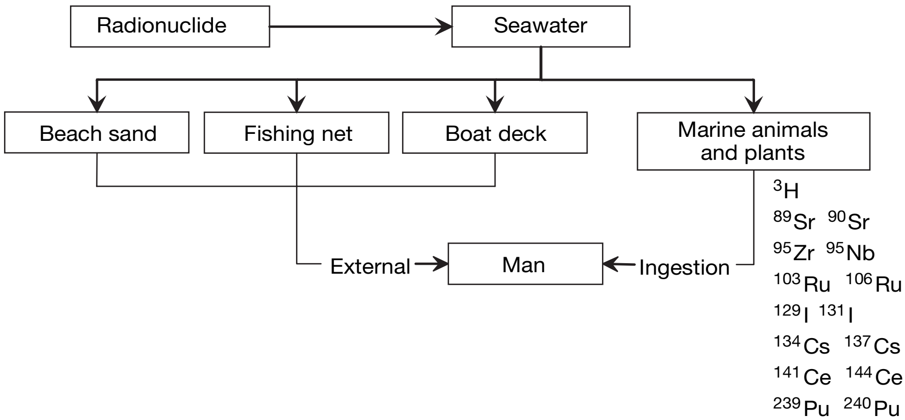

FIG. 6. Exposure pathways to man in the marine environment.

4. CONSIDERATIONS FOR PROPER EFFLUENT CONTROL

Next, our continuous efforts to reduce the amount of radioactivity discharged into the environment are shown. When we design, construct and operate nuclear facilities, we need to consider:

— compliance with national laws and/or international rules;
— incorporation of leading edge technology;
— response to social requirements.

4.1. Hierarchical structure of effluent control

One example of compliance with national laws and/or international rules is a hierarchical structure of effluent control, which consists of 'Guide value for the public dose' in the site vicinity, 'Discharge limits' and 'Detection limits' set up based on the dose limit of 1 mSv/year. A 'guide value for the public dose' is 50 μSv/year has been prescribed by the Nuclear Safety Commission of Japan. This value is for nuclear power plants, but other nuclear facilities such as reprocessing plants, fuel fabrication plants, etc. also refer to this value. 'Discharge limits' and 'Detection limits' are prescribed in the operators' Safety Prevention Rules to show that effluent control is carried out properly.

— Guide value for the public in the site vicinity is prescribed by the Nuclear Safety Commission of Japan as a quantitative target to promote reducing the amount of radioactivity discharged into the environment from the

ALARA point of view. This value is not determined from the possibility of radiological hazard but is based on the practical consideration on plant operations.
- Discharge limits for effluent control are annual discharge amounts, discharge rate, radioactive concentration, etc. Based on these values exposure doses to man can be calculated. These values are determined so that it can be confirmed that the estimated public dose are below the guide value for the public in the site vicinity taking account of the operational conditions of each nuclear facility. Operators are required to prescribe these values in their Safety Prevention Rules.
- Requirements for detection limits: (1) to have necessary sensitivities to confirm that the discharged radioactivity is within the control concentration, (2) to have a sufficient concentration range covered by practical instruments and measuring methods, (3) to be practical from the view of sampling, the time of treatments, frequencies of measuring, measurement times, etc.

This hierarchical structure of effluent control is based on the dose limit of 1mSv/year. The established concept of the radiological protection of man has worked well for decreasing radioactivity to the environment from nuclear facilities.

4.2. Concepts of reducing radioactivity into the environment

Figure 7 shows the schematic flow of waste treatment systems at the TRP. Airborne/liquid effluents are discharged into the environment after reducing treatments and monitoring. High active level wastes from the main process are to be stored in the TRP after treatments. High and low levels of liquid wastes are treated, stored and then vitrified or solidified, respectively. Solvents and acids are reused after recovering.

When we think about reducing the discharge of radioactivity into the environment, we have to consider how much radioactivity to allocate to discharge and storage, respectively. There are four main types of disposal methods to prevent hazardous impact of radioactivity to man, depending on the kinds of radionuclides and the range of radioactive concentration used:

- by diffusing radioactivity (Diffusion type);
- by the land disposal of solid radioactive waste whose radioactivity is expected to be significantly decayed in the course of the control period,

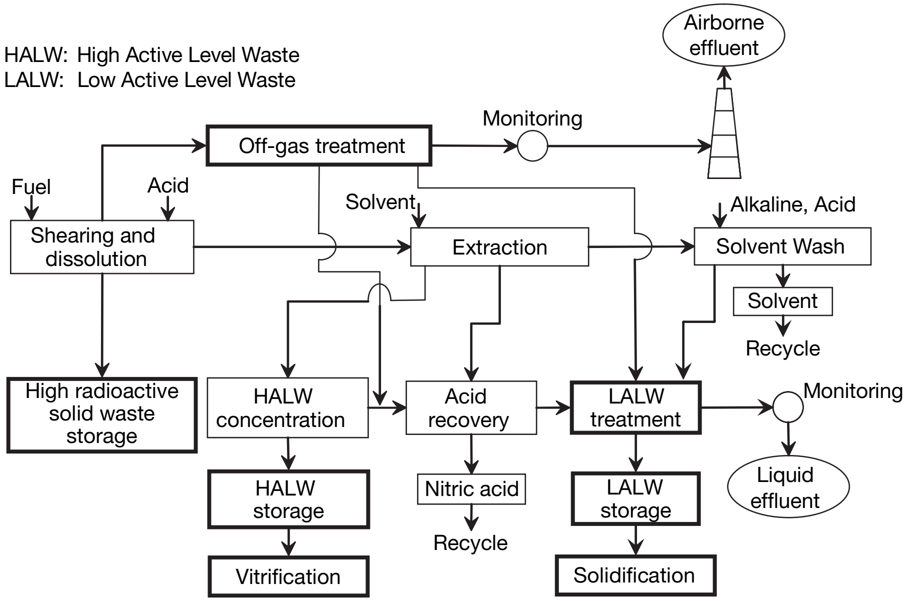

FIG. 7. Schematic flow of waste treatment systems at the TRP.

under step by step control until radionuclides fully decayed (Control type);
- by isolating radioactive waste for a long period of time safely at a stable place isolated enough from the human environment (Isolation type);
- by reusing or recycling very low level radioactive waste in the resources and materials, etc. under certain conditions (Reuse type).

Reducing the amount of radioactivity discharged into the environment requires:

- increasing the amount of storage;
- forcing operators to store high radioactive materials over the long term;
- exposing radiation workers to high and continuous long range exposures.

As all risk will be ever present, it is not clear whether it is better to discharge or to store over the long run. The main point may be how we should balance the environmental burden and the negative elements caused by storage for present and future generations. Time is also an important element we have to think about.

It is a matter of course that "the nuclear fuel cycle technology" allows us to use uranium resources several to several dozens of times more efficiently than we do now by reprocessing spent fuel for reuse as a fuel. Excessive regulations could also reduce the opportunity to achieve the environmental benefits of nuclear power.

4.3. Efforts for reducing radioactivity into the environment

While we have above issues to be resolved, we have made efforts to reduce the radionuclides discharged into the environment from the TRP. We have developed the following technologies:

— The sea discharge amount of beta activities was reduced by additional installations of liquid treatment evaporators [4, 5].
— In order to develop recovery and storage technology for radioactive krypton from the TRP, a pilot plant was constructed and many kinds of tests have been executed [4–6].

Besides above issues, we have made efforts to reduce atmospheric I-129 discharge by installations of silver impregnated filters for iodine traps and etc. Due to space limitation, the following two cases are introduced here.

4.3.1. Reducing radioactive releases to the sea

In February 1969 the Radiation Council, a governmental organization, recommended that the guidelines for the public exposure dose caused by discharges to the sea be one tenth of the public dose limit. That was 0.05 rem (500 μSv) per year for the 1st reprocessing plant in Japan. In January 1970 the PNC (Power Reactor and Nuclear Fuel Development Corporation, the predecessor organization of JNC) received "a construction permit authorization" from the Prime Minister.

However, in 1971 the Fisheries Cooperative Association (FCA) and others litigated the PNC demanding for improved methods of liquid discharge to the sea. In April 1974 the PNC came to reach a settlement with the FCA etc. by promising 1) to reduce the radioactive concentration of discharged liquids to be one tenth of designed value, 2) to expand the length of discharge pipe from 1km to 1.8km, and 3) to make continuous efforts for reducing radioactivity to the sea, etc.

In 1980 the PNC built new liquid treatment facilities in the TRP to reduce discharges of radioactive substances to the sea.

— Initial designed discharge plan of beta nuclides was 260 Ci (9.6TBq) at the maximum per year, except H-3.
— The 2nd/3rd evaporators were built in the TRP as an additional liquid treatment installation to reduce radioactive liquids from 260 Ci (9.6 TBq) to 26 Ci (0.96 TBq) per year in design base. And a de-acidification process was also built in as a pollution control technology.
— As a result, an annual public dose was improved from 5.7 mrem/year (57 μSv/year) to 0.58 mrem/year (5.8 μSv/year).
— Total cost was about US $30 million at the time.

This is the example that we addressed at the request of a 3rd party. Although we had received a construction permit from the government, the 3rd party had a big effect on the design and operation of our facilities. This doesn't seem to be a logical outcome, but these days this phenomenon is growing, and it is important to signal a commitment to hear outside interests, while it goes without saying that operators and regulators are responsible to make the final decision as a 1st party or a 2nd party.

4.3.2. Reducing radioactive releases to the air

Around 1970 it was planned to develop Kr-85 recovery and storage technology due to the predicted increase of the electricity generated by nuclear power. The worldwide release and accumulation of Kr-85 was cause for concern. Therefore the PNC decided to construct a Krypton recovery development facility.

The exposure dose caused by Kr-85 is very small when weighed against the pubic dose limit recommended by the ICRP. The estimated public dose based on the annual discharge limit of Kr-85 is 5.1 μSv/year (0.5% of the dose limit). But as shown in Table 1, the nuclide, which causes the biggest exposure to the public in the site vicinity, is Kr-85 among discharged nuclides from the TRP. Therefore, the JNC has developed related technology for the recovery and storage of Kr-85 in anticipation of global increase.

We have been examining the Liquefied distilled technique as a recovery technology, and the Ion plantation technique as a storage technology. Recovery technology of Kr-85 is nearing completion in pilot plant scale, but storage technology is in an early state of development.

— Construction cost: ca. US $40 million at the time
— Operation cost: ca. US $4 million per year.

In regard to reducing the exposure dose caused by Kr-85, we have installed a storage vessel to hold Kr-85 during the shearing and dissolution under the calm conditions, which is less than 1 metre/second of the wind speed at the top of the stack, because air dose rates in the vicinity of the plant sometimes show a slight increase depending on meteorological conditions such as wind direction/speed and atmospheric stabilities.

We have been operating our nuclear facilities safely, aiming to reduce the release of radionuclides into the environment by incorporating new technology as they become available. With the role of the JNC to develop nuclear fuel cycle technology in Japan, we have worked on these projects on a voluntary basis.

5. COLLABORATION WITH OTHER MEMBERS OF SOCIETY

Radiation/radioactivity is discharged not only from nuclear industry but also from other industries such as petrochemicals and medicine. And outside of the nuclear industry, other pressing environmental issues include air pollution, water pollution, soil contamination, noise, vibration, ground subsidence, offensive odours, effects of non-nuclear industries and other human activities. We need to deal with environmental issues under a unified principle applied for radiation/radioactivity and other hazardous materials/activities.

6. SUMMARY

(1) Operators are in charge of enhancing radiation protection of man and the environment.
(2) Operators have carried out their duties according to laws, administrative directives, guidelines, advice, etc., which are based on the best current scientific evidence shown by the ICRP, the IAEA and so on.
(3) Operators have also tried to manage 3rd parties' issues into consideration, while it goes without saying that operators and regulators are responsible to make a final decision.
(4) Operators have made efforts to reduce the amounts of radioactivity into the environment on a voluntary basis.
(5) Consequently, the levels of environmental radiation and radioactivity have shown no significant increase or accumulation.
(6) To accomplish effective effluent control, operators need unified and solid standards.
(7) Excessive regulations to reduce the amount of radioactivity to the environment would increase the amount of storage, also forcing

operators to store highly radioactive materials over the long term, and to expose radiation workers to high and continuous long range exposure doses. Excessive regulations could also reduce the opportunity to achieve the environmental benefits of nuclear power.

(8) The non-human species outside the food chain have not been monitored in the present monitoring programme. More attention may help protect the whole environment although there is still no evidence of harm, nor any expectation of harm on the basis of current scientific understanding.

(9) Environmental pollution, such as, air pollution, water pollution, soil contamination, noise, vibration, ground subsidence and offensive odours, which affect an extensive area, have been spread as a result of non-nuclear power industries business and other human activities.

(10) The radiological protection of the environment including non-human beings should be addressed in coordination not only with the established radiological protection of man but also with the environmental protection from other harmful materials/activities, based on clear and accumulated scientific evidence.

(11) Therefore it is necessary to exchange views on environment protection with regulators, operators, professionals, interest groups and the public across national borders and also across various fields of expertise to establish a common platform for promoting more effective use of our limited resources.

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Topical Session 1

DISCUSSION

M. MOMEN-BEITOLLAHI (Islamic Republic of Iran): We are talking here about protection of the environment from the effects of ionizing radiation. What about the effects of natural radiation?

A. OLIVEIRA (Argentina): Natural radiation is excluded from regulatory control unless it has been enhanced by human activities — practices.

With non-radioactive pollutants, one does not generally have to take the natural background into account in environmental protection; with radioactive pollutants, one does have to take it into account. However, ionizing radiation is considered to be a minor environmental stressor compared with non-radioactive pollutants.

M. MOMEN-BEITOLLAHI (Islamic Republic of Iran): Humans are the most important element of the environment and also the weakest. How does one take that into account when protecting the environment from the effects of ionizing radiation?

A. OLIVEIRA (Argentina): The present system of radiation protection is based on the so-called “human approach”, which takes account of the fact — supported by a lot of scientific evidence — that humans are more radiosensitive than other species. Nevertheless, although there is no scientific evidence of harm to the environment due to justified — and regulated — practices involving radionuclides, there has been a shift towards concern for the radiation protection of non-human species due to changes in societal thinking. I am sure, however, that the validity of the present system of radiation protection will in due course be demonstrated by the scientific evidence.

L. KEEN (Canada – Chairperson): We regulators are having to adjust to the shift towards concern for the radiation protection of non-human species that Mr. Oliveira just mentioned.

S. SMITH (WWF): Could Mr. Ishida and Mr. Oliveira tell us whether the organizations for which they work make their monitoring data available to the public?

J. ISHIDA (Japan): Our institute displays the data from its airborne effluent and other monitors on its website, which can be accessed by the general public.

In addition, every three months we submit our monitoring data to the local government authorities, who publish the data with their comments. Once a year, the same procedure is followed with the central government authorities.

A. OLIVEIRA (Argentina): Our information policy is based on openness and full disclosure to stakeholders — the public, the government and so on. Besides raw data, however, we provide explanatory information, since lay persons may misinterpret radionuclide concentration values which are always above zero even if they are of no radiological significance.

Round Table 1

DISCUSSION

T. CARLSSON (Sweden): The Oskarshamn municipality, of which I am a former mayor, is host to three nuclear power reactors and to a number of other nuclear facilities, and it is one of the Swedish municipalities being considered as a possible future host to a final repository for spent nuclear fuel.

Nuclear facilities are controversial, and positive decisions on their siting cannot be arrived at without trust among those involved in the decision making. Trust depends on, inter alia, the existence of clear rules. In the case of the siting of the envisaged final repository, for example, the nuclear industry must be responsible for proposing the technical solution and the site. The competent authorities and independent experts must be responsible for reviewing the licence applications and approving or rejecting them; the municipality — where the population knows the local conditions best and has its own ideas about what the future should bring — is responsible for taking the final decision on the basis of the conclusions of the competent authorities and independent experts; and the central government is responsible for issuing the licences if the municipality's final decision is positive.

In addition, there must be a strong, independent and competent regulatory body that interacts helpfully with the municipality and an open dialogue in which the technical information is presented in an understandable manner.

Furthermore, in order that the local people may have real influence on the decision making process, everything must be on the table — there must be no hidden agenda.

At Oskarshamn, we found that the public and environmental groups made valuable contributions, Also, with the help of the nuclear industry we learned what questions to ask.

A.A. SHPYTH (Canada): The nuclear industry is very much aware of the public concerns about the environmental impact of major industrial developments. Such concerns, which relate to major industrial developments not just in the nuclear field, are not new to the nuclear industry.

Successive Canadian governments have, in response to the public's concerns, often required that industry involve the public in decision making processes, particularly environmental impact assessment processes, and since the early 1970s the level of public involvement has been high.

The nuclear industry involves the public not just because there is a legal requirement that it do so. There is the good corporate citizenship aspect, and also a recognition that not involving the public may adversely affect the project in the long run. Moreover, the nuclear industry realizes that the societal environment is constantly changing and that involving the public is important for being attuned to the prevailing collective wisdom — to what is currently regarded as acceptable and unacceptable.

The nuclear industry also realizes that — in addition to regulatory issues — it often needs what one might call “societal licences”, so it engages with stakeholders at the community level. Besides the residents of communities, however, it regards its owners, it employees, its customers, environmental groups and others as stakeholders. It also regards itself as a stakeholder — and one with important attributes: it is often the most knowledgeable stakeholder; it is usually the stakeholder responsible for implementing whatever is ultimately decided upon; and it is the stakeholder responsible for the safety of workers, the public and the environment.

J. SUTCLIFFE (United Kingdom): At this conference, I am wearing three hats — I am a member of the public, I am an environmental specialist and I help to advise governments on wildlife issues. I have participated in public inquiries, I am participating in the current dialogue about decommissioning of the United Kingdom’s Magnox reactors and I have organized workshops for a wide range of people on wildlife and ionizing radiation issues. With that background, I have come to the conclusion that you should not leave decision making exclusively to the experts. Stakeholder consultation involving a wide cross section of people with different interests in the issue makes for a better final decision.

Such stakeholder consultation also makes for greater transparency. In the formulation of policy relating to ionizing radiation, the decisions used to be taken behind closed doors by self-elected groups. Things are changing in the direction of greater transparency, but not as quickly as they might. There needs to be greater legitimation of the policy relating to ionizing radiation, including the policy on nuclear power, and that policy needs to be integrated with other policies — for example, the policies on health and the environment.

Unfortunately, with so many people, organizations and governmental departments coming to the table with different values and expectations, there is a risk of “death by consultation”. So much consultation takes place that people become worn out and do not wish to continue, especially if they are uncertain how their inputs will be taken into account or suspect that the consultation is just for show.

Another problem is that members of the public participate in the consultation process in their spare time, without being paid to do so, whereas the representatives of industry and government and the environmental consultants are being paid. So equity is an important issue in stakeholder involvement.

D.H. OUGHTON (IUR): I believe that stakeholder involvement is definitely an essential element of environmental radiation protection. The next question ought perhaps to be "Who should participate in stakeholder involvement?" There are two common responses to the question "How do you come to be participating?"

The straightforward answer is "I was chosen to participate and I know a lot about the subject". The people representing industry will normally give that answer. For them it is particularly easy to justify their presence at the table.

The other answer is "I share the concerns and opinions of the group which I am representing". This answer is not as straightforward. After all, it was not so long ago that, in the Western world, men spoke for women and masters spoke for servants — and that is still the situation in some parts of the world.

The problem is — who should represent the environment? The environment — like future generations — cannot invite a representative, and the problem is a philosophical one to which I cannot provide an answer.

R.C. MORRIS (United States of America): Something which we often encounter in the United States is the NIMBY ("not in my back-yard") syndrome, where people acknowledge that a project is worthwhile and should be implemented but refuse to accept it "in their back-yard". I should be interested to hear how the NIMBY syndrome is dealt with in other countries.

A.A. SHPYTH (Canada): The NIMBY syndrome has had an impact on a number of nuclear industry projects, and a social impact assessment pioneer who has studied nuclear industry projects negatively affected by the NIMBY syndrome came to the conclusion that such projects had to have at least 80% public support at the outset if they were to survive the approval process; if there was 30% opposition, the projects were doomed.

The nuclear industry alone cannot overcome the NIMBY syndrome. There has to be a lot of governmental involvement, and a project that might falter as a result of the NIMBY syndrome should be proposed within a broad public policy context, in a manner that emphasizes the project's importance for the greater good.

J. SUTCLIFFE (United Kingdom): In the 1980s, the United Kingdom's Central Electricity Generating Board (CEGB) announced a proposal for the construction of nuclear power plants in Cornwall — a county in the far south-western part of England. The local opposition was very strong from the outset, and when the County Council voted there were 59 votes against the proposal and only 19 for it — with one abstention. The CEGB may have attributed the opposition to the NIMBY syndrome, but perhaps people in Cornwall were simply opposed to a decision imposed on them from London.

L. PERSSON (Sweden): In my view, the main reason why there is so little opposition in the Oskarshamn municipality to the construction of a final repository for spent nuclear fuel is that the local population is relatively knowledgeable about nuclear power and does not act from an antinuclear gut feeling like people in other Swedish municipalities.

T. CARLSSON (Sweden): That is true. The Swedish nuclear industry has all along been very open about its activities. In addition, the people from the industry who have visited Oskarshamn for consultations have tended to be the same each time — there have been very few new faces. That also has helped to build trust.

L. KEEN (Canada – Chairperson): We have had situations in Canada where it has not been made clear to a community what is going to happen to the radioactive waste existing — in some cases, for many years — in that community. The local people assumed that the waste was going to be taken away, and they were very unhappy when they learned that — after conditioning — the waste was going to remain within the community.

That is what happened at Port Hope, since no other community was willing to accept the waste that had been there for many years, even though it was low-level waste.

A.A. SHPYTH (Canada): The facility that produced the radioactive waste at Port Hope was one that refined radium for medical purposes. After what Mr. Persson just said, you might have expected the local people to be less opposed to the retention of the radioactive waste within the community. At all events, in the past few years major stakeholder involvement efforts have been under way to improve relations with the community.

A.J. GONZÁLEZ (IAEA): Further to what Ms. Oughton just said regarding the question “Who should participate in stakeholder involvement?”, I should like to make three comments.

Firstly, nobody would openly oppose stakeholder involvement, because to do so would be political suicide.

Secondly, at some stakeholder meetings which I have attended there have been stakeholders who expressed different opinions informally in the corridors from those which they expressed formally in the meetings.

Thirdly, how does stakeholder participation fit into the democratic systems which we have in many of our countries? Under those systems, we elect parliamentary representatives who take decisions on our behalf. With stakeholder participation in decision making, however, people who may not represent anyone except themselves come along and influence the parliamentary representatives. This is another issue which nobody seems to want to address.

L. KEEN (Canada – Chairperson): Regarding Mr. González's second and third comments, I would emphasize how important it is to know your stakeholders.

D.H. OUGHTON (IUR): The answer to the question "Who should participate in stakeholder involvement?" is very context-specific. At all events, the people who are going to be affected by a decision should be represented in the decision making process. Moreover, stakeholders can, if they have the necessary knowledge, make a useful contribution to that process.

Incidentally, there are two basic types of stakeholder involvement. With one type, the stakeholders are essentially trying to obtain information. With the second, they are advising or even playing a stronger role.

J. SUTCLIFFE (United Kingdom): For the past five years, British Nuclear Fuels (BNFL) has been spending £500 000 a year on engaging with its stakeholders. It has found that process very useful, although often uncomfortable, and its decision making procedures have been modified in the light of the results.

Stakeholder involvement is slower at the outset than "announce and defend", but the latter approach creates problems which take a long time to resolve. Building up trust is a slow process, but you can destroy trust very quickly.

A.A. SHPYTH (Canada): Clearly, regulators and local communities are among those who should participate in stakeholder involvement. From the point of view of the nuclear industry, anybody who could take it to court should participate.

Again from the nuclear industry's point of view, stakeholders should be involved from the very outset. Stakeholders who become involved late in the consultation process can create serious problems. The nuclear industry does its best to identify the stakeholders relevant to a particular project, some of whom are "self-identifying", and it hopes that there will be no unpleasant surprises later. For example, you may have a project with which 90% of the stakeholders have come to feel comfortable, and then someone who cannot live with the project comes along; delays occur and sometimes decisions are even overturned.

In this connection, I would note that an IAEA "report for discussion" (Working Material) issued in August 2003 and entitled "A practical approach for protection of the environment from the effects of ionizing radiation" states that "Some characteristics of sources, the ecosystems involved, and the radiation exposures are likely to be of greater interest and concern to some stakeholders than to others." So there are degrees of stakeholder interest and concern, and that has to be taken into account.

T. CARLSSON (Sweden): At Oskarshamn, we have never told anyone that they could not take part in the stakeholder debate, whatever their aims were.

L. KEEN (Canada – Chairperson): Regarding Mr. González's comment about stakeholders in democratic systems, I would note that we elect our parliamentary representatives for a period of four years or so on the basis of their positions regarding a wide range of issues. With individual — very specific — issues, we may need in addition to be represented by stakeholders or to be stakeholders ourselves.

L.-E. HOLM (Sweden): I often hear operators and regulators expressing concern about the possibility that the stakeholder dialogue will simply result in an agreement to disagree. How important is agreement, and how do you measure the success of a stakeholder dialogue?

J. SUTCLIFFE (United Kingdom): In the stakeholder dialogue regarding the decommissioning of the United Kingdom's Magnox reactors, insufficient trust was built up initially and the process became rather adversarial.

A second phase of dialogue is about to be launched, with all possible options on the table, and it is hoped that the various stakeholders will consider all those options and not simply stick to their old positions. We have only a year in which to produce our report on decommissioning options, and we consider that the stakeholder dialogue will have been a success if we produce our report within that time.

A.A. SHPYTH (Canada): A process perceived as simply dialogue for dialogue's sake tends to result in frustration on all sides.

From the nuclear industry's point of view, a successful stakeholder dialogue is one that leads to strong support for the envisaged project, with final proposals that strike a balance between economic, environmental and social needs and will allow decisions to be taken in a timely manner.

D.H. OUGHTON (IUR): Perhaps a stakeholder dialogue can be considered successful if the stakeholders are still talking with one another cordially after a few days. I have experienced stakeholder dialogues where, after a few days, stakeholders have been threatening one another with legal action.

If stakeholders end up at least understanding why they disagree, that is some sort of success, but, if there is a requirement that there ultimately be agreement, then you have a problem, especially if agreement has to be reached within a certain time. But that's life.

T. TANIGUCHI (IAEA): In the field of environmental radiation protection, it is not clear who the stakeholders should be. Environmental impacts are very complex, with many uncertainties, so that you cannot simply say that the local community "knows best".

In this connection, I would mention that, in my view, the communication between the nuclear community and the environmental protection community is not close enough. For example, in the Intergovernmental Panel on Climate Change, of which I used to be Vice-Chairman, the few members who were from the nuclear community tried to communicate with the many members who were opposed to or sceptical about nuclear power generation, but I do not think they had much success. We should be considering how to communicate better with the environmental protection community and also with the general public.

S. MUNDIGL (OECD/NEA): We have organized a number of workshops — called “Villingen Workshops”, because they have been held in Villingen, Switzerland — on radiation protection decision making, the aim being to see how stakeholder involvement processes have worked in specific situations.

For the next such workshop, due to take place soon, we have asked consultants to analyse stakeholder involvement processes associated with a uranium mine siting issue in Canada, the cleanup at Rocky Flats, the operations at La Hague, and the Ethos project — a remediation project in Belarus supported by France. The idea is that the consultants should try to identify procedures which might usefully be followed in other situations.

M. BALONOV (IAEA): How important are environmental radiation protection issues for stakeholders?

A.A. SHPYTH (Canada): In — say — the area of uranium mining and milling, our primary stakeholders are workers living in and representatives of the northern communities where the mining and milling operations are taking place. In my view, they simply assume that we are taking care of the environment, which is not a matter of major concern to them. If I had told them that I was going to Stockholm in order to participate in a conference on environmental radiation protection, they would probably have regarded the conference topic as being somewhat remote.

T. CARLSSON (Sweden): Environmental radiation protection issues are important to the farmers living near the Oskarshamn nuclear facilities.

D.H. OUGHTON (IUR): The students on the environmental science courses which I give would undoubtedly say that environmental radiation protection issues are important.

J. SUTCLIFFE (United Kingdom): Environmental radiation protection issues should be important to stakeholders. During the inquiry following the 1957 fire at Windscale, a participant drew attention to how radionuclides move through the environment and thus through food chains — an issue that many other participants had not thought about before. I should like to see closer communication between, on one hand, people concerned with human health and, on the other, people concerned with environmental health.

A.A. SHPYTH (Canada): In my view, the purpose of this conference is to close a conceptual gap. We are not here because of widespread evidence of environmental harm around nuclear facilities.

P.A. THOMPSON (Canada): At a symposium held in Ottawa in 1999, it was concluded that a stakeholder involvement process was successful if it led to all participants being better informed, so that the decisions taken had a sounder basis. What characteristics must a stakeholder involvement process have in order to be successful in that sense?

D.H. OUGHTON (IUR): The stakeholders must know from the outset what input from them to the decision making process is going to be accepted and how account is going to be taken of that input.

Also, there must be a reasonable balance among the participants — not too many NGO representatives, not too many governmental representatives, not too many industry representatives, not too many regulators, and so on.

J. SUTCLIFFE (United Kingdom): The participants in the stakeholder involvement process must not try to control it. Assistance from a facilitator can be helpful in that connection.

In addition, the participants must expect to feel uncomfortable from time to time, they must respect each other's views and they must be able to deliver on any commitments they enter into.

A.A. SHPYTH (Canada): In order to be successful, the stakeholder involvement process must be meaningful, even if the outcome is unexpected.

To illustrate what I mean by "meaningful", I recall the situation in a community where very many people were opposed to a project proposed by the nuclear industry. On being asked why they were opposed, they said it was because their neighbours were opposed. The source of the opposition was ultimately found to be one man who nobody from the nuclear industry had bothered to talk with. He was then given an opportunity to ask his questions, and he received answers to those questions. That was all he had wanted.

T. CARLSSON (Sweden): Having an opportunity to ask questions is very important. Many stakeholders are satisfied once they have asked their questions even if they do not like the answers.

CASE STUDIES

(Topical Session 2)

Chairperson

L.B. ZONDO
South Africa

ASSESSMENT OF MARINE BIOTA DOSES ARISING FROM RADIOACTIVE DISCHARGES TO THE SEA BY THE COGEMA LA HAGUE FACILITY
A comprehensive case study

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Abstract

The paper presents an assessment of radiation doses to marine biota arising from the radioactive sea discharges (as liquid effluents) of the COGEMA La Hague facility. The primary objective of this study was to select a representative set of marine biota for the study area (i.e. the Nord-Cotentin Peninsula coast) and to assess the potential radiological impacts, in terms of biota dose rates and their related potential health effects on marine biota, arising from the radioactive sea discharges of the COGEMA La Hague facility. For assessing potential effects to biota, the predicted biota dose rates were compared to the available guidance for the protection of populations of non-human biota. The guidance values are based on published data by international organizations (e.g. UNSCEAR and IAEA) and on a screening review of a recent database (by FASSET) on biological effects of ionizing radiation on non-human biota. The major conclusion of the case study was that the predicted dose rates to marine biota attributable to radioactive sea discharges from the La Hague facility are small, and in general, well below comparison guidance levels at which deleterious and observable health effects to populations of marine biota might, according to current knowledge, be

expected. The predicted incremental dose rates arising from the La Hague facility are also, in general, well below those caused by the background radioactivity in the region.

1. PRESENTATION OF THE LA HAGUE CASE STUDY

1.1. Background

In July 2002, SENES Consultants Limited (SENES) was commissioned by COGEMA to conduct an assessment of radiation doses to marine biota arising from the radioactive sea discharges (as liquid effluents) of the COGEMA La Hague facility [1–3]. The La Hague facility is located in the northwest part of France, in the northwest tip of the Nord-Cotentin Peninsula, along the south shore of the English Channel. Figure 1 shows the La Hague facility area within France and its regional and local settings. The assessment focused mainly on the areas along the coast of the Nord-Cotentin Peninsula.

It is emphasized that sea currents in the La Hague area are very strong, among the highest in Europe, especially at the northwest tip of the Nord-Cotentin Peninsula where the off-shore sea discharge pipe outfall of the La Hague facility is located. Within about 500 m from the outfall, the effluents are dispersed by about a factor of 100 000. With the strong sea currents, marine biota tend to concentrate and flourish in rocky areas along the Peninsula coast which offer protection. Away from the coast, this protection is reduced especially in sandy and muddy areas where it can be more difficult for biota to stay and survive. Sessile algae are particularly important along the coast and are a key part of the habitat structure for many organisms. A number of important food species such as lobsters, crabs, whelks, scallops, squid, and fish species are also present along the coast.

1.2. The objectives of this study

The first objective of this study is to select a representative set of marine biota for the study area (i.e. the Nord-Cotentin Peninsula coastal area) and to assess the potential impacts on the marine biota arising from the radioactive sea discharges of the La Hague facility. The impacts on the marine biota are estimated in terms of potential radiation dose rates and their associated potential health effects.

Radiation dose rates in the study area are modelled. For assessing the potential effects to the biota, predicted biota dose rates are compared to guidance values for the protection of populations of marine biota. The

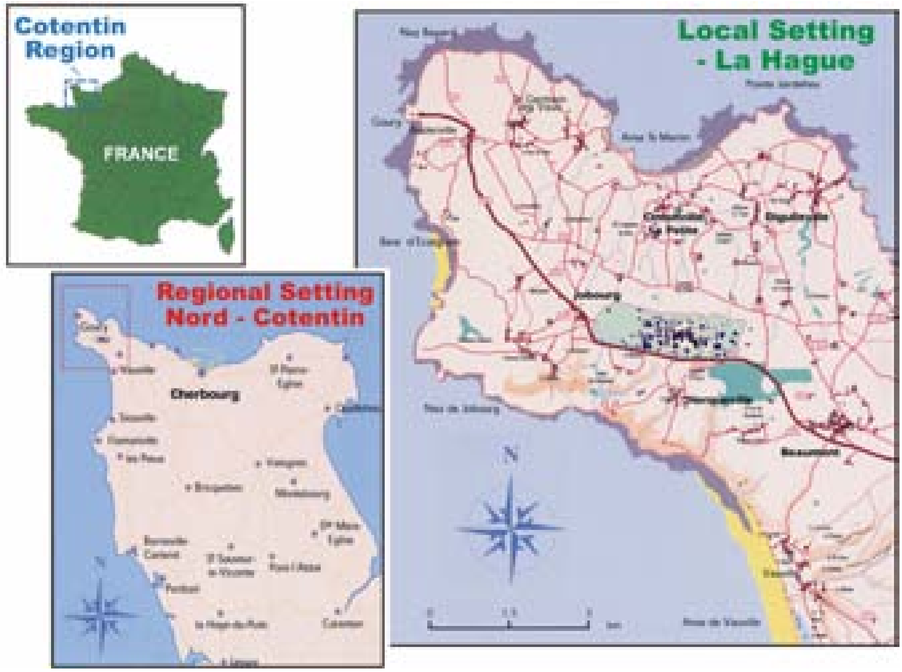

FIG. 1. The La Hague facility and its local and regional settings in Nord-Cotentin.

guidance values are based on published data by international organizations [4, 5] and on a screening review by SENES of a recent database (by FASSET[1]) on biological effects of ionizing radiation on non-human biota [6]. The generic guidance values derived by SENES are similar to those published in MARINA II[2] [7]. References [6–8] are two recent key European studies of particular relevance for this case study of the La Hague facility.

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[1] Framework for ASSessment of Environmental impacT (FASSET) is a major European research project, funded by the European Commission, which has carried out, a set of specific studies on the assessment fundamentals for marine biota exposed to radiation; including the identification of candidate representative (called “reference”) biota for European marine ecosystems and an extensive database on doses and effects.

[2] MARINA II is a set of studies undertaken for the European Commission to provide the Oslo Paris Convention with information on radioactive discharges, concentrations and an assessment of their impact. It gives dose rate results for a number of marine biota categories of the COGEMA La Hague facility and of the BNFL Sellafield facility coastal areas. MARINA II also includes generic guidance values for the protection of marine biota.

Beyond the comparison to the guidance values, a second objective is to compare the results of this assessment to the related FASSET guidance [8]; to the marine biota dose rate results in Ref. [7]; and to identify considerations for potential study follow-up.

1.3. Method of assessment

The assessment carried out by SENES was largely based on the results of environmental studies conducted by the Nord-Cotentin Radioecology Group (GRNC[3] according to its acronym in French) which provides the most comprehensive knowledge base on environmental measurements (sea water, sediment, marine biota) and environmental transfer models of radionuclides for the La Hague coastal area [9, 10]. It also accounts for the most recent (1996) environmental impact assessment of the La Hague facility [11], which comprises a baseline description of the Nord-Cotentin marine environment.

1.3.1. Base case (Goury)

In this study, the dose rate to marine biota attributed to La Hague sea discharges is the key parameter for assessing the potential health effects of ionizing radiation on the populations of marine biota. The most recent full review by the GRNC of all available data has addressed historical data up to the year 1996 which is taken as the reference year. Goury was chosen as the reference location for estimating doses to marine biota because this coastal region was reported to have, in general, the highest coastal radionuclide concentrations in environmental media as a result of the radioactive sea discharges of the La Hague facility. The dose rate assessment results for each location along the coast are simply proportional to the ratio of the dispersion factors relative to Goury.

The base case dose rate calculations were made in units of absorbed dose and do not account for the differences in the relative biological effectiveness (RBE) of alpha, beta and gamma radiation. The base case dose rates do not

[3] In 1997, the GRNC was set following a French government initiative. It includes experts from various stakeholders: governmental agencies, operators, NGO laboratories and foreign organizations. Its main mandate was to conduct: an in depth review and analysis (data validation included) of the historical radioecological data (both routine emissions and accidental releases) obtained from various organizations; and a retrospective dose assessment (model development and validation included) of the Nord-Cotentin.

account for background (man-made or natural) radioactivity as this was addressed separately in this study. In order to assess dose rates to marine biota in the coastal area of La Hague, SENES carried out the following activities:

(a) Developed a Conceptual Representation of the Marine Coastal Environment:

- Reviewed the most recent environmental impact assessment of the La Hague facility [11] and the GRNC studies [9, 10];
- Considered several coastal locations including Goury (the base case);
- Identified biota categories and selected representative biota species (reference biota) for each biota category: crustaceans, filtrating molluscs, non-filtrating molluscs, round fish, flat fish and algae. These biota categories were selected to represent a good range of ecological and physiological types. The reference biota were compared to the related FASSET guidance [8];
- Adapted for dose assessment, the GRNC radioactive source terms and the related environmental transfer models which cover, based on an extensive analysis, a comprehensive list of over 90 radionuclides [9, 10]. The GRNC environmental transfer models (dispersion factors, sea water-biota and sea water-sediment concentration factors, and the related correction factors) account for an extensive analysis of modelling and field results. Background data for man-made and natural radionuclides in the environment are also provided. The list of radionuclides was compared to the related FASSET [8] guidance.

(b) Assessed Environmental Radioactive Concentrations in Marine Biota:

For the base case (Goury), SENES was able to use the GRNC radioactive source terms and environmental transfer models to accurately reproduce the radioactivity concentrations (in water, sediment and biota) as reported and modelled by the GRNC [10].

(c) Estimated Radiation Dose Rates to Representative Marine Biota (reference biota):

The base case dose rates for marine biota were estimated using a dose assessment model [12] which included geometry factors and occupancy factors to account for body sizes, and habits of the region-specific organisms, respectively. Both the internal dose rates from the radionuclide concentrations in the organisms and the external dose rates from the radionuclide concentrations of the media in which the organism lives (i.e. water and sediments) were estimated. The total dose rate is the sum of the internal and external dose rates. Uniform radionuclide distribution was assumed in the organisms (soft tissue) and in environmental media.

For the habits of crustaceans, filtrating molluscs, and non-filtrating molluscs, biota were assumed to spend all of their time in sediment. This is very conservative since these organisms tend to live at the sediment/water interface with some time away from the sediments. Flat fish were assumed to spend half of their time in the water column and the other half in sediment. Again this is very conservative since flat fish do spend a significant amount of time away from the sediments. Round fish and algae were assumed to spend all their lives in the water column.

1.3.2. Background radioactivity

Doses from background levels of radioactivity (both man-made and natural, but exclusive of the La Hague facility contributions) were also estimated. For man-made background radiation, the contributions (i.e., other than from La Hague: e.g., fallout from past nuclear weapon tests) from: ^{3}H, ^{14}C, ^{60}Co, ^{90}Sr (+Y), ^{106}Ru (+Rh), ^{125}Sb, ^{129}I, ^{131}I, ^{134}Cs, ^{137}Cs (+Ba), ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{241}Am were included in the background dose assessment. For natural radioactivity, ^{3}H, ^{14}C, ^{40}K, ^{210}Po and ^{238}U were included in this study.

1.3.3. Comparison to guidance values

Further to a screening review by SENES of the FASSET dose-effect database [6], SENES has derived a range of generic dose-effect guidance values (from about 0.01 to 10 gray per day; Gy/d) for the protection of populations of marine biota. It is noted that these generic guidance values are similar to those reported in Ref. [7] for different biological end points of concern. However, it is recognized that Ref. [7] also reports lower guidance values down to 0.001 Gy/d (or slightly lower) for “finer” types of effects. These guidance values set the preliminary boundary of the zone of deterministic effects on the health and reproduction of marine organisms. SENES also considered the international generic guidance values of 10 mGy/day (or 0.01 Gy/d) for the protection of biota [4, 5]. Together, these generic guidance values form the basis of the comparison to the dose rates estimated in this study.

1.3.4. Comparison to MARINA II

The MARINA II report [7] addressed the dose rate estimates to biota relating to marine organisms in the OSPAR region, including the Cap de La Hague coastal area in France and the Sellafield coastal area in the U.K. The dose rate results estimated herein are compared to those of Ref. [7].

1.3.5. Sensitivity analysis

A sensitivity analysis was carried out to deal with several factors that might provide more insight to the estimated marine biota dose rates relative to the radioactive sea discharges of the La Hague facility. These considerations include:

— Influence of various key parameters to the predicted biota dose rates for the base case, Goury. The parameters considered include the maximum value of concentration factors and correction factors reported by the GRNC and the RBE values;
— Comparisons between the SENES base case dose rates and dose rates predicted using the UK Environmental Agency (UK EA) biota dose assessment model [13];
— Dose rates to assumed existing marine biota potentially located closer to the discharge point (within about 500 m in radius);
— Dose rates to biota for which site specific data are limited; specifically an attempt was made to use generic factors to determine dose rates to oystercatchers, a wading bird — which is one of the recommended FASSET reference biota categories not covered by the existing site specific data.

1.4. Results of dose assessment

1.4.1. Base case coastal zone – Goury

The marine biota dose rates estimated for selected species in coastal areas are low, at least 2 to 3 orders of magnitude lower than the lowest generic guidance values for the protection of populations of marine biota (Figure 2). Since the radionuclide concentrations in biota, water and sediments from Goury are higher than for other coastal locations, the dose rates to biota in other coastal regions are expected to be lower. The highest dose rate

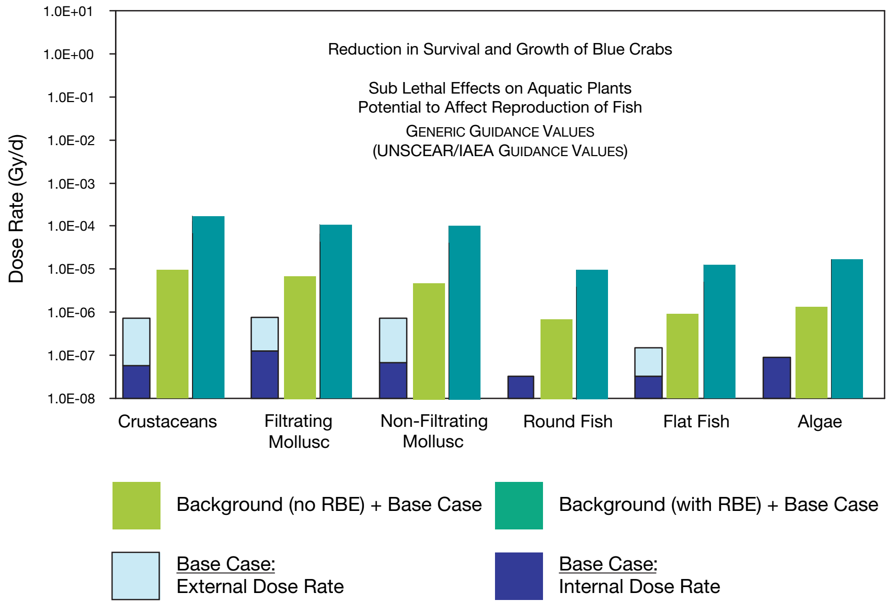

FIG. 2. Base case and background dose rates (internal and external) to reference biota in the Goury coastal area, 1996 data.

determined for the base case was estimated for filtrating molluscs. The major contribution to dose rate is ^{106}Rh (Figure 3)

Molluscs are also the biota category that showed the highest dose rates for Sellafield as reported in MARINA II [7]. In Ref. [7], doses to marine biota at the Cap de la Hague coastal area in France were described to be "*somewhat lower than those at Sellafield coastal area*" throughout the assessment period 1982–1997. It was noted from the MARINA II study that for molluscs, the results for Sellafield are more than 10 times higher than those for the Goury base case. For further comparison, SENES also estimates dose rates for the marine biota of Cap de La Hague (Goury base case) using an RBE value of 20 for alpha emitters as was done in MARINA II. With this assumption, the estimated dose rates for the Goury base case are comparable to — but slightly higher than — the results reported in Ref. [7] (Figure 4).. The change due to the RBE value was very small, thus indicating that the impact from alpha emitters discharged from the La Hague facility is minimal. Since the dose rates for marine biota predicted by MARINA II [7] and SENES are comparable, the conclusions drawn in this report are similar to the main conclusion of Ref. [7]: "*According to the …and the dose assessment for the selected industry-impacted*

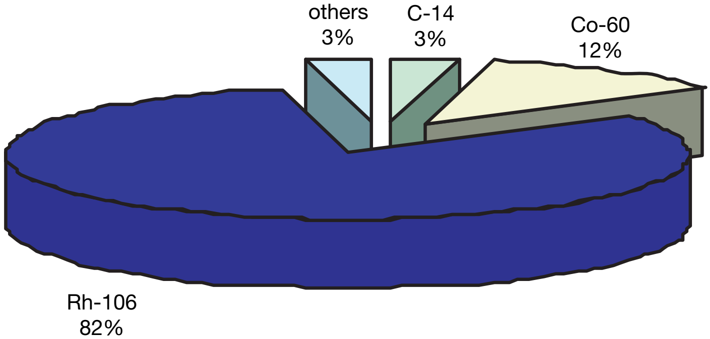

FIG. 3. Radionuclide contributions to the base case reference marine biota (i.e. filtrating mollusc) with the highest dose rate (7.8 × 10^{-7} Gy/d), 1996 data.

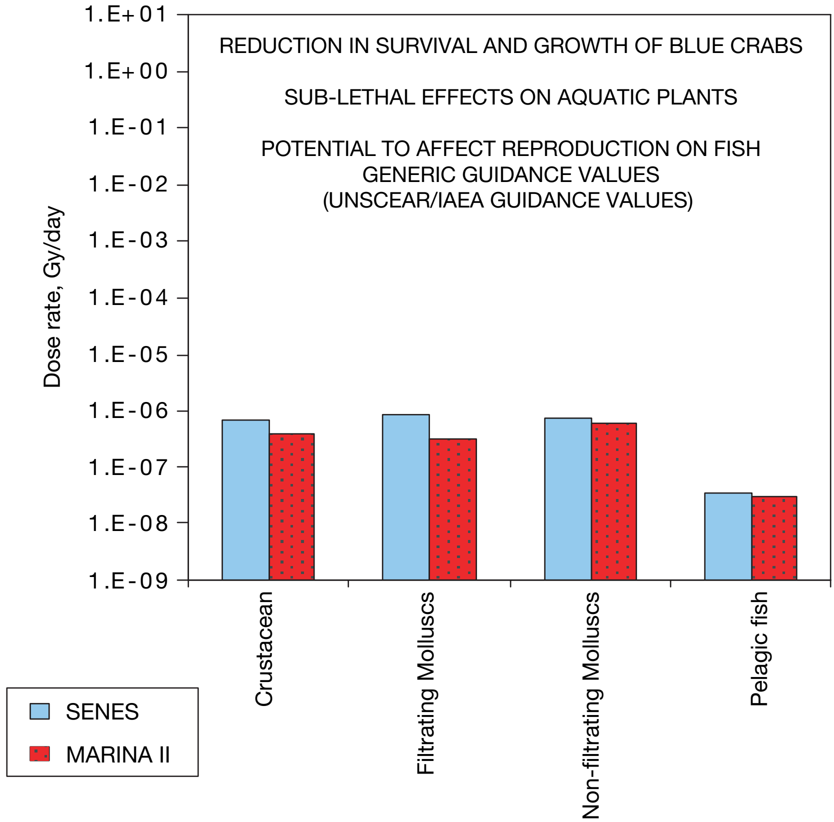

FIG. 4. Comparison of the marine biota dose rate for Goury: SENES (1996 data) to MARINA II estimates. (For comparison purposes, the SENES estimates include an RBE of 20 for alpha-emitters, as was used in MARINA II (2002).)

locations in the OSPAR region, there is no identifiable impact on populations of marine biota from radioactive discharges".

1.4.2. Background radioactivity

The effect of including or not an alpha weighting factor (RBE) can be seen clearly from the background dose rates (Figure 2). In general, the contributions from man-made background radionuclides to the dose rates were very low in comparison to those from the natural radionuclides. Most of the dose is due to the naturally occurring levels of ^{210}Po. The highest radiation dose rate from natural and man-made background was estimated for crustaceans and molluscs, respectively. Dose rates estimated from background levels of radiation (i.e., natural and man-made radionuclides) are higher, by more or less 1 to 2 orders of magnitude, than the base-case dose rates predicted for the radioactive sea discharges of the La Hague facility. Background dose rates are also lower, by at least 1 to 2 orders of magnitude, than the lowest of the generic guidance values viewed earlier.

1.4.3. Sensitivity analysis

The results of the sensitivity analysis showed that the value of the correction factor (CF) has the largest influence on the dose rate (about a factor of 10 higher). However, all dose rates estimated with different parameters, as part of the sensitivity analysis for the Goury base-case, were small compared to the generic guidance values. Similarly, the dose rates estimated closer to the outfall of the La Hague sea discharge pipe (at the average concentration within 500 m radius from the outfall) were also below the generic guidance values. The dose rate estimated for the oystercatcher was also well below the generic guidance values.

1.5. Comparison to FASSET guidance

From a biological perspective, a first level comparison indicates that the reference biota categories in this study are generally consistent with the guidance in Ref. [8]. All of the categories used are ones recommended by FASSET. Not all categories recommended by FASSET were studied, either because they were not applicable or because of the limitations of site specific data. Some follow-up suggestions are included for further studies of some of the FASSET categories using generic data.

From a radiological perspective, a second level comparison to FASSET indicates that the GRNC data provide a very comprehensive dataset for radionuclides. The present study considered over 90 radionuclides reported in the GRNC radioactive source terms and the related environmental transfer models. Of the 37 radionuclides identified by FASSET [8], only ^{89}Sr, ^{210}Pb, ^{227}Th, ^{230}Th, and ^{232}Th are not included. However, for these radionuclides the dose attributable to sea discharges from La Hague is negligible.

From a more global perspective, a third comparison to FASSET indicates that the predicted dose rates to marine biota in the coastal area (Goury base case) potentially attributable to sea discharges from the La Hague facility are expected to be small. Though, in consideration of the first level comparison to FASSET guidance, potential consideration of additional reference biota are suggested in Section 1.6.

1.6. Potential study follow-ups for consideration

The dose rates estimated for biota in coastal areas, either with base case assumptions or in the sensitivity analyses are small. In our opinion, the range of radionuclides reported by the GRNC and assessed in this report is very comprehensive and any addition to the list of radionuclides would be unlikely to have any effect on the conclusions of this study. Since not all of the potential reference organisms in the FASSET guidance were considered, the dose rate to a wading bird, the oystercatcher, was estimated using generic data. It was found that the estimated dose rate for a (generic) oystercatcher was also well below the guidance values. While there is a wide range in the radiosensitivity of biota considered in this study, in our opinion, based on the small dose rates predicted for the six basic biota categories (plus the oystercatcher), consideration of additional biota categories would be unlikely to change the conclusions of this assessment. Nonetheless, there are some areas in which potential study follow-ups might be considered:

(1) General — It is important that COGEMA keeps abreast of potential development in the area of biota dose assessment, including for example: the detailed evaluation of the FASSET database (expected in 2003); ongoing developments in dose assessment methods for biota; and ongoing developments in the definition of potential reference biota, amongst others; and

(2) Additional reference biota — dose rates to marine biota in the La Hague coastal area potentially attributable to sea discharges from the La Hague facility are expected to be small. However, in consideration of the 1st level comparison to FASSET guidance, potential consideration of additional reference biota categories such as worms, fish eating birds (e.g.

cormorants and shags) and marine mammals (e.g. seals and dolphins) is suggested.

1.7. Conclusions

With respect to the study's first objective, based on the available information from the most recent COGEMA La Hague facility environment impact assessment [11] and the GRNC studies [9,10], a representative set of marine biota was selected for the study area (i.e. the Nord-Cotentin Peninsula coast, with a focus on the potentially most impacted location, Goury). Potential impacts on the representative marine biota, arising from the radioactive sea discharges (as liquid effluents) of the La Hague facility, were assessed. These impacts were expressed in terms of biota dose rates and their related potential health effects. The predicted dose rates were compared to generic guidance values for the protection of populations of marine biota that have been either published by international organizations (e.g., UNSCEAR and IAEA) or derived by SENES further to a screening review of a recent database (by FASSET) on biological effects of ionizing radiation on non-human biota [6].

In this study, the marine biota dose rate assessment showed that the predicted dose rates to marine biota attributable to radioactive sea discharges from the La Hague facility are small, and in general, well below comparison guidance levels at which deleterious and observable health effects to populations of marine biota might, according to current knowledge, be expected. The incremental predicted dose rates arising from the La Hague facility are also, in general, well below dose rates from background radioactivity in the region.

With respect to the study's second objective to compare this assessment to the related guidance in FASSET [8] and the related dose rate results in MARINA II [7], and to identify, for consideration, potential study follow-ups, the following points are noted:

(1) The selected biota categories are consistent with the FASSET guidance for European marine ecosystems although not all FASSET biota categories were evaluated (due to the limitations or the non-applicability of site specific data); and
(2) the dose rate results for Goury are generally comparable to those given in Ref. [7] for the Cap La Hague area.

As well, the main conclusion is similar in both studies, namely, no identifiable impact is expected on populations of marine biota from the radioactive discharges. The potential study follow-ups suggested for consideration are:

(1) COGEMA should keep abreast of potential developments in the area of dose assessment to marine biota; and
(2) It should consider augmenting the reference biota categories to include worms, fish eating birds and sea mammals using generic data.

2. CONSENSUS APPRAISAL ON THE LA HAGUE CASE STUDY FROM A GROUP OF INTERNATIONAL EXPERTS

This case study has been presented and discussed at a recent specific workshop of international experts held at La Hague on April 15, 2003. The participants had been previously provided with a copy of the final draft report prepared by SENES. The consensus appraisal [1] is intended to summarize the key observations and agreements arising from the participants' inputs and discussions at the workshop, and from their comments on the draft consensus appraisal text that was distributed on May 5, 2003 for review and comment. The key outcomes of the consensus appraisal, which have been incorporated in the final report of the La Hague case study [1–3], are:

— There was general consensus amongst the participants on the second paragraph of Section 1.7 just viewed. Also, there was a general consensus that:
— This conclusion and the dose rate predictions in this study are in close agreement with those for the marine biota of Cap La Hague reported in MARINA II [7].
— The methods used to assess the dose rates to the marine biota in this study have been available in the open literature for some time and are appropriate and acceptable for the purposes of this case study.
— A set of key observations that relate to: relevance of the study for the assessment of potential impacts to biota populations, reference biota categories, comparison to guidance values for the protection of populations of biota, comparison to background dose rate and its variation, presentation of biota dose rate results, some topics that might be more appropriate for basic research, a perspective on the near-field (closer to the outfall) as part of the sensitivity analysis.

The points highlighted in the consensus appraisal have been incorporated in the study final report [1–3]. The reader is invited to consult the consensus appraisal, contained in the final report, for an independent and transparent opinion on the La Hague case study that was expressed by a group of international experts.

3. AN INDUSTRY PERSPECTIVE ON THE EMERGING TOPIC OF PROTECTION OF NON-HUMAN SPECIES

Over the last few years, the challenge put on the ICRP Publication No. 60 [14] position with respect to the environment (*"The Commission believes that the standard of environmental control to protect man…will ensure that other species are not put at risk"*) has contributed to the emergence of the topic of protection of non-human species in many international forums. With this rich basis of opportunity for information exchange and communication, thinking has gradually evolved from a perception that the current system of radiological protection (ICRP 60) was incomplete for the protection of non-human species, and perhaps not adequate in some specific situations, to the general recognition that the current system has in practice provided an appropriate standard of environmental protection but that it needs to be further developed for completeness. As stated at the outcome of the ICRP/NEA forum in Lanzarote (April 2003), ICRP's recent decision *"to develop a systematic approach to radiological assessment of non-human species, has not been driven by any particular concern over environmental radiation hazards, but to fill a conceptual gap in radiological protection, and to clarify how ICRP can contribute to the attainment of society's goal of environmental protection"*. The gap mostly relates to a finer demonstration of protection of non-human species where human is absent and rather for exceptions: i.e. particular situations for sites with higher potential environmental impacts. The industry highlights the fact that its experience with the current biota dose assessment methodologies (e.g. in this case study and in others such as [7, 15]) indicates that the impacts from nuclear sites are very small even for sites with the most significant historical discharges. On this basis, the industry welcomes the IAEA and ICRP leadership to modestly develop the future system of protection with the aim of filling the said conceptual gap, but it is essential that the system stays simple and of practical use and that it does not impose a disproportionate burden on operators. The industry seeks to continue to work constructively both at the level of international debate and with the scientific community to ensure that its own expertise and data can best contribute to a new system of protection that is practical for end users (industry and others).

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US DEPARTMENT OF ENERGY'S REGULATORY AND EVALUATION FRAMEWORK FOR DEMONSTRATING RADIATION PROTECTION OF THE ENVIRONMENT
Implementation at the Hanford Site

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Abstract

The United States Department of Energy (DOE) currently has in place a radiation dose limit for the protection of aquatic organisms, and has considered dose limits for terrestrial biota. Guidance on suitable approaches to implementation of these and other proposed limits for protection of biota is needed. In response to this need, we have developed methods, models and guidance within a *graded approach* for evaluating radiation doses to biota. DOE's multi-tiered process is described in a technical standard document. The full spectrum of screening and analysis methods are encoded in the computer program RESRAD-BIOTA (developed at Argonne National Laboratory for DOE) to assist the user in progressing through the evaluation process. A key component of the graded approach is a screening methodology that provides limiting concentrations of radionuclides, termed Biota Concentration Guides (BCGs), for use in screening water, sediment, and soil media to determine if dose limits for biota are likely to be exceeded. The graded approach provides flexibility and the ability to iterate through the evaluation process. DOE's graded approach framework provides a practical and effective tool for demonstrating protection of biota relative to Dose Rate

Guidelines, and for conducting ecological screening assessments of radiological impact. The utility of this method is examined through application at a radiologically contaminated site. In 2001, a study was conducted to characterize potential environmental effects from radiological and chemical contaminants on the near-shore environment of the Columbia River at the 300 Area of the DOE's Hanford site. Various environmental components were sampled, including: river water, riverbank spring water, sediment, fish, crustaceans, bivalve molluscs, aquatic insects, riparian vegetation, small mammals, and terrestrial invertebrates for analyses of radiological and chemical constituents. The radiological analysis results for water and sediment were used as initial input into the RESRAD-BIOTA code. The methodology, through implementation of the RESRAD-BIOTA code, showed that maximum radionuclide concentrations measured in water and sediment were lower than the initial screening criteria for concentrations that produce dose rates at existing dose rate guidelines. Radionuclide concentrations measured in biota samples were used to calculate site specific bioaccumulation coefficients (B_{iv}) to test the utility of the method's site specific screening phase. To further evaluate site specific effects, the default Relative Biological Effectiveness value (RBE) for internal alpha particle emissions was reduced by half. The method's "organism wizard" was used to develop customized dose factors for a representative aquatic organism. The subsequent calculations showed the initial results were conservative, which is appropriate for screening purposes.

1. INTRODUCTION AND BACKGROUND ON THE DOE METHODOLOGY

There is growing national and international interest concerning the explicit protection of the environment (biota and ecosystems) from the effects of ionizing radiation. The use of human radiation protection criteria to infer ecological protection from the effects of ionizing radiation is being revisited and scientifically challenged for certain exposure scenarios. Increasing regulator and stakeholder interest in demonstrating protection of biota from the effects of ionizing radiation will likely need to be considered in actions regarding the remediation, decontamination and decommissioning (D&D), and long term maintenance, surveillance, and monitoring of contaminated sites. The United States Department of Energy (DOE) has been active in the area of requirements and guidance for radiological protection of the environment since the late 1980s. DOE currently has in place a dose limit of 10 mGy/d for native aquatic organisms [1], and has proposed dose limits for terrestrial plants (10 mGy/d) and animals (1 mGy/d) [2]. These dose limits represent expected safe levels of exposure, and are consensus No Adverse Effects Levels (NOAELS) for effects on population-relevant attributes (i.e., using rep roduction as the critical end point of concern) in natural populations of biota

[3–5]. Recommendations from the public comment process on DOE's proposed biota dose limits highlighted the need for standardized evaluation approaches for demonstrating compliance, cost effective methods that employ screening concepts, and flexibility to apply site specific information. In the USA and internationally, no standardized methods have been adopted for evaluating radiation doses and demonstrating protection of plants and animals from potential radiation effects. In response to this need, DOE has developed methods, models and guidance within a *graded approach* for evaluating radiation doses to biota. An objective of this initiative was to advance the inclusion of biota dose evaluation as a routine part of site radiological and environmental surveillance programmes, and the inclusion of biota dose evaluation results in site annual environmental reports.

1.1. DOE's graded approach

The graded approach was developed using an interdisciplinary team approach through the DOE Biota Dose Assessment Committee (BDAC). The BDAC, formed in 1998, has broad representation from DOE sites and facilities, national laboratories, universities, and the private sector. A guiding principle for the BDAC was that both model "developers" and "users" be part of the methods development process. DOE's graded approach to biota dose evaluation consists of a three-tiered process which is designed to guide a user from an initial, prudently conservative general screening phase to, if needed, a more rigorous analysis using site- and receptor-specific information. The three-tiered process includes: (1) a data assembly phase in which the evaluation area and its characteristics are defined, and radionuclide concentration data for water, sediment and soil are assembled for subsequent screening; (2) an easy to use general screening methodology that provides limiting radionuclide concentrations (termed Biota Concentration Guides, BCGs) in soil, sediment, and water such that the dose limits for protection of biota are not exceeded; and (3) an analysis phase containing three increasingly more detailed steps comprised of site specific screening, site specific analysis, and site specific biota dose assessment. Any of the three phases of the graded approach may be used at any time, but the general screening tool will usually be the simplest, most cost effective, and least time consuming.

1.2. Derivation of Biota Concentration Guides (BCGs)

The technical basis for the general screening methodology within the graded approach is based on the fact that biota dose is a function of the contaminant concentration in the environment, and is the sum of internal and external contributions of dose to the organism. It is possible, given a unit concentration (i.e., 1 Bq/kg) of a contaminant in a single medium (e.g., soil), to estimate the potential dose rate to an organism from both internal and external exposures. Once the dose rate from this unit concentration of contaminant has been calculated, it can be used to back calculate a concentration of the contaminant that will generate a dose rate at *any* specified limit, such as DOE's existing and proposed biota dose limits. This radionuclide- and media-specific limiting concentration is termed a Biota Concentration Guide (BCG). When multiple radionuclides are present in multiple environmental media, the sum of fractions rule is applied to account for all sources of exposure. The derivation of the BCGs and their default assumptions and parameters is discussed in detail elsewhere [6–9]. Key elements of the technical approach are highlighted below:

— Four reference organism types (aquatic animals, riparian animals, terrestrial plants, terrestrial animals) were selected as the basis for methods development. Internal and external sources of dose are incorporated in the derivation of the graded approach methodology.
— The source medium to which the organisms are continuously exposed is assumed to contain uniform time-invariant concentrations of radionuclides.
— Internal doses were calculated as the product of media concentration, concentration factor(s), and dose conversion factors. Kinetic and allometric techniques were used to fill data gaps in predicting radionuclide concentration factors across a large range of terrestrial and riparian species of animals. Default internal dose factors assumed that all of the decay energy is retained in the tissue of a very large organism (i.e., 100% absorption), and to include progeny of chain-decaying radionuclides. External doses were calculated based on the assumption of immersion of the organism in soil, sediment, or water.
— Estimates of the contribution to dose from external sources of radioactive material were made assuming that all of the ionizing radiation was deposited in the organism (i.e., no pass-through and no self-shielding). This is conservative, and is tantamount to assuming that the radiosensitive tissues of concern (the reproductive tissues) lie on the surface of a very small organism.

1.3. DOE Technical Standard and RESRAD-BIOTA Code

The technical standard document and the RESRAD-BIOTA are discussed below. Both products can be downloaded from the BDAC web site (http://homer.ornl.gov/oepa/public/bdac). The RESRAD-BIOTA code was principally sponsored and developed by DOE, with support from the U.S. Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC). RESRAD-BIOTA is designed to provide a full spectrum of analysis capabilities, from practical conservative screening methods to more realistic organism-specific dose assessments. The RESRAD-BIOTA code has many advanced features such as dose conversion factors for eight ellipsoid organism geometries, sensitivity analysis capability for studying parameter sensitivities, and text and graphic reports for easy interpretation of results. The first publicly accessible version of the code was made available on 30 September 2003. Code development was coordinated through a DOE-lead ECORAD-workgroup partnership among offices of the DOE, EPA, and NRC. The DOE graded approach (originally presented in the RAD-BCG calculator) for evaluating radiation doses to biota [6] was used as the starting foundation for code development. A beta version was released in 2002 for test and evaluation and the RESRAD-BIOTA code was presented in the Third International Symposium on the Protection of Environment from Ionising Radiation (SPEIR 3) held in Darwin, Australia in July 2002 [10]. Many new and advanced features have been added to the code since the SPEIR 3 Symposium. These advanced features and a new, redesigned, user interface are described and implemented in this paper.

1.4. Progress resulting from an initial trial use period

The graded approach was made available to DOE field and programme elements for a trial use period beginning in July 2000 through an interim Technical Standard document. The graded approach methodology also received interest from other national and international organizations during this period. An independent external technical peer review of the methodology and associated guidance contained in the Technical Standard was also performed and several papers on the graded approach were submitted and accepted for publication in peer-reviewed journals [7–9, 11, 12].

Comments and suggestions resulting from this trial use period and the technical peer reviews were used to refine and make improvements to the methods and guidance For example: (1) several radionuclide-specific BCGs were re-evaluated and modified; (2) guidance on the relationship between the graded approach and the ecological risk assessment framework (ERA) typically used for the evaluation of chemical stressors was added, along with guidance on specific technical issues inherent in evaluating radiation that are different from those encountered when evaluating chemical stressors to the environment; and (3) guidance was added regarding how to utilize the graded approach in support of other types of environmental assessments.

There was a noticeable increase (e.g., from 10% in 2000, to 50% in 2002) in the evaluation of doses to biota as reported in site annual environmental reports received by Doe's Office of Environmental Policy and Guidance. This steady increase is attributable to the awareness, availability and use of the graded approach to biota dose evaluation at DOE sites, and the standardized but flexible screening and analysis methods contained within the graded approach framework.

1.5. International coordination

The Department of Energy continues to cooperate in discussions regarding concepts for the development of an international framework for protection of the environment from the effects of ionizing radiation. This has included participation in Specialists' Meetings held in 2001 and 2002 by the International Atomic Energy Agency (IAEA), participation as a corresponding member to the International Commission on Radiological Protection's (ICRP) current "Task Group on Protection of the Environment," and participation in the Nuclear Energy Agency's "Forum on Radiological Protection of the Environment: The Path Forward to a New Policy?" (2002). DOE was also a contributing sponsor of the "Third International Symposium on the Protection of the Environment from Ionizing Radiation" (2002).

The DOE's graded approach methodology has the potential for application within an international framework for radiological protection of the environment, as indicated in the following summary statement included in an IAEA Specialists' Meeting Summary Report [13]: "A variety of models continue to be developed along these lines. The U.S. Department of Energy has developed a generic reference organism screening model (contained in their graded approach methodology) and generic/reference organism models are being developed as part of the FASSET program. It was agreed that these approaches are, more or less, complementary and that they could provide the basis for and agreed methodology within an international framework." DOE will continue to work with international organizations to: (1) harmonize the different biota dose evaluation approaches in use or under development within individual countries and organizations; and (2) foster the inclusion of practical approaches for evaluating doses to biota in concepts for an international protection framework on this topic.

2. HANFORD CASE-STUDY USING RESRAD-BIOTA

The 300 Area of the Hanford Site is located just north of the city of Richland, Washington. This area borders the Columbia River and covers 1.5 km^2. From the 1940s, most of the research and development for the U.S. Department of Energy's Hanford Site was conducted in the 300 Area. In addition, the 300 Area was used to produce nuclear fuel elements for the Hanford reactors. Metallic uranium was extruded into pipe-like cylinders and encapsulated with aluminium or zirconium cladding to produce nuclear fuel rods. This process resulted in substantial amounts of uranium and heavy metals, such as copper, in the 300 Area liquid waste streams. Initially, liquid waste from the research facility and fuel production was routed to waste ponds in the northern part of the 300 Area that were located near the Columbia River shoreline. Later in the fuel production period, the liquid waste was sent to process trenches in the northern part of the 300 Area. At the present time, all liquid waste from the 300 Area is treated at the 300 Area Treated Effluent Disposal Facility and released to the Columbia River under the requirements of a National Pollutant Discharge Elimination System permit.

The study was conducted in late August to October 2001 to coincide with expected low river stage. Low river stage facilitates locating riverbank springs and collecting riverbank spring water samples along the Columbia River shoreline. A number of contaminants are present in groundwater at the 300 Area [14] and the near-shore environment can be exposed through riverbank springs and groundwater upwelling. Therefore, the sampling locations selected for this study were centered near historic riverbank spring discharges and the contaminants of concern were primarily known groundwater contaminants (i.e. radionuclides).

2.1. Methods

This section describes methods used to sample water, sediment, and various biotic components of the ecosystem. It also briefly describes the screening and radiological dose calculations performed.

2.1.1. Water and sediment sampling

Near-shore river water samples were collected from near the river bottom by using a peristaltic pump and Tygon® tubing with the sample inlet positioned less than 6 cm above the river bottom. The samples were collected at the major riverbank spring locations. At each location, four unfiltered river water samples were collected with samples taken at the immediate shoreline (0.25 m depth), and offshore where the river depth was 0.5 m, 1 m, and 1.5 m.

Riverbank spring water samples were collected using either a hand pump or a peristaltic pump. All samples were unfiltered water, except for samples for metals analysis where both unfiltered and filtered samples were collected (0.45 μm Geotech high volume filter).

Sediment samples at the riverbank spring locations and at the background site were collected at each of the major riverbank spring locations and the background site using nylon ladles.

2.1.2. Biota samples

Riparian vegetation samples (new growth only) of the perennial plant white sweet clover (*Melalotus alba*) and leaves and stems from mulberry trees (*Morus alba*) were cut with stainless steel scissors; samples were placed in glass jars for metals analyses or plastic bags for radiological analyses.

Prickly sculpin (*Cottis asper*) and crayfish (*Pacifasticus leniusculus*) were collected along the near-shore (less than 0.5 m deep) and within 10 m of the spring sites. Sculpin were collected with the use of a Smith-Root Type IV backpack electrofisher and crayfish were netted by hand. Samples were placed in cleaned glass containers, labelled, and stored in ice-filled coolers until the samples were processed. The hepatopancreas was removed from each crayfish, weighed, and split for individual analyses of metals. The metals analysis included uranium.

Asiatic clams (*Corbicula* sp.) were collected concurrently with water samples at all four spring sites, at two down-river locations, and at the reference site above Vernita, (0.25, 0.5, 1.0, 1.5 m water depths at each site).

Macrophytic vegetation (submerged aquatic vegetation) samples were collected by hand and generally consisted of milfoil (*Myriophyllum spicatum*). Samples obtained for radiological analyses required large (>600 g) quantities of the media and may have included elodea (*Elodea* sp.) and potomogeton (*Potomogeton* sp.).

Adult mayflies (*Ephemeroptera*) and darkling beetles (*Eleoides* sp.) samples were hand picked at each location within 50 m of each spring site. Adult mayfly samples were rinsed in de-ionized water because they were obtained along the water's edge and were covered in dirt particles. All samples were placed directly into the individual sample containers and labelled and stored for shipment to the analytical labs.

House mice (*Mus musculus*) were chosen to represent the small mammal species because they are highly dependent on the riparian habitat for open water and succulent foods. Animals were collected with the use of pre-cleaned

Sherman live traps baited with peanut butter. Whole body weight, length, sex, age, reproductive status, and target organ weights of each individual specimen were measured and recorded.

2.1.3. Contaminant analysis

When sufficient sample mass was available, radiochemical analyses were performed. For small biota samples, inductively coupled plasma mass spectrometry (ICP Mass Spec.) was used to obtain uranium concentrations.

2.1.4. Evaluation using general screening phase of RESRAD-BIOTA

Maximum radionuclide concentrations reported for river water, riverbank spring water and sediment were used for graded approach general screening phase assessments using RESRAD-BIOTA. The initial screen was based on those samples analysed by radiochemical techniques. If data was not available for sediment, the sediment concentrations were derived with generic distribution coefficients by the code. Likewise, if a radionuclide was not identified in water, but was identified in sediment, generic distribution coefficients were used to generate data. Maximum measured and derived concentrations in water and sediment were compared to biota concentration guides (BCGs) with RESRAD-Biota.

2.1.5. Calculations using site specific screening phase

Site specific screening and assessment calculations were performed to test the utility of the various phases of RESRAD-BIOTA and to compare its results to its predecessor, the RAD-BCG Calculator. The radionuclide/media combination producing the largest contribution to the sum of fractions is identified and available data were used to calculate site specific parameters for use in the program. The ICP Mass Spec. data for uranium in aquatic biota were converted to radioactivity concentrations assuming a natural distribution of uranium isotopes. Site specific bioaccumulation coefficients were calculated which generated site specific BCGs for uranium isotopes.

2.1.6. Evaluation using site specific analyses phase

To test the utility of the site specific assessment phase, the alpha Relative Biological Effectiveness (RBE) factor for aquatic animals was reduced by half. New site specific BCGs for alpha emitting radionuclides were calculated by RESRAD-BIOTA. To further test the model, a site specific organism was configured. RESRAD-BIOTA allows site specific organisms to be created whereby the code generates size and geometry specific dose conversion factors. Other parameters can be modified as needed, using the DOE primary reference organisms as a starting point, including ingestion rate, B_{iV}s, exposure profile, and organism residence times.

2.2. Results and discussion

Case Study Results show that biota doses were below applicable dose rate guidelines. The DOE Graded Approach and RESRAD-BIOTA provide practical, cost effective means for demonstrating protection. General screening is an effective compliance tool. *Detailed dose estimates on specific receptors can be done but are not always necessary — illustrated by the design of the Graded Approach.*

2.3. Water and sediments

The screening assessment was based on maximum radionuclide concentrations measured in either water or sediment (Table 1).

Although measured concentrations of strontium-90 in sediments were below detection limits, the errors associated with those measurements were less than the reported value. So, for completeness, they are included in the analyses.

TABLE 1. MAXIMUM RADIONUCLIDE CONCENTRATIONS MEASURED IN WATER AND SEDIMENT[a]

Radionuclide	Water minimum detection limit	Water (Bq m^{-3})	Sediment minimum detection limit	Sediment (Bq kg^{-1})
Sr-90	22.2	7.5	1.9	9.6×10^{-1}
Cs-137	370	—	1.1	8.5
U-234	2.22	2.0×10^{3}	0.75	1.0×10^{2}
U-235	2.22	8.3×10^{1}	0.75	3.8
U-238	2.22	1.8×10^{3}	0.75	9.1×10^{1}

[a] This list represents a selection of nuclides detected in water and sediment, and is used to illustrate the application of the RESRAD-BIOTA code.

2.4. Biota

Maximum radionuclide concentrations measured in biota samples were used for subsequent site specific screening and site specific analyses (Table 2).

2.5. General screening phase evaluation

The total sum of fractions based on maximum water and sediment concentrations was 0.50 (Table 3). The relative dose contribution from the water pathway was roughly a factor of 200 greater than the sediment pathway.

This total sum of fraction is the result of the RESRAD-BIOTA screening and indicates that regardless of where the water and sediment samples were collected for this study, the maximum measured radionuclide concentrations for this characterization effort were insufficient to exceed the concentrations necessary to produce dose rates exceeding current and recommended dose rate guidelines. Uranium was the major contributor to radiological dose for both water and sediment pathways. The results did not exceed the screening value and the site passed this initial screen.

TABLE 2. MAXIMUM RADIONUCLIDE CONCENTRATIONS MEASURED IN SELECTED BIOTA SAMPLES[a]

Biota Media	Sr-90 Bq kg^{-1}	Cs-137 Bq kg^{-1}	Uranium $\mu g\ g^{-1}$
Detection Limits	1.5	1.5	0.01
Riparian Community			
Sweet Clover	6.7	10.0	0.12
Mulberry Leaves	6.3	1.1	0.12
Small Mammal		1.5	0.02
Aquatic Community			
Milfoil	3.3	4.4	9.29
Clam			6.77
Sculpin	0.7	–0.4	0.06

[a] This list represents a selection of nuclides detected in water and sediment, and is used to illustrate the application of the RESRAD-BIOTA code.

TABLE 3. INITIAL 300 AREA SHORELINE STUDY SCREENING ASSESSMENT BASED ON THE RESRAD-BIOTA SUMMATION OF PARTIAL FRACTIONS[a]

Nuclide	Water limit (Bq m^{-3})	water partial fraction	Sediment limit (Bq kg^{-1})	Sediment partial fraction	Combined sum of fractions
Sr-90	1×10^4	7.3×10^{-4}	2×10^4	4.5×10^{-5}	7.8×10^{-4}
Cs-137 [b]	2×10^3	1.1×10^{-2}	1×10^5	7.4×10^{-5}	1.1×10^{-2}
U-234	7×10^3	2.6×10^{-1}	2×10^5	5.1×10^{-4}	2.7×10^{-1}
U-235	8×10^3	1.0×10^{-2}	1×10^5	2.7×10^{-5}	1.0×10^{-2}
U-238	8×10^3	2.1×10^{-1}	9×10^4	9.9×10^{-4}	2.1×10^{-1}
Total		5.1×10^{-1}		2.8×10^{-3}	5.0×10^{-1}

[a] This list represents a selection of nuclides detected in water and sediment, and is used to illustrate the application of the RESRAD-BIOTA code.

[b] Denotes nuclide only identified in sediment, water value generated by program default distribution coefficient.

2.6. Evaluation results from site specific screen phase

Although the maximum measured water and sediment data collected passed the initial screen, site specific screening and assessment calculations were performed to test the utility of the various phases of the DOE evaluation framework and the RESRAD-BIOTA code. The ICP mass spectral results for uranium in aquatic biota were converted to radioactivity concentrations assuming a natural distribution of uranium isotopes. Site specific bioaccumulation coefficients for uranium isotopes in water were calculated. These coefficients were entered into the code and revised site specific BCGs for uranium isotpes were calculated (Table 4).

The total sum of fractions (0.16) for the site specific screen was 68% lower than the initial screen results indicating a lower dose rate to biota when site specific parameters were employed. The biggest contribution to the total sum of fraction was still uranium isotopes in water, but the limiting organism changed to a riparian animal when site specific bioaccumulation coefficients for aquatic animals were employed. The results of this site specific screen indicate the dose rate to biota were below current or recommended dose rate guidelines.

2.7. Evaluation of results from the site specific analysis phase

To test the utility of the site specific analysis phase, the alpha relative biological effectiveness (RBE) factor for aquatic animals was changed from its default factor of 20. Kocher and Trabalka [12] suggested radiation weighting factors should be substantially less than 20, perhaps in the range of 5 to 10. The upper bound of their suggested range was chosen for this test and entered into the code. New site specific BCGs were calculated by the program (Table 5).

The resultant BCGs, for alpha emitting radionuclides, calculated for this third analysis were higher than those calculated for the site specific screen, in the second analysis, resulting in a lower total sum of fractions. By reducing the RBE by half, reduced the sum of fraction to 55% of the site specific screen value and to approximately 17% of the initial screen sum of fractions value. The limiting organism listed for this site specific analysis was a riparian animal.

2.8. Configuring the site specific "secondary" organism

RESRAD-BIOTA also has the capacity to create new organisms which can take advantage of size-specific radiation dose-factors. For this particular case a "clam" was configured as one of the test organisms. The clam geometry was selected from a drop down list of pre-set default sizes. In this case, default size/geometry number 2 ($2.5 \times 1.2 \times 0.62$ cm) was chosen. This geometry is appropriate for organisms such as fish (young of year), molluscs (the secondary organism to be created in this case), plant seedlings and tadpoles. A mass of 0.001 kg was selected and internal ingestion parameters were set for the generic aquatic animal. Site specific B_{iV}s of U were entered for the clam. Dose calculations were run and the dose results again indicated that the site would pass. Doses were 3.66×10^{-5} Gy/d. The total sum of fractions in the original screening stage showed a sum of fractions at 0.5 which indirectly implies a maximum dose rate of 0.05 Gy/d. This illustrates that the methodology can be used to refine dose estimates for specific organisms, if it is so desired.

The total sum of fractions in the general screening phase of this analysis indicates that radiological doses to biota residing along the 300 Area shoreline were below applicable or proposed regulatory limits. Results of screening calculations of radionuclide concentrations in water and sediment were conservative when compared to subsequent assessment results.

TABLE 4. THE 300 AREA SHORELINE STUDY SITE SPECIFIC SCREENING ASSESSMENT BASED ON THE RESRAD-BIOTA SUMMATION OF PARTIAL FRACTIONS USING SITE SPECIFIC AQUATIC ANIMAL B_{IV}S FOR URANIUM IN WATER[a]

Nuclide	Water limit ($Bq \cdot m^{-3}$)	Water partial fraction	Sediment limit ($Bq \cdot kg^{-1}$)	Sediment partial fraction	Combined sum of fractions
Sr-90	1×10^4	7.3×10^{-4}	2×10^4	4.5×10^{-5}	7.7×10^{-4}
Cs-137[b]	2×10^3	$1. \times 10^{-2}$	1×10^5	7.3×10^{-5}	1.1×10^{-2}
U-234	3×10^4	7.9×10^{-2}	2×10^5	5.1×10^{-4}	2.7×10^{-1}
U-235	3×10^4	3.0×10^{-3}	1×10^5	2.8×10^{-5}	8.0×10^{-2}
U-238	3×10^4	6.4×10^{-2}	9×10^4	9.9×10^{-4}	6.5×10^{-2}
Total		1.6×10^{-1}		2.8×10^{-3}	1.6×10^{-1}

[a] This list represents a selection of nuclides detected in water and sediment, and is used to illustrate the application of the RESRAD-BIOTA code.
[b] Denotes nuclide only identified in sediment, water value generated by program default distribution coefficient.

TABLE 5. THE 300 AREA SHORELINE STUDY SITE SPECIFIC ASSESSMENT BASED ON RESRAD-BIOTA. SUMMATION OF PARTIAL FRACTIONS, WITH RBE SET TO 10

Nuclide	Water limit ($Bq \cdot m^{-3}$)	Water partial fraction	Sediment limit ($Bq \cdot kg^{-1}$)	Sediment partial fraction	Combined sum of fractions
Sr-90	1×10^4	7.3×10^{-4}	2×10^4	4.5×10^{-5}	7.7×10^{-4}
Cs-137[a]	2×10^3	1.1×10^{-2}	1×10^5	7.3×10^{-5}	1.1×10^{-2}
U-234	5×10^4	4.0×10^{-2}	4×10^5	2.6×10^{-4}	4.0×10^{-2}
U-235	5×10^4	1.5×10^{-3}	2×10^5	1.9×10^{-5}	1.6×10^{-3}
U-238	5×10^4	3.3×10^{-2}	1×10^5	7.9×10^{-4}	3.4×10^{-2}
Total		8.6×10^{-2}		1.8×10^{-3}	8.8×10^{-2}

[a] Denotes nuclide only identified in sediment, water value generated by the method's default distribution coefficient.

3. SUMMARY AND RECOMMENDATIONS

RESRAD-BIOTA and the graded approach provide a useful means for determining compliance with current applicable or proposed dose limits. Although the initial screen, using maximum water and sediment data, indicated that no further analyses were necessary, subsequent analyses showed a reduction in the total sum of fraction at each progressive step indicating a reduction in dose rates to organisms being evaluated as more site specific parameters are employed. The analysis showed that detailed dose estimates on specific receptors can be done but are not always necessary, as illustrated by the design of the DOE graded approach and RESRAD-BIOTA code. The RESRAD-BIOTA code was easy to install and was user-friendly. The code, like the graded approach, already implements the concepts of primary and secondary reference organisms being considered by the ICRP, which should enhance the methodology's attractiveness nationally and internationally.

The Department of Energy's development and implementation of the graded approach framework and our participation in international discussions regarding the need for a radiological protection framework for the environment has resulted in the following lessons learned and recommendations:

— The availability of the graded approach to biota dose evaluation is effecting change within DOE. Sites are increasingly assessing potential radiological impacts to biota as a result of the availability of the graded approach methodology. This is in large part because of the design of the graded approach framework. The framework provides users with "a place to start" and "an analysis path forward" where needed. The BCGs are not stand-alone. Exceedance of the BCGs leads the user to the more detailed tiers of analysis as needed in a stepwise manner. These linkages are an integral part of the graded approach framework and are "built-in" to the RESRAD-BIOTA code.
— DOE's existing and recommended biota dose limits are not intended to be a "bright line" that, if exceeded, would trigger a mandatory regulatory or remedial action. Rather, they are applied by DOE more as "Dose Rate Guidelines" that provide an indication that populations of plants and animals could be impacted from ionizing radiation and that further investigation and action is likely necessary. We recommend that the term "Dose Rate Guidelines" be carried forward when establishing national or international dose rates corresponding to effects end points.
— Screening is vital as a compliance tool, and as a first step in ecological risk assessments of radiological impact. Screening uses conservative, simple

models. It provides a practical approach that is usually cost and time effective. As such, it should be part of a multi-tiered process for evaluating the impacts of radiation within any proposed international framework.

- "Standardized" approaches have benefits, but users must have the ability to select alternative approaches. One method or model may not fit all users and application scenarios.
- There are numerous ancillary issues that need to be considered and for which guidance needs to be provided. Topics for additional guidance would include: (1) space and time averaging of contaminant concentrations and dose rates; (2) dealing with high levels of natural background; (3) addressing data gaps in environmental transfer factor parameters necessary for calculation of realistic doses to biota; and (4) how to proceed if biota dose limits or effects levels are exceeded. DOE's technical standard document provides guidance on many of these implementation issues.
- Future international efforts should first concentrate on high-level "umbrella" policy and guidance that: (1) clarifies and re-affirms as appropriate the current ICRP assumptions concerning those exposure scenarios where "if man is protected, then biota is also sufficiently protected"; (2) provides additional policy if there are exposure scenarios where explicit evaluations to demonstrate that biota are protected may be warranted; and (3) provides recommendations on acceptable effects and assessment end points for protection of biota.
- Further consideration should be given to the need for a flexible and performance-based evaluation framework that would allow users to work with existing evaluation methods and models, and dose effects data matched to the purpose and data quality objectives of their assessment. There are many biota dose evaluation methods and models that already exist or are under development in the U.S. and internationally that could be directly applied in such a performance-based framework.
- The ecological risk assessment framework typically applied in the evaluation of chemical stressors is general in nature and could serve as a performance-based framework (i.e., allowing for the use of different dose evaluation methods) for evaluating radiation as a stressor to the environment. The DOE graded approach is consistent with the ecological risk assessment framework, but with a particular emphasis on ionizing radiation.
- New international guidelines and approaches must offer practical means of implementation if they are to be widely adopted within the regulatory community.

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PROTECTION OF THE ENVIRONMENT FROM THE EFFECTS OF IONIZING RADIATION ASSOCIATED WITH URANIUM MINING

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Abstract

The general principles that apply to environmental regulatory regimes in Australia are reviewed and used as a basis for developing a framework for a possible regulatory regime for the protection of the environment from the effects of ionizing radiation. It is concluded that the principal issues that need to be addressed are: (i) review of the range of end points to be used in determining acceptable dose rates for non-human biota, and (ii) determining and implementing an appropriate programme to obtain no-observed-effect dose rate data for a range of biota from a number of taxonomic groups. For the specific case study considered in this paper, the discharge of waters from an uranium mine, it was found that the limiting factor in ensuring protection of people and ecosystems is the chemical toxicity of uranium to aquatic animals. Restricting consideration to the effects of ionizing radiation, it has been found that, in this case study, the limiting factor is protection of aquatic animals rather than people. While there are ancillary reasons for this result (for example, the use of a concentration factor approach in the assessment) the principal factor leading to the conclusion is that the exposure pathway for aquatic animals is quite different from that for people. This may well be the case in other radiation exposure scenarios. It is concluded that it is highly unlikely that operation of the Ranger uranium mine in Australia's Northern Territory over the past 22 years has resulted in harm to aquatic biota as a result of exposure to ionizing radiation.

1. INTRODUCTION

The regulatory regime for the discharge of waters from uranium mines in Australia has, in common with regimes elsewhere in the world, focused on the protection of ecosystems from the toxic effects of chemicals and the protection of people from the effects of exposure to ionizing radiation. In May 2000, the International Commission on Radiological Protection established a Task Group on the Protection of the Environment from the effects of ionizing radiation. Following the adoption of the report of the Task Group by the Main Commission in January 2003, Australian authorities have begun to consider the type of regulatory regime that could be applied to the protection of non-human biota from the effects of ionizing radiation.

In this paper, we consider the general principles that apply to environmental regulatory regimes in Australia and discuss the application of these principles to the protection of the environment from the effects of ionizing radiation. The mining of uranium at the Ranger mine in Australia's Northern Territory is considered as a case study.

2. GENERAL PRINCIPLES FOR ENVIRONMENTAL REGULATION REGIMES

There are three principal components in any regulatory system for the protection of the environment from industrial activity. These are the determination of environmental protection objectives, the implementation of control measures that are designed to ensure that these objectives are met, and the implementation of an environmental monitoring programme that is designed to determine whether or not the environmental protection objectives are met in practice.

In Australia, the environmental protection objectives are determined within the context of the National Strategy for Ecologically Sustainable Development (NSESD) which was developed over the years 1989 to 1992 in response to the 1987 report of the World Commission on Environment and Development, Our Common Future [1] (the Bruntland report). In parallel with the development of NSESD in Australia, the United Nations developed its global action plan for sustainable development. This plan, Agenda 21 [2], was adopted at a Heads of Government Conference — The United Nations Conference on Environment and Development — in Rio De Janeiro in June 1992. The two plans are entirely compatible and complementary. Key principles of ESD that are relevant to the setting of objectives are the conservation of biodiversity, the protection of rare and endangered species and the use of the precautionary principle.

In the case of discharges of water from an industrial site, the control regime usually consists of the setting of discharge limits that specify either (i) the maximum concentration of constituents and the maximum discharge rate, or (ii) a minimum dilution for effluent waters in receiving waters. In the case of (ii), the value of dilution specified is determined on the basis of whole effluent toxicity testing. These values (concentrations and dilutions) are set to ensure that constituent concentrations in the receiving waters do not exceed values at which the environmental protection objectives would be breached.

Specification of a suitable monitoring programme requires the choice of a range of indicators of ecosystem health and a proposed indicator measurement programme that can be used to determine whether or not the environmental protection objectives have been met. The indicators may be physico-chemical or biological measurements that assess responses and/or the health of animals and plants. It needs to be recognized that no monitoring programme can measure every facet of ecosystems. The scope of the programme needs to be developed in cooperation with stakeholders to ensure that, when implemented, it can provide the level of assurance required.

3. APPLICATION OF THE GENERAL PRINCIPLES — CHEMICAL CONSTITUENTS

The mining of uranium at the Ranger site in the Alligator Rivers Region (ARR) of Northern Australia is presented as a test case in this paper. Before considering a possible regulatory regime for ionizing radiation at this mine site, it is appropriate to describe how the general principles outlined above have been applied when considering chemical constituents in waters discharged from the mine site.

The revised Australian and New Zealand Guidelines for Fresh and Marine Water Quality [3], based on the philosophy of the Australian National Strategy for Ecologically Sustainable Development [4], recognize three ecosystem conditions — highly disturbed, slightly to moderately disturbed, and high conservation value ecosystems — warranting progressively higher standards of environmental protection. The ecosystems downstream of the Ranger mine form part of Kakadu National Park, a World Heritage Property, and are clearly recognized as being in the high conservation category. The environmental protection objectives adopted in this case are based upon key ESD principles and aim at providing assurance that:

(1) There is no important change to key indicators of biological diversity;
(2) Rare or endangered species are not harmed; and
(3) A precautionary approach is adopted in environmental management programmes.

The aquatic ecosystems downstream of the Ranger mine are young in geological terms [5] and highly seasonal in nature. As a result, while the species found there are diverse, they are highly vagile and generally cosmopolitan. For this reason it has not been necessary to address the second of the above objectives specifically in the control measures adopted or the monitoring programme.

The control measures for discharges of waters from the mine site consist of the setting of discharge limits on the following basis:

- Where high quality chronic toxicology data are available on local native species, the concentrations of constituents in receiving waters will not exceed the value at which 99% of species will be protected (conservation of biological diversity), or
- Where such data are not available, concentrations of constituents are retained within their natural range (a precautionary approach).

As an alternative or in addition to the above, the toxicity of important effluents may be determined for a suite of test species to determine a minimum dilution that must be achieved in the receiving waters.

The data presented in Figure 1 illustrate this approach. The figure shows the toxicity data used in Australia and New Zealand [3] to derive a safe concentration for zinc in freshwater ecosystems. The toxicity of zinc has been reported

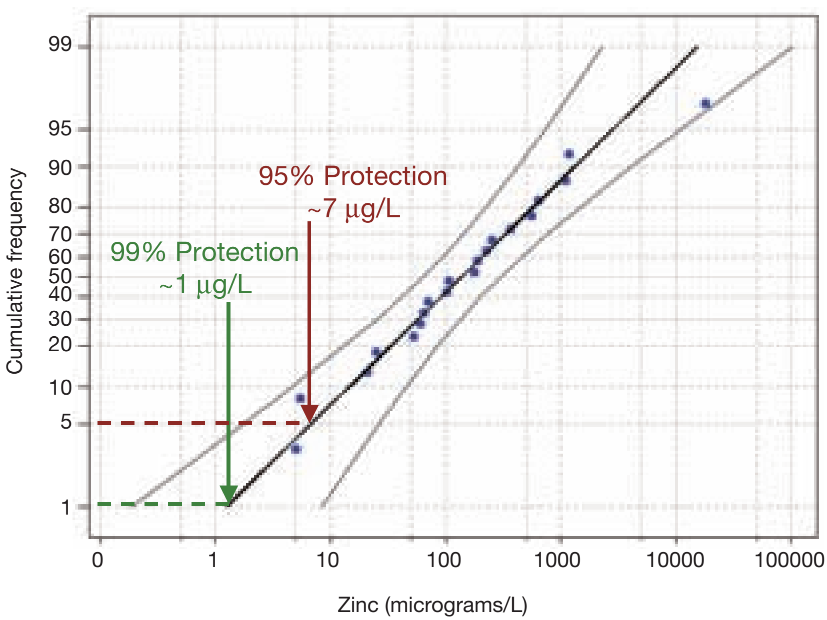

FIG. 1. Cumulative frequency distribution of NOEC concentrations for zinc in toxicological measurements using a range of aquatic biota.

extensively in the literature. Each point in the figure represents the concentration at which no adverse chronic effect has been observed in an aquatic animal or plant species (NOEC). To constitute an acceptable data set, the species for which chronic toxicity data are available must come from at least four different taxonomic groups. The data are presented in the form of cumulative frequency versus concentration of zinc and the line through the data is the best fit using an appropriate distribution, in this case the log-logistic distribution. The maximum concentrations allowable for a target of protection of 95% and 99% of aquatic species are shown in the figure.

A less extensive data set has been used to determine acceptable concentrations for uranium in the ARR [6, 7]. Although the data set is much smaller, and consequently the "safe" concentrations which have been derived are less robust, the results used were all for species which are local native species in the waters of Kakadu National Park.

The monitoring programme associated with water discharges consists of the following:

— Chemical monitoring to ensure that the receiving water standards have been met,
— A primary biological monitoring programme in which any changes in the community structure of key representatives of the ecological system (fish and macroinvertebrates) can be detected — this addresses the conservation of biological diversity, and
— A secondary biological monitoring programme in which both bioaccumulation of chemical constituents in selected biota as well as possible toxicological effects are measured in the field — this provides early warning of adverse effects and addresses the need for a precautionary approach.

4. APPLICATION OF THE GENERAL PRINCIPLES — RADIOACTIVE CONSTITUENTS

Clearly it would be desirable that any regulatory regime for radioactive constituents in mine waters is consistent with the regime adopted for non-radioactive constituents. Thus, the objectives for any regulatory regime for the discharge of radionuclides in mine waters as well as the principles underlying the control measures and the monitoring programme (e.g., protection of 99% of species) would be the same as those listed in the previous section.

Considering control measures first, it will be necessary to determine appropriate discharge limits. The derivation of discharge limits requires (a) an estimate of dose rate that is considered "safe" for aquatic animals and (b) estimates of the dose rates in a range of aquatic animals in the region resulting from the discharge of waters from the site.

Various recommendations on dose limits to biota are discussed and summarized by Copplestone et al. [8]. For freshwater organisms, a dose rate limit of 400 μGy/h is generally considered by the NCRP, the IAEA and the US Department of Energy as being a dose rate below which significant effects are considered to be unlikely [8].

For this reason, a dose rate limit of 400 μGy/h will be adopted in this paper. However, it should be noted that it is questionable whether or not its use would provide protection for 99% of species in the ecosystems of Kakadu National Park. It is desirable that a systematic assessment of all available data is carried out to determine a "safe" dose rate using the method adopted in Australia and New Zealand [3] for chemical constituents or a similar method.

Such an assessment and subsequent modelling (of the type shown in Figure 1), is reported by Twining et al. in a paper presented at this conference [9]. This paper is, in our view, a major advance in developing an appropriate regulatory regime and it raises a number of important issues including:

(i) *End points*: many of the end points in the available data set are biochemical (including genetic). These end points are considered of doubtful ecological relevance by the OECD [10] and are excluded from the derivation of primary water quality guidelines for other chemicals in countries such as Australia and New Zealand [3] and Canada [11]. There is a need to agree on the range of end points to be used.

(ii) *Acute vs. chronic*: a significant proportion of the available data relate to acute exposure. For chemical constituents, chronic data are preferred in the derivation of guideline values [3].

(iii) *Species balance*: the available data are heavily biased in favour of fish species. To estimate a "safe" concentration (or dose rate) at the ecosystem level, it is recommended that data from at least four different taxonomic groups be included in the modelling [3]. There is a need to reduce the influence of fish data on the outcome by obtaining data for a diverse range of biota.

In considering the design of a monitoring programme for the possible effects of ionizing radiation on biota, we note that the principal effects being assessed are deterministic rather than stochastic. Thus, an approach similar to that outlined above for chemical constituents would be appropriate; that is, water quality (physico-chemical) monitoring, community structure monitoring and early warning monitoring. A specific monitoring programme will be considered below for the case of the Ranger mine.

5. CASE STUDY: DISCHARGE OF WATERS FROM THE RANGER URANIUM MINE

To illustrate a possible practical regulatory regime, we consider the discharge of waters from Retention Pond No. 2 (RP2) at the Ranger mine. These waters have been in contact with uranium ore but do not contain process water from the mill circuit. Although more benign waters are regularly discharged from the mine site, water from RP2 has never been directly discharged into the external surface water system, but discharge might be necessary in exceptional climatic conditions.

Since the Ranger mine is located in the tropics with a characteristic wet/dry seasonal cycle, discharges of water from the site only occur over a short period in the wet season. In this example, we consider the discharge of water uniformly over one month of the wet season to the Magela Creek which flows past the Ranger mine and enters Kakadu National Park about 5 km downstream from the mine. We assume that the regulatory regime requires a minimum creek flow rate of 20 m^3/s throughout this period. Typically, this would give rise to an average flow rate in the creek of about 50 m^3/s during the release period.

5.1. Protection of biota from radiological effects

The steps required to specify a maximum discharge rate of water from the site include:

— Modelling to derive the approximate concentrations of radionuclides in the aquatic ecosystem (water and sediment) downstream of the discharge point,
— Determining the change in concentrations of each nuclide in a range of aquatic animals and plants as a result of uptake from the water and sediment,
— Determining the dose rate to which each animal is exposed as a result of both natural background radiation and the discharge of waters from the mine site, and
— Determining the rate of discharge that gives rise to the limit on dose rate that is considered acceptable in the most exposed aquatic animal or plant, namely 400 μGy/h.

Studies of natural radionuclides and trace metals in the Magela Creek system have shown that there is likely to be negligible deposition of any released activity on the sandy creek bed between Ranger and the upper regions of the creek's floodplain, a distance of about 12 km. However, all of the particulate activity and most or all of the dissolved and colloidal activity can be expected to be deposited on the upper floodplain [12–14].

Consequently, two assessments have been carried out; one for organisms located in the creek itself just downstream of the zone of mixing of release water with creek water, and the other for organisms in the upper floodplain region (constituting ~10% of the total floodplain area of approximately 220 km2). In the former case, the expected radionuclide concentrations in the water column during the period of release were calculated, while sediment concentrations were assumed to be the same as for the undisturbed creek. In the case of the upper floodplain, the increase in annual average concentrations of radionuclides in water and sediment were estimated [15–17].

Bioaccumulation was modelled by use of concentration factors previously determined in the region [18–20] for the following biota: freshwater mussels, a water lily, two species of fish (bony bream and forktailed catfish), crocodile, filesnake, freshwater shrimp and magpie goose. For bacteria and phytoplankton, default concentration factors supplied with the spreadsheet program described below were used [21].

Dose rates to the organisms were calculated using a version of the spreadsheet program described by Copplestone et al. [8] which has been modified [21] to include the uranium series radionuclides listed in Table 1. This table provides the water concentration data used in the assessment.

The predicted contributions to the weighted absorbed dose for organisms in Magela Creek downstream from the mine are shown in Figure 2. To obtain these data, the discharge rate of RP2 water was adjusted until the maximum dose rate for any organism became 400 Gy/h. The resulting limiting discharge rate was 2 m^3/s, limited by the dose to freshwater mussels and primarily as a

TABLE 1. RADIONUCLIDE CONCENTRATION DATA (FOR RP2 WATER AND NATURAL MAGELA CREEK WATER) USED IN THE ASSESSMENT

	^{238}U (Bq/L)	^{230}Th (Bq/L)	^{226}Ra (Bq/L)	^{210}Po (Bq/L)
RP2 a	36	0.02	1.4	0.02
Magela Creek b	0.002	0.003	0.003	0.005

a RP2 data from the past five years of wet season monitoring data, and (for Th-230 and Po-210) data from reference [22].

b Data are for Mudginberri billabong, from Martin et al. [14].

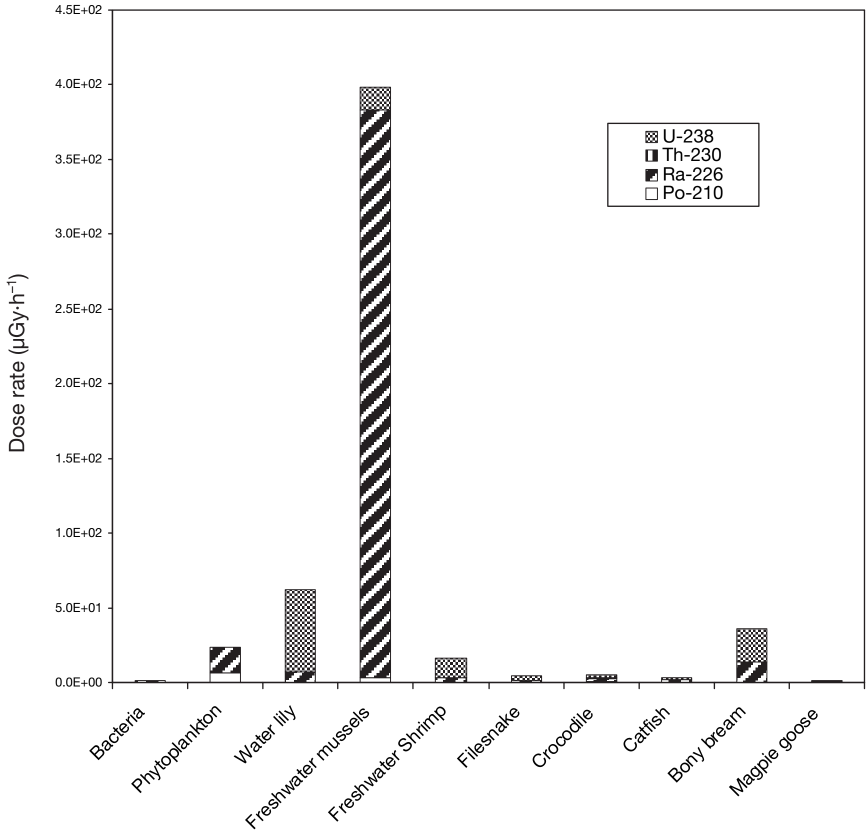

FIG. 2. Predicted contributions to the weighted absorbed dose for organisms in the creek with an RP2 discharge rate of 2 m^3/s.

result of uptake of ^{226}Ra. For the upper floodplain zone, a much higher discharge rate limit of 160 mm^3/s was obtained, limited by the dose to bacteria in the sediment.

For the purposes of this paper, we will use the results presented in Figure 2. However, the limitations of the concentration factor approach need to be recognized. For example, a detailed investigation of the uptake of radionuclides in the freshwater mussel *Velesunio angasi* [23] has shown that the biological half-life of radium in mussel flesh is about 9 years. Hence, the uptake of radium will be much lower than derived using the concentration factor method and the dose rate derived above for radium in mussels will be significantly overestimated. This effect would need to be taken into account in a practical regulatory regime.

5.2. Monitoring

For water-borne contaminants other than radionuclides, a variety of biological indicators has been assessed for their monitoring potential. For the majority of contaminants, including metals, gill-breathing, aquatic organisms are at most risk from exposure due to toxicity across the permeable, respiratory membranes. The exceptions are certain organic forms of metals such as methyl mercury; these substances, as well as certain other non-metallic organic compounds (e.g. some pesticides), can biomagnify through food chains to levels of high toxicity.

Based upon an analysis of such issues, macroinvertebrate and fish communities, or species within these assemblages, have been selected as indicators of potential harm arising from mine waste water releases in the ARR. Humphrey and Dostine [24] have summarized the traditional and inherent virtues of these groups for monitoring.

For radionuclides, higher vertebrates with their greater organizational (including genetic) complexity, appear to be the most sensitive to acute exposures of ionizing radiation [25]. This phylogenetic order of sensitivity is generally the converse of that found for toxicants. During the Dry season many higher terrestrial and semi-aquatic vertebrates are concentrated around waterbodies on the main watercourses of the ARR. This is not the case during the wet season when any releases of mine waste waters would occur. At this time, these animals are usually dispersed, occurring in habitats such as woodland, temporary pools and wetlands away from the main watercourses or sources of contamination. Hence, for these animals, the risk of exposure to ionizing radiation is likely to be very small. The sensitivity of fish to acute exposure to ionizing radiation appears to be reasonably high [25] and the inclusion of fish species in a monitoring programme would appear to be well justified. Since fish communities are included in the ARR monitoring programme, we conclude that potential risks to ecosystems from ionizing radiation are being assessed in the current programme.

The biomagnification of some radionuclides through food chains has been reported in the world literature though this potential has not been well investigated in the ARR. Rather, a more conservative approach has been taken, namely to identify aquatic plants and animals (e.g., mussels) that may concentrate these contaminants and to monitor concentrations of contaminants in these organisms. Thus, the current monitoring programme to assess the radiological risk to people includes the measurement of radionuclides in fish and freshwater mussels. From the results presented in Figure 2 we conclude that the current programme is also adequate to assess the radiological risk to biota.

5.3. Comparison with radiological effects on humans and chemical effects on biota

A limit on the volumetric discharge rate of water from Retention Pond 2 at the Ranger mine was derived above on the basis of the criterion that the dose rate to aquatic biota should not exceed 400 μGy/h. This use of a volumetric rate limit as the regulatory instrument has been adopted in this example rather than discharge rates for individual radionuclides to enable an estimate to be made of the relative significance of chemical toxicity in biota, radiological exposure of humans and radiological exposure of non-human biota in determining constraints on the discharge of waters in the retention pond.

Extensive studies of the chemical toxicity of Retention Pond 2 waters using site specific ecotoxicological procedures [7, 8] have demonstrated that the toxicity of RP2 waters to aquatic biota is dominated by uranium. Using the discharge conditions considered in the previous section and the trigger value derived for uranium to protect 99% of aquatic species, 6 μg/L [7, 8], the limiting discharge rate on the basis of aquatic toxicology would be 0.1 m^3/s.

The radiological impact on people living downstream from the Ranger mine has been studied through modelling the dispersion and transport of radionuclides in the Magela Creek system, determining the uptake of radionuclides in aquatic organisms and estimating the traditional diet of the local Aboriginal population [18–20, 26]. The concentration data and discharge conditions summarized in the previous section have been used to estimate the discharge rate of RP2 waters that would give rise to a committed effective dose which is at the dose limit for members of the public of 1 mSv/a. The resulting limiting discharge rate is 35 m^3/s. The primary (79%) contributor to the dose is predicted to be intake of ^{226}Ra from the consumption of freshwater mussels.

The limiting discharge rates for water in RP2 at Ranger to ensure the protection of aquatic biota from adverse effects arising from chemical toxicity, the protection of people from adverse radiological impact, and the protection of non-human biota from adverse radiological effects are summarized in Table 2. Other factors would also play a role in limiting maximum allowable RP2 flow rates but the figures in Table 2 give an indication of the relative importance of the various risks.

The data in Table 2 clearly indicate that the limiting factor in ensuring of protection of people and the environment is the chemical toxicity of uranium. Considering only radiological effects, the limiting factor is protection of aquatic animals in the creek just downstream of the mine, and specifically protection of freshwater mussels from the radiological effects arising from uptake of ^{226}Ra.

This is a surprising result and contrary to the ICRP maxim that radiological protection of humans would result in radiological protection of

TABLE 2. DERIVED MAXIMUM DISCHARGE RATES FOR WATER IN RP2 AT RANGER FOR A SINGLE RELEASE OVER A PERIOD OF ONE MONTH

Protection objective	Hazard	Location	Maximum allowable RP2 discharge rate (m^3/s)
Ecosystem	Ionizing radiation	Creek	2
Ecosystem	Ionizing radiation	Floodplain	160
Ecosystem	Chemical toxicity	Creek	0.1
People	Ionizing radiation	Floodplain	35

non-human biota. On analysis, the origin of this result lies in the different exposure pathways for people and other biota. The human critical group lives at the head of the upper floodplain area and they obtain their food and water from a wide variety of locations within and outside the creek system (including shop-bought food). In addition, any release of mine waters would only occur at a time of high flow rate when physical access to food within the creek would be extremely limited. In particular, harvesting of freshwater mussels during an actual release would be impossible. In contrast, the most exposed aquatic animals are located within the creek itself, at the geographical and temporal point of maximum radionuclide concentrations during any release period.

In addition to the hypothetical example of RP2 releases considered above, the dose rates to biota were also calculated for the conditions under which the Ranger mine has operated since its establishment. The resulting maximum dose rate, again for mussels, was found to be about 30 μGy/h, 90% of which is due to naturally occurring radionuclide concentrations. We conclude that it is highly unlikely that operation of the Ranger mine over the past 22 years has resulted in harm to aquatic biota arising from exposure to ionizing radiation.

6. CONCLUSIONS

The general principles that are currently used in regulatory regimes for the protection of ecosytems from the adverse effects of chemical toxicants have been used to develop a framework for a possible regulatory regime for protection of ecosystems from the effects of ionizing radiation. We have concluded that the principal issues that need to be addressed are: (i) review of the range of end points to be used in determining acceptable dose rates for non-human biota, and (ii) determining and implementing an appropriate programme to obtain no-observed-effect dose rate data for a range of biota from a number of taxonomic groups using these end points.

For the specific case study considered in this paper, the discharge of waters from an uranium mine, it was found that the limiting factor in ensuring protection of people and ecosystems is the chemical toxicity of uranium to aquatic animals. Restricting consideration to the effects of ionizing radiation, it has been found that, in this case study, the limiting factor is protection of aquatic animals rather than people. While there are ancillary reasons for this result (for example, the use of a concentration factor approach in the assessment) the principal factor leading to the conclusion is that the exposure pathway for aquatic animals is quite different to that for people. This may well be the case in other radiation exposure scenarios.

It is concluded that it is highly unlikely that operation of the Ranger uranium mine in Australia's Northern Territory over the past 22 years has resulted in harm to aquatic biota as a result of exposure to ionizing radiation.

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Topical Session 2

DISCUSSION

S. SUNDELL-BERGMAN (Sweden): In her presentation, Ms. Higley said that the alpha RBE was reduced from 20 to 10 in the case study described by her. Why was it reduced?

K.A. HIGLEY (United States of America): Largely in order to illustrate the functionality of the RESRAD-BIOTA code.

D.B. CHAMBERS (Canada): I should like to know whether the chemical toxicity of uranium was considered in the case studies described by Ms. Higley and Mr. Johnston.

K.A. HIGLEY (United States of America): We did not consider the chemical toxicity of uranium.

A. JOHNSTON (Australia): Yes, we carried out site specific toxicity testing for uranium using a range of local native species. With the method employed for zinc, a 99% protection value for uranium of 6 μg/litre was derived.

R.M. ALEXAKHIN (Russian Federation): I should be interested in hearing answers to the question “If human beings are protected, is non-human biota also protected?”

A. JOHNSTON (Australia): We came to the somewhat surprising conclusion that in the particular circumstances of a hypothetical (“worse case”) scenario related to a discharge of water from the uranium mine, the protection of non-human biota from the effects of ionizing radiation would give rise to a more stringent discharge requirement than the protection of people. So the ICRP maxim would not apply.

The reason for the “anomaly” is that the pathway by which animals would be exposed is very different from the pathway by which people would be exposed.

S. SAINT-PIERRE (France): We were not surprised at all by our results. It is nice to have methodologies that are robust, but to see effects on non-human biota you usually need laboratory conditions. By and large, there is nowhere around nuclear facilities where you find effects in the general environment.

So, if the whole purpose of such assessments is to fill a gap, fine! But clearly simplicity is a necessity.

J.F. KNOWLES (United Kingdom): In topical Session 1, Mr. Ishida said that he had seen no effects and did not expect to see any, and he seemed to be saying that on the basis of the 400 μGy/h dose level which UNSCEAR and other bodies have published. In this session, Mr. Saint-Pierre also mentioned that dose level when saying that no effects would be seen.

The 400 μGy/h dose level was admittedly derived from the examination of a lot of data, but from the FASSET database it is clear that there are whole phyla which have not been investigated with regard to chronic radiation effects, so I wonder how happy people are with the 400 μGy/h dose level, which seems to be well on the way to being “cast in concrete”.

S. SAINT-PIERRE (France): When we carried out the La Hague study, we were not implying that 400 μGy/h was the limit. We know that our results were at least three orders of magnitude lower than this. We also know that there are more subtle dose effects, but I am not sure that it is a very important issue.

D.S. WOODHEAD (United Kingdom): Mr. Johnston indicated that the aim is to preserve biodiversity, which I would think means protecting populations.

In the case study described by Mr. Johnston, I would have expected the population to extend downstream from the discharge point, so that there might be effects in the immediate vicinity of the discharge point. However, if you look at effects or doses in the whole area occupied by what is effectively the population, you may not reach the same conclusion about the relative sensitivity of humans and non-human biota.

Would Mr. Johnston agree with that?

A. JOHNSTON (Australia): Yes, I would.

The issue of how one addresses the question of moving from effects on the individual to effects on the population needs to be considered extensively.

However, the same logic could be applied to the effects of uranium as a toxicant on aquatic animals. In our study we applied the same logic in the case of chemical toxicants as in the case of ionizing radiation.

L. KEEN (Canada): The word “anomaly” has just been used, and I found that a little disturbing. When we reviewed the Canadian examples, we were looking at a risk assessment based on the type of facility, and in my view an uranium mine is not an “anomaly”. It exists, and the ecosystem around it must be considered in its own way.

A. JOHNSTON (Australia): I did not say “anomaly” in the context of uranium mining. I was simply suggesting that our results might be considered anomalous by those who support the ICRP maxim.

S. SAINT-PIERRE (France): We may wish to carry out studies even if there is no expectation of harm, for demonstration purposes. However, if we carry out studies at every site there is a possibility of misallocation of resources.

H. VANMARCKE (Belgium): Mr. Johnston said that radium-226 in mussels gave the largest dose. Were the long lived decay products of radium taken into account? According to the UNSCEAR 2000 Report, apart from potassium-40, the largest dose to humans is from polonium-210.

A. JOHNSTON (Australia): The dose from radium-226 included the dose from the short-lived decay products, with 100% retention of radon being assumed — a conservative assumption, I believe, as there is some evidence to suggest that radon retention is lower than that.

Polonium was originally included in the calculations, but then it was removed and considered separately.

A. JOUVE (France): If the most exposed species is protected, are all other species protected? If they are, could the most exposed species be taken as a reference species?

L. MOBERG (Sweden): In the papers which I reviewed as Rapporteur, there was no indication that the authors believed that, if the most exposed species is protected, all other species are protected.

S. SAINT-PIERRE (France): In various assessments carried out by me, the filtrating mollusc appeared to be the most exposed species. Molluscs can be found in all aquatic and marine environments, but I am not sure that it should be taken as the basis for the “worst case” scenario for generic application.

K.A. HIGLEY (United States of America): We were looking at a riparian environment, so both aquatic and riparian species were present.

The most exposed species might be the mussel, but if you went through some of the different levels of assessment, you could discount the exposure of the mussel. Then a riparian species becomes more important when you are considering its potential exposure relative to its particular dose limit — one rad per day for aquatic species and a tenth of a rad per day for terrestrial and riparian species in the United States.

So you have to consider which organism is getting a dose relative to its particular dose limit.

A. JOHNSTON (Australia): In our case, the most exposed species was the freshwater mussel.

Molluscs are very high on the scale of acute lethal doses. So one could argue that there is not much of a problem in this case, because, although the exposure rate is high, the mollusc’s radiosensitivity is extremely low.

I had difficulty deciding what approach to take in these circumstances, but I finally concluded that the approach we take in the case of exposure to chemicals was probably appropriate — you use the animals which are being tested as surrogates for the ecosystem, and you end up with a dose rate value below which you think you will achieve a certain level of protection. Then, you set up a control regime so that the protection applies to all species.

It is an interesting issue, and I do not know whether it has been fully resolved.

D.B. CHAMBERS (Canada): As Mr. Knowles said, there are whole phyla which have not been investigated with regard to chronic radiation effects. However, all biota is exposed — naturally — to ionizing radiation.

Background radiation levels are very variable, and I should therefore be interested in hearing views about how the variable natural background could provide at least the context for the dose rates that we anticipate and see in real settings.

A. JOHNSTON (Australia): Background data are extremely important. The paper by Twining et al. gives very low dose rates, at least at the 95% protection level. In our case, background radiation gives rise to a dose rate of about 30 μGy/h, but the animals have obviously adjusted to it at the very least.

I would therefore suggest that we can use the background radiation data to obtain some information about lower limits of sensitivity.

K.A. HIGLEY (United States of America): In the early stages of developing our screening process, we compared some of our screening numbers with the background conditions, just to see whether we were completely wrong. The raw numbers were of the order of 30 μGy/h or more, so we realized that we were not setting impossibly restrictive concentration numbers.

S. SAINT-PIERRE (France): In the La Hague study, the variation of the background data was not very great.

The La Hague input was perhaps a factor of 10 lower than background. In general terms, we seem to be in a situation very similar to the human radiation protection situation, where the effects are known — at about 100 mSv — but the slope is unknown between 100 and a few mSv, and below that we do not know at all.

L. MOBERG (Sweden): The background problem is relevant, but is it really different from what we discuss when we talk about the radiation protection of humans? There you have a policy for handling the background in relation to artificial sources, and I think one can apply the same policy here.

A. JOHNSTON (Australia): Here we are dealing with deterministic effects on the whole, so I am not sure that the background in the case of humans is comparable. Here one adds the additional dose rate to the background, whereas in the case of humans the fraction of the dose that is additional to background can be considered separately.

R. NICKERSON (United Kingdom): Background levels are important, but here we should be talking about man-made radiation. The nuclear industry is always telling us that, if we stand in the streets of Aberdeen, the background radiation dose we receive from the surrounding granite is higher than what we would receive by standing near a nuclear facility.

A. JOHNSTON (Australia): As I just said, in the case of humans you are dealing with stochastic effects, and you therefore use a dose rate limit that applies to additional doses above background. In the case of animals, you are dealing with deterministic effects, and you must therefore include the background in the dose estimates when comparing doses with dose rates at which harm could occur.

So there is a difference.

S. SAINT-PIERRE (France): This is a topic we discussed in the appraisal of the La Hague study by international experts. The results were presented with and without the background, and with and without allowance for RBE. However the results are still two orders of magnitude less than the guidance values.

F. BRECHIGNAC (France): From case studies we get an idea of the current situation, and it is interesting to compare the radiological side and the non-radiological side on the same basis.

I would be interested to hear people's predictions for the future.

S. SAINT-PIERRE (France): Our assessments and conclusions reflect almost 50 years of nuclear operations.

A similar study was carried out on the River Rhône, downstream from the nuclear facilities located along the river, and the outcome was the same. So I would predict that there is no indication that radiation represents a great hazard to the environment.

K.A. HIGLEY (United States of America): We have been using the methodology which I described for several years at various nuclear weapons sites, and we know that there are areas with very localized high contaminant concentrations there. In general, the larger areas of the sites have passed the screening assessment. However, there are some very localized contaminated areas that we know potentially present problems. Thus, unlike operating nuclear power plant facilities, there are sites that are undergoing aggressive decontamination and remediation, so it is not surprising that you would find areas where there may be some adverse effects.

A. JOHNSTON (Australia): Regarding the likely future, I suspect that further work may well indicate that the dose rate at which harmful effects could occur might be a little lower than has been suggested now. On the other hand, I would suggest that the actual dose rates which occur as a result of operations are in general very low, so there is probably some scope for a change in the dose rate limit. I do not think there will be a significant impact on animals due to radiation facilities.

D. CANCIO (Spain): In her presentation, Ms. Higley mentioned the formation of an inter-agency group. What is the objective of that group?

Also, is it possible that the DOE, the NRC and the EPA will adopt the same screening methodology?

K.A. HIGLEY (United States of America): The methodology started out as a means whereby the DOE might address the environmental issues at some of its sites, and, in the interests of developing a consensus methodology, the NRC and the EPA were asked to participate.

Recently, the technical basis document used in developing the graded approach — including the RESRAD-BIOTA code and the BCG calculator — will be available under an inter-agency cover, which indicates that it can be used as a technical tool by other agencies in the United States.

It is by no means a standard for those other agencies; it is simply making this particular tool available.

The DOE and others want to continue working with the international groups in this area.

Rapporteur's Summary 1

CONTRIBUTED PAPERS ON REGULATORY APPROACHES AND CASE STUDIES

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Abstract

Twenty-three contributions have been accepted covering the four subjects: (i) Existing approaches — case studies; (ii) approaches adopted for non-radioactive pollutants — implications for radiation protection; (iii) ethics, principles and end points; and (iv) establishment of standards and criteria and compliance issues. This report briefly summarizes these papers and highlights some issues. Examples are given concerning similarities and differences between three case studies. The possible need for correspondence between protection systems for non-radioactive and radioactive pollutants, respectively, is discussed. Some ethical issues are exemplified. Reported assessment frameworks are commented upon.

1. INTRODUCTION

For this conference, 23 contributions have been accepted covering the 4 subjects: (i) existing environmental protection approaches — case studies (10 papers); (ii) approaches adopted for non-radioactive pollutants — implications for radiation protection (3 papers); (iii) ethics, principles and end points (5 papers); and (iv) establishment of standards and criteria and compliance issues (5 papers). These contributions are briefly summarized and discussed in this report. The main focus is on a limited number of contributions which have been selected for their particular relevance to the four subjects. These are discussed under separate headings but some of the contributions are discussed under more than one heading. Some more general conclusions are given at the end of this paper.

2. EXISTING ENVIRONMENTAL PROTECTION APPROACHES — CASE STUDIES

In this paper, a case study is defined as an estimate of radiation doses (and effects) resulting from discharges of radioactive substances at a particular site. The dose estimate could either be based on discharge data and model calculations of the migration of the discharged radionuclides in the environment, or on measurements of the radionuclide concentrations in the environment. Recent case studies are for example the MARINA II study [1] and the La Hague study [2], the latter also presented at this conference. The MARINA II reports doses and effects to biota in the North East Atlantic while the latter deals with the effects on aquatic organisms outside the La Hague facility (which is also covered by the MARINA II study).

Of the ten "case study" contributions, three [3–5] in particular, more or less fulfil the description of a case study given above. In addition to a brief description, some relevant information from these contributions are summarized in Table 1 for comparison. In [3] internal and external dose rates to six relevant groups of marine aquatic biota are calculated for continuous exposure to tritium releases in a worst case scenario. Dose-response data selected from the recently completed FASSET Radiation Effects Database (FRED), which brings together published information on the effects of ionizing radiation on different biota, are used together with an ecological risk assessment software to produce probabilistic dose rate criteria for protection of biota. When both chronic and acute response data are included, the estimated criterion for the protection of 95% of species, 15 μGy/h, is quite low. With dose rates estimated from monitoring data there is a very low likelihood of environmental damage (Table 1).

The case study in [4] is based on the contamination of soil and freshwater systems by naturally occurring radionuclides from mining and mineral processing giving rise to chronic exposure of wildlife species. A number of species were chosen to represent the terrestrial and freshwater ecosystems. For terrestrial species, the mean dose rate varies between approximately 0 (bacteria) and 500 (herbivorous mammal) μGy/h, and between 10 (bacteria) and approximately 250 (benthic molluscs, small and large benthic crustacea) μGy/h. A comparison with the dose levels for biota recommended by the IAEA [5] indicates that the dose rates to mammalian herbivores and benthic molluscs are above the IAEA guideline levels.

The RAD-BCG Calculator developed by USDOE has been used in [6] to assess the potential risk to ecological receptors from radionuclides present in sediments proposed for dredging. The sediments were thought to contain elevated levels of radioactivity due to release of produced water during

TABLE 1. A SUMMARY OF THE CASE STUDIES DESCRIBED IN REFERENCES [3–5]

	Twining, J.R., et al. [3]	Petr, I.L., Tsela, A.S [4]	Steevens. J.A., et al. [5]
Site(s) in	Australia	South Africa	USA
Source	Research reactor	Mining	Sediment dredging
Nuclide(s)	Tritium (discharge data)	U decay chain	Ra-226, Ra-228, Cs-137
Ecosystem	Marine	Terrestrial, freshwater	Water, sediments
Biota	Zooplankton to pelagic fish (6 groups)	10 terrestrial and 12 aquatic species	Mussels
Exposure situation	Chronic	Chronic	Chronic
Dose	External, internal (ellipsoidal, equilibrium)	External, internal (ellipsoidal, equilibrium)	External, internal (hypothetical organism)
Dose rate	Pelagic fish 0.012–0.97 μGy/h; fish eggs 0.015–1.2 nGy/h	0–500 μGy/h (terrestrial), 10–250 μGy/h (aquatic)	Screening value 0.347<1 (=criterion) (water and sediment)
Dose-response data	FRED (LOEDR and HNEDR data chosen; 554 entries, 83% fish)	—	—
Standards/ criteria	15 μGy/h (for protection of 95% of species). (Canadian criteria: 5–10 μGy/h)	IAEA Aquatic animals 400, terrestrial animals 40 and plants 400 μGy/h	DOE, IAEA Aquatic animals 400, terrestrial animals 40 and plants 400 μGy/h
Effect	All response effects included. 0–0.8% of species potentially affected	(Doses to mammalian herbivores and benthic molluscs above IAEA values)	(Riparian animal most likely to reach limiting dose)
Software/ methodology/ dose calculation	Dose estimate, FRED, AQUARISK	Crystal Ball/ Monte Carlo; Copplestone et al.	RAD-BCG calculator

TABLE 1. A SUMMARY OF THE CASE STUDIES DESCRIBED IN REFERENCES [3–5] (cont.)

	Twining, J.R., et al. [3]	Petr, I.L., Tsela, A.S [4]	Steevens. J.A., et al. [5]
Comment	Acute and/or chronic data; α, β, γ or tritium exposure. Conservative assumptions. Very low likelihood of environmental damage.	Underestimation of doses? not all nuclides included, lack of CF and dose factors. Ra-226 dominates doses to terrestrial species. Synergetic effects?	Screening – multi-tiered approach. Doses to members of the public and workers also calculated.

petroleum drilling and production. The results of the screening calculations show that the investigated site passes the screen analysis. The calculation further shows that the organism most likely to reach the limit of 1 mGy/d (for terrestrial animals) is a riparian animal.

The three case studies [3, 4, 6] are conservative or very conservative, possibly with an exception for the South African case [4]. It is a possibility that some species around the mining facilities may receive doses above the IAEA values. It is not discussed whether this may have any biological effect or not. The Australian study [3] includes a method to calculate the criteria for protection which are then used for comparison with monitoring data. The two other studies make comparisons with recommended national or international standards. As shown in [3], FRED can be a useful resource, but it is limited by the quality of the information existing in the literature and the interpretation of data in FRED should be cautious. More information may be required on the impact of ionizing radiation in conjunction with conventional pollutants, i.e. synergistic effects may be relevant. In addition to these three studies, a microcosm case study is discussed in [7] (see below) in connection with relations between approaches for non-radioactive and radioactive pollutants.

The remaining seven (case study) contributions give more traditional descriptions of the system for protection against ionizing radiation. These contributions describe methodologies (Cuba [8]) and national legal framework (Latvia [9], Turkey [10]) for waste management including environmental impact assessments; the emissions to air (Morocco [11]) and emissions to air and discharges to water (Lithuania [12], Romania [13]) from nuclear installations and the resulting doses to the public; and, uranium mining (Niger [14]) including brief information about tailings, in particular radium and radon.

These seven contributions give valuable information about the situation in the respective countries, and also mention the importance of protection of the environment to various degrees.

3. APPROACHES ADOPTED FOR NON-RADIOACTIVE POLLUTANTS — IMPLICATIONS FOR RADIATION PROTECTION

Of the three contributed papers, two [7, 15] discuss relations between approaches adopted for non-radioactive pollutants and radioactive contaminants, respectively. But this subject is also partly touched upon in contributions under other headings. Paper [7] also contains a comparative microcosm case study. The third contribution [16] describes a system for chemical pollutants but give few implications for radiation protection. Brief summaries of [7] and [15] are given below.

A common index for comparative evaluation of ecological effects of radiation and other toxic agents is proposed in [7]. This Ecological Effect Index (EEI) was applied to an aquatic model ecosystem (microcosm) consisting of species representing producer, consumer and decomposer. The ecological effects of γ rays were compared with various toxic agents. In general, the EEI was positively correlated with log-transformed doses of each toxic agent. A 50% effect dose, ED_{50}, was calculated for each toxic agent. It is assumed to be comparable to EC_{50} (50% effect concentration), and may be a measure of community level effects. ED_{50} is also considered to be useful for quantitative comparisons of effects on microcosm between γ rays and the other toxic agents. It should be noticed, however, that acute radiation and high levels of toxic agents are used in a simple system.

Various economic concepts and principles have been developed to take economy into account in the decision process for non-radioactive pollutants after the Rio conference in 1992. One of these principles is the polluter-pays principle. This principle is used as a starting point in [15] to discuss environmental valuation and its potential use for environmental radiation protection.

Considering the potential for cross-fertilization between the radioactive and the non-radioactive fields, it is a little surprising that there were so few contributions on this subject (heading) at this conference. However, several of the other contributions, for example [17–20], covered by this paper use, or are in favour of using, methodologies originating from the non-radioactive field. For example, in [20] an approach based on ERA is used to define the scope and complexity of environmental monitoring programs. This approach is said to allow consistent and comparable risk assessments from exposure to both hazardous and radioactive substances.

It could be added that the FASSET project [21] has examined a number of national and international programmes for assessing environmental risks of hazardous chemicals as well as for radionuclides. It was found, inter alia, that a number of features are in common including the sequence: hazard identification, contaminant source characterization, environmental transport, exposure to contaminants, assessment of effect on individuals, assessment of effect at higher levels of organization and assessment of effect on the environment. Another conclusion in [21] is that most of the programmes for the assessment of the terrestrial compartment are not supported by the same level of experience, validation and documentation as the ones for the aquatic compartment. This seems to largely true for also for radioactive contaminants. So, there does not seem to be any obvious reasons why similar principles for the protection of non-human biota could not be applied for ionizing contaminants and for hazardous chemicals as the expected effects are similar.

4. DEVELOPMENT OF AN INTERNATIONAL ASSESSMENT FRAMEWORK FOR RADIATION PROTECTION

The development of an international assessment framework for radiation protection of the environment will rely upon the frameworks being actually used in a number of countries as well as the outcome of discussions in international organizations like IAEA and ICRP. Based on the contributed papers some aspects of this are discussed in the following two sections on “Ethics, principles and end points”, and “Establishment of standards and criteria and compliance issues”.

4.1. Ethics, principles, end points

Of the five contributions, three [17–19] discuss primarily ethics and principles but also end points to some extent. Some information from these contributions is summarized in Table 2 for comparison. In [22] and [23], the focus is much more on experimental studies and physical/biological end points.

How do we explicitly demonstrate that the environment is protected? For chemicals, ERA is a process to evaluate the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors [17]. One difficulty in applying ERA for radioactive pollutants is the lack of data concerning chronic low-level exposures, which is also discussed in other contributions. According to the FASSET database (FRED) the crucial

TABLE 2. ETHICS, PRINCIPLES AND END POINTS, DATA FROM REFS [17–19]

Garnier-Laplace, J., et al. [17]	Michel, R., et al. [18]	Oughton, D.H. [19]
		Interface "reference flora and fauna" and "ERA" approach?
	Human impact on the abiotic environment must be included (in contradiction to ICRP discussion paper) — sustainability key.	Anthropocentric, ecocentric, biocentric — rabbits exemplify differences.
ERA as process to evaluate adverse ecological effects — *lack of data for chronic low-level exposure* limits application for radioactivity — safety factors.		Problem formulation in ERA critical first step, should consider *social, ethical, political issues* in addition to technical issues — transparency essential. Reference flora and fauna similar to tiered approach — "bottom-up" — focus on biological end points in individuals.
Safety factors / extrapolation precautionary approach — uncertainties.		Uncertainties in predictions; needed for application of the precautionary principle.
Research is needed to handle (i) extrapolation, (ii) biological effects; (iii) biomonitoring data and (iv) quantitative risk assessments with accepted uncertainties.	Indicators for sustainability should take into account the dynamics of abiotic compartments — similar application for non-radioactive pollutants.	Value judgements should be transparent in protection systems; Clearer focus on non-technical issues in problem formulation (ERA); reference fauna and flora approach valuable but only one input.
Uranium examples.	Kr-85, H-3, C-14, Cl-36, I-129 and Tc-99 — examples where abiotic criteria are missing.	

information gaps notably concern the chronic exposures of some taxonomic groups and internal contamination of α and β emitters. Gaps in knowledge constitute a significant limitation to making a reasonable risk estimates and biological effects at any organizational level remain unknown. Some examples of such gaps are given in [17] for uranium. It is concluded that (i) bioavailability is the key to an accurate assessment of both exposure and effect, in particular media quality criteria are needed; (ii) knowledge about chronic exposure is important for effect assessment; (iii) different scales of biological effects are crucial to find ecologically relevant indicators. It is further concluded that the determination of the no-effect dose, or dose rate, is of primary importance and should be linked to the effort to integrate the behaviour of pollutants (bioavailability, bioaccumulation, and biotransformation) to develop an understanding of this domain.

According to [18] there is a conflict in the ICRP draft report on protection of the environment. In order to comply with a sustainable development a concept for the protection of the environment has to include also the compartments atmosphere, hydrosphere, and geosphere, or at least pedosphere. With respect to the status of the abiotic environment the radiological aspects should be assessed in close connection with the status of other non-radioactive harmful substances and should allow for a generalization with the goal of a consistent concept of environmental protection. It is concluded that indicators for sustainability should take into account the dynamics of the abiotic compartments of the environment and should be likewise applicable to radioactive and non-radioactive environmental pollutants.

The rabbits around Dounrey are a starting point in [19] for discussing the interaction between ecological risk assessment (ERA) and the reference flora and fauna approach. In ERA, problem formulation is defined as the first step of any risk assessment and it is intended to identify the context and purpose of the assessment framework. This includes the process of choosing appropriate assessment end points, identifying sources and describing the environment, as well as ecological and political issues related to the question being addressed. The reference flora and fauna system has been identified with a "bottom-up" or reductionist method of dose-response analysis. The approach focuses explicitly on effects (or various biological end points) observable in individuals, and extrapolates potential effects on populations (and ecosystems) from that data. It is concluded that problem formulation is a critical step in ecological risk assessment and one that deserves more attention in developing a system of protection of the environment from ionizing radiation. In addition to consideration of technical issues, the step should consider social, ethical and political issues. The reference flora and fauna approach can provide a systematic tool to the collation and analysis of available knowledge on radiation effects in non-human species. However, there is a danger that the tool will be used to shape both the problem and the solution. The information provided by the reference flora and fauna approach is only one input to an evaluation of consequences, and although a necessary input it should not be taken as sufficient.

Two contributions [22, 23] are about different aspects of the concept of end points. "At what level of biological organization are the first changes seen that indicate negative effects in the environment caused by radiation?" is a question asked in [22]. The answer given is that it is the genetic test systems that should be used for an early diagnosis of the alterations caused by human industrial activity. This is based on analysis of cell aberrations observed at low irradiation levels which showed a non-linear dose-effect relationship. In [23] it is said that the consequences of the Chernobyl accident made it obvious that there is a need for radiation effects bioindicators at different levels of biota organization (from cell to ecosystem). For the example forest ecosystems, the biological test-objects should be divided into: (i) species concentrators of radionuclides and (ii) species in which biological effects can be observed. Both these categories represent "key compartments" (end points). After defining the key compartments, ecotoxilogical research will be the next step. One conclusion in [16] is that in spite of significant success in the study of ecotoxicology, we can still not answer many of the vital questions.

The ethical principles that could underlie a system for protection of the environment have been discussed during recent years and are summarized in [24]. Protection of the environment may involve a wide range of end points. These end points should be defined in the initial phase of an assessment as a measure of expected or possible effects. According to [21] the following criteria are often used in the choice of end points: importance to the structure and function of the ecological community; the degree of exposure expected from the distribution of the contaminant in the environment and the type and behaviour of the organism, the degree of sensitivity to the contaminant, and relevance to management goals. Critical or reference organisms are used in a number of assessment systems. It is important to note that assessment end points may not be directly quantifiable or measurable in which case measurement end point(s) can be used as indicators.

The environment is defined within the framework of national laws and international legal instruments, and may be considered to include man, biota, abiota, physical surroundings, and their interactions. According to [24] all living things are dependent upon their abiotic surroundings and thus the concept of environmental protection also has to include this component of it. In particular, it is the presence of any radionuclides and the effect of radiation on living things that is the issue to address in a general pollution context.

4.2. Establishment of standards and criteria and compliance issues

This subject comprises three papers describing the situation in Canada [20, 25, 26]. The two other papers describe the EPIC project [27] and the historical development of radiation protection [28], respectively.

The first paper describes a regulatory approach in Canada [20] with the objective of showing that released pollutants do not give rise to unreasonable risks. It is based on site specific ecological risk assessment to define the scope and complexity of a required environmental monitoring programme. The result of the ERA is used to classify the facility into one of three risk categories: low, medium or high, where increased risk leads to a more complex monitoring program. In particular, higher risk facilities are required to have an additional biological effects monitoring component. This additional monitoring should detect measurable biological effects for non-human biota exposed to hazardous and radioactive substances at the population or community level. Selecting the biological level at which biological effects monitoring operates is then a significant decision.

This regulatory use of ERA has required the derivation of benchmarks suitable for the protection of populations and communities. The ERA is based on toxicity benchmarks derived from chronic exposure studies with end points of significance to reproduction or survival in sensitive species. The benchmarks, expressed as Expected No-Effects Values (ENEVs), have been derived from literature data of relevant Critical Toxicity Values (CTVs) with safety factors incorporated as appropriate, i.e. an ecotoxicological approach. In the reports, ENEVs are given for mammals [25], in particular small rodents, and for aquatic biota [26]. For aquatic biota the ENEVs range from 0.6 mGy/d to 4.6 mGy/d for an average population. These values are not widely different from 10 mGy/d to the most highly exposed individuals in a population which would be protective of populations of aquatic plants and animals as recommended by the IAEA and UNSCEAR (based on “expert review”). However, the ENEVs for radiation exposure developed using an ecotoxicological approach have the advantage, for environmental protection purposes, of having clearly stated assumptions and provide values that are consistent with ENEVs derived for non-radioactive hazardous substances.

In [27] some very general results obtained so far are presented for the EPIC project, a practical application of a system for environmental protection from ionizing radiation to Arctic areas. A broad “historic” description of development of radiation protection of man and the environment is given in [28]. A conclusion is that developments at the cellular level could provide a joint basis on which to base assessments of radiation damage to cells regardless of species affected.

5. SOME CONCLUSIONS

Environmental radiation protection is influenced by a multitude of factors. This is also reflected among the contributions covered by this review which cover ethical, scientific, economical and regulatory questions.

An assessment framework (and a case study) should ideally include three parts: problem formulation, assessment and risk characterization against standards or criteria. In the lack of an internationally established framework, various approaches for the protection of environment against ionizing radiation have been tested. These have included the use of methods applied for non-radioactive contaminants. The contributions indicate a need for coherence and consistency between non-radioactive and radioactive contaminants.

This review indicates the need to handle uncertainties of scientific nature (inherent variability and complexity of ecosystems, lack of knowledge of effects of radiation on flora and fauna, radiological sensitivity of different species to different radionuclides (radiation type), effects on different ecosystem levels, acute and chronic exposure (data availability).

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APPROACHES FOR NON-RADIOACTIVE POLLUTANTS — SEARCHING FOR COHERENCE AND CONSISTENCY

(Topical Session 3)

Chairperson

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REGULATING NON-RADIOACTIVE ENVIRONMENTAL POLLUTANTS IN CANADA

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Abstract

The paper provides a brief overview of the framework used by the Canadian Government for assessing and managing risks from non-radioactive environmental pollutants. The paper focuses on the Canadian Environmental Protection Act 1999, Canada's main law for managing toxic substances. The paper emphasizes that Canadian risk management approaches are precautionary and account for risks to both the environment and human health. The paper also describes the cooperative approach to developing risk management measures. This approach relies on significant stakeholder input, and seeks to utilize the appropriate legal framework, which may include a range of Federal Acts as well as provincial and territorial measures. Finally, the paper describes the ongoing evolution and expansion of Canada's risk management tool box.

1. INTRODUCTION

This paper provides an overview of the framework used by the federal government for assessing and managing risks from non-radioactive environmental pollutants in Canada. The paper reviews various federal authorities, but focuses primarily on the Canadian Environmental Protection Act 1999 [1], the main mechanism for assessing and managing toxic substances in Canada.

2. RISK MANAGEMENT IN CANADA TYPICALLY ADDRESSES BOTH ENVIRONMENTAL AND HUMAN HEALTH RISKS

Responsibility in Canada for managing risks to environmental and human health can be a federal, provincial/territorial or shared responsibility, depending on the issue. For example, the provinces and territories are extensively involved in the licensing of industrial facilities. This gives them authority to regulate various emissions and waste streams. Provinces also play an important role in regulating occupational health and safety. The Federal Government manages activities on federal and aboriginal lands as well as many issues that cut across provincial jurisdictions, such as food and drugs, hazardous products, pesticides, nuclear safety, feeds, seeds, and fertilizers.

Almost all of the federal regulatory frameworks governing the management of these issues require risk managers to account for both risks to human health and risks to the environment. Examples of these legal mandates include:

- Food and Drugs Act [2]: Section 30 authorizes the Minister of Health to “make regulations respecting the assessment of the effect on the environment or on human life and health…”
- The purpose of the Nuclear Safety and Control Act [3] is “to provide for the limitation…of the risks to…the health and safety of persons and the environment…”
- The Canadian Environmental Assessment Act [4] focuses on "environmental effects,” which Section 2(1) defines as “any change…in the environment, including any effect…on health.”
- Health of Animals Act [5]: Section 120 stipulates that “no person may release a veterinary biologic unless…the proposed release is…unlikely to pose a risk to the environment or to human or animal health.”
- National Energy Board Processing Plant Regulations [6]: Section 7 authorizes the Board to require information if it suspects an energy processing plant may cause “a detriment to property or the environment; or…a hazard to the safety of persons.”
- Hazardous Products Act [7]: Section 6 authorizes the Minister of Health to ban or restrict products, materials or substances that are “…toxic…or likely to be a danger to the health or safety of the public.”

The Government has also recently developed a draft replacement for the Pest Controls Products Act [8]. When it comes into force, the new Act will clarify that it is “an Act to protect human health and safety and the environment by regulating products used for the control of pests.” Section 2(2) states, for example, that “For the purposes of this Act, the health or environmental risks of a pest control product are acceptable if there is reasonable certainty that no harm to human health, future generations or the environment will result from exposure to or use of the product, taking into account its conditions or proposed conditions of registration.”

Most of these examples pre-date the Canadian Environmental Protection Act 1999. As the primary mechanism for regulating toxic substances, CEPA 1999 enables the government to intervene unless a regulation under another federal law already provides “sufficient protection to the environment and human health” with respect to the issue (Section 93(4)). A number of federal statutes have an equivalent approach to CEPA 1999. For example, regulations under the Seeds Act, the Feeds Act and the Fertilizers Act all authorize restrictions or controls on new products that meet the same health and environmental risk-based test for “toxic” as is prescribed under CEPA 1999.

3. A PRECAUTIONARY APPROACH

Canada has a long-standing tradition of applying precaution in federal regulatory activities, and in particular to its various science-based regulatory programs. Many federal risk management statutes authorize measures where the government “suspects” a risk will occur or where it determines that a risk “may” occur. In addition, CEPA 1999, the Canada National Marine Conservation Areas Act and the (not yet in force) modernized Pest Control Products Act explicitly refer to the precautionary principle, using the Rio definition that, “where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation.” In order to provide guiding principles for the application of precaution, the Government of Canada recently issued A Framework for the Application of Precaution in Science-based Decision Making about Risk [9].

4. THE CANADIAN ENVIRONMENTAL PROTECTION ACT, 1999

Jointly administered by the Departments of Environment and Health, CEPA 1999 represents a significant revision to the original 1988 Canadian Environmental Protection Act. CEPA 1999 places a strong emphasis on pollution prevention, emphasizing the application of the precautionary and polluter pays principles, and authorizing the Federal Government to deploy a wide range of information gathering and risk management measures for “the protection of the environment and human health”. The Act establishes strict timelines for managing substances found to be “toxic”, and requires the “virtual elimination” of persistent, bioaccumulative, anthropogenic “toxic” substances.

CEPA 1999 requires the Government to take "preventive or control actions" regarding any substance it determines to be "toxic" according to the following test:

Section 64. "A substance is toxic if it is entering or may enter the environment in a quantity or concentration or under conditions that:

(a) have or may have an immediate or long term harmful effect on the environment or its biological diversity;
(b) constitute or may constitute a danger to the environment on which life depends;
(c) constitute or may constitute a danger in Canada to human life or health."

The Act does not prescribe the kind of information the Ministers must account for when deciding whether a substance should be considered "toxic". As such, the Government may follow a widely agreed upon international conclusion regarding the toxic nature of a substance. This was the case, for example, with the addition of CFCs to the CEPA List of Toxic Substances following the Montreal Protocol. In most cases, however, decisions to classify and manage a substance as 'toxic" result from the application of one of a number of relatively well-defined risk assessment paths. For example, anyone proposing to manufacture or import a substance that is new to Canada or to introduce a "significant new activity" regarding certain existing substances, must comply with the New Substances Notification Regulations. These require the proponent to submit prescribed information to demonstrate that the substance is not "toxic" or that the proposed new activity will not cause the substance to become "toxic."

For substances already in commerce in Canada, the Act establishes multiple assessment paths. Under the original 1988 CEPA, the primary focus was on conducting intensive risk assessments of substances that had been recommended for inclusion on the first and second iterations of the "Priority Substances List" (PSL) by a multi-stakeholder expert panel.[1] CEPA 1999 provides additional assessment paths, including a requirement that the Ministers of Health and Environment "categorize" all substances on the Domestic Substances List (comprising the approximately 23 000 chemicals, polymers and biological substances in commerce in Canada during the 1980s). The categorization process is a relatively cursory review "on the basis of

[1] Between 1988 and 1995, the Departments determined that 25 of the 44 substances on PSL1 are toxic. And between 1995 and 2001, they concluded that 18 of the 25 substances on the second PSL are toxic.

available information" to identify those substances that "present to individuals in Canada the greatest potential for exposure" or that are "persistent or bioaccumulative…and inherently toxic". Substances identified by this filter are then subjected to a "screening level risk assessment" to determine whether they are "toxic" under the Act. This assessment accounts for additional information, including evidence about exposure and potential for exposure. A third, relatively novel requirement is that the Ministers must "review" the decision of any provincial, territorial, Canadian aboriginal or foreign government to prohibit or substantially restrict a substance for environmental or health reasons.

As Figure 1 illustrates, the Departments of Health and Environment share the assessment process, assessing possible risks to human health and the environment, respectively.

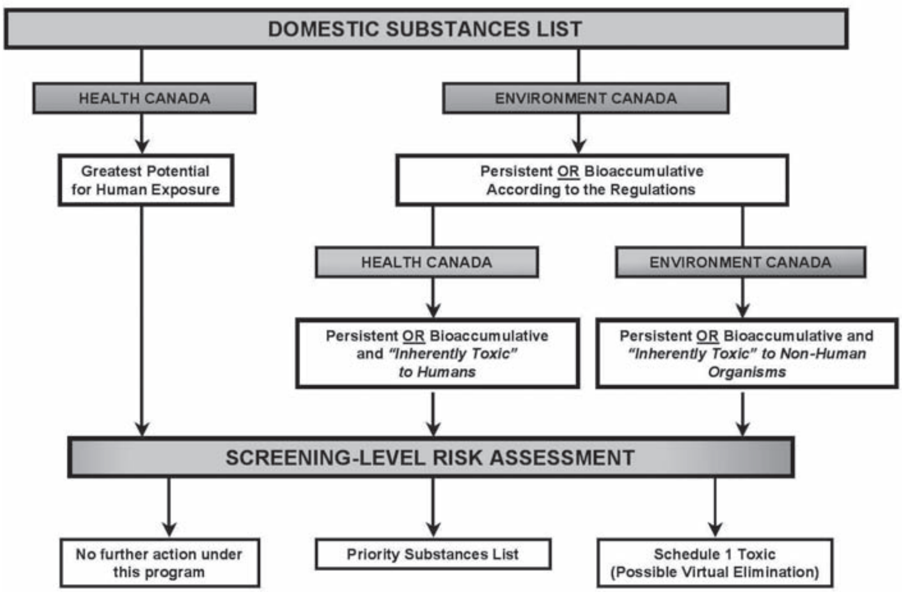

FIG. 1. Categorization and screening of substances of the Domestic Substances List (DSL).

5. RISK MANAGEMENT OF TOXIC SUBSTANCES UNDER CEPA 1999

5.1. Overview

The Toxics Substances Management Policy [10] provides overall guidance on the management of toxic substances by the Federal Government. It calls for the "virtual elimination" of substances that are persistent, biaccumulative, anthropogenic and toxic, and it commits the government to ensure the life cycle management of all other toxics.

CEPA 1999 authorizes considerable information gathering power, both to assist risk assessments and to help develop and monitor the efficacy of risk management measures. The Act also provides for the National Pollutant Release Inventory, Canada's national pollutant transfer and registry system [11].

Environment Canada and Health Canada lead the development of a Risk Management Strategy for each substance concluded as toxic under the Act. Each Strategy: defines the problem; describes the sources of the problem throughout the substance's life cycle; identifies the sectors that pose the greatest threat; establishes risk management objectives for each target sector; describes the primary risk management measures that will be implemented; and outlines the consultation approach that will be used to refine the design of the risk management measures.

In most cases, risk management objectives reflect the results expected from application of the best available techniques that are economically achievable (BATEA), where "economically achievable" applies to the sector under discussion rather than to each facility.

5.2. A coordinated approach

Although the Federal Government plays the lead role, other governments are involved in the management of toxic substances. Environment Canada is committed to considering the range of possible tools and to recognizing appropriate jurisdictional roles when it is developing strategies to manage substances that are determined to be toxic under CEPA 1999. The CEPA National Advisory Committee (NAC), consisting of representatives from provincial, territorial, and aboriginal governments, advises the Federal Government on activities under the Act and on cooperative, coordinated approaches to the management of toxic substances. Environment Canada consults with the NAC during the development of each Risk Management Strategy.

Canada-wide Standards (CWSs) are another important example of the inter-jurisdictional approach taken to managing toxic substances (and other issues related to environmental management). The Canadian Council of Ministers of the Environment (federal, provincial, and territorial environment ministers) develops CWSs on a range of issues to coordinate action to establish and achieve common environmental standards across the country. Developed under the framework of the Canada-Wide Accord on Environmental Harmonization [12] and its Canada-wide Environmental Standards Sub-agreement [13], CWSs represent commitments by governments at all levels in Canada to address key environmental protection and environmental health risk issues.

CWSs may be agreements to target specific substances from sectors within a defined time frame, or they may be very broad control management strategies covering a number of sectors, sources, and substances. The Canada-wide Accord establishes the expectation that action will be taken by the most appropriate jurisdiction. Thus, each government is responsible for implementing the CWS in its own jurisdiction, with the goal of effective, efficient, and harmonized implementation.

5.3. An emphasis on sectoral approaches

Although many Risk Management Strategies are substance-specific, sectoral strategies may be developed in cases where there are several substances requiring management in a sector. Under CEPA 1988, the Government initiated Strategic Options Processes (SOP) for seven industrial sectors and seven specific substances. These SOPs combined detailed analysis with extensive multi-stakeholder processes. Some of these processes led to the development of regulations. Others (e.g., the steel sector) laid the foundation for the ongoing development of suites of non-regulatory measures.

The federal Government is also engaged in ongoing collaborative work with the provinces and territories on Multi-Pollutant Emission Reduction Strategies (MERS) related to air emissions from seven sectors. In 2000, thirteen of Canada's fourteen jurisdictions[2] (the federal, provincial and territorial governments) agreed to "Canada-wide Standards" for particulate matter (PM) and ground-level ozone. The joint initial actions agreed to by the signatory governments included the development of national MERS for seven sectors. These MERS are in the process of being developed. In addition to PM

[2] Quebec did not sign the Canada-wide Environmental Standards Sub-agreement.

and ground level ozone, they also account for GHGs and other air pollutants, such as mercury in the case of electric power generators.

5.4. Stakeholder input

There is a strong tradition of stakeholder input into environmental risk management in Canada. CEPA 1999 stipulates public notice and comment periods for various key decisions. Moreover, as a matter of policy and practice, Environment Canada and Health Canada rely heavily on stakeholder engagement to help clarify issues and expectations, to identify new information and, where possible, to seek consensus-based outcomes.

There is more involvement of stakeholders during the selection and design of risk management measures than during risk assessments, although the Government seeks input from a range of outside experts — including expert representatives of various stakeholders — during the design and implementation of risk assessment processes. Depending on the issues that need to be addressed in the management of a given substance, Environment Canada may hold preliminary consultations with the most affected stakeholders during the development of the Risk Management Strategy. Environment Canada also provides for focused, time-bound consultations on Risk Management Strategy documents through direct contact with industry and non-governmental organizations and, more broadly, through postings on the National Office of Pollution Prevention web-site [14] of Environment Canada's Greenlane. The CEPA Environmental Registry is also a valuable source of information for our stakeholders. [15]

Once an overall Risk Management Strategy has been developed, the Government typically convenes more intensive consultations to help refine the risk management measures. These consultations often include a wide range of stakeholders, including other federal government departments, other orders of government, industry, NGOs, academia and others. The type of engagement process will vary depending on the factors such as the importance of a quick resolution of the issue, the disparity of views and the potential economic implications. Processes used range from Internet-based public notice and comment mechanisms to bilaterals and focus groups, through to time-intensive multi-stakeholder consensus processes.

5.5. The tool box is expanding

Management tools may be used to control any aspect of a substance's life cycle — from the design and development stage to its manufacture, use, storage, transport, and ultimate disposal. Typically, the initial selection is based on qualitative analyses to help identify the most appropriate tools for achieving the risk management objective for a certain sector. If more detailed information or further assessment is needed, quantitative analyses are carried out on the most promising tools. If a regulation is selected as a risk management tool, a more detailed quantitative analysis serves as the basis for a Regulatory Impact Analysis Statement — a requirement for any federal regulation.

When identifying risk management measures, the Government considers all available options, encompassing instruments provided for by CEPA 1999 as well as other risk management tools that are outside of CEPA 1999, including the regulatory provisions of other governments and voluntary approaches. Increasingly, the Government is emphasizing the deployment of a suite of measures that, together, can create efficient and mutually reinforcing levers to support the desired outcome by a range of actors.

5.6. Examples of risk management tools

The following illustrates the suite of risk management tools that are considered when identifying options for managing a toxic substance in Canada:

- Instruments authorized under CEPA 1999: regulations (including deposit-refund and trading system regulations); pollution prevention plans; environmental emergency plans; codes of practice; environmental quality objectives; environmental quality guidelines; and release guidelines.
- Non-CEPA 1999 economic instruments: financial incentives and subsidies, environmental charges and taxes.
- Other federal Acts — e.g., Fisheries Act, Pest Control Products Act, Hazardous Products Act.
- Voluntary approaches: Environmental Performance Agreements, Memoranda of Understanding.
- Joint federal/provincial/territorial initiatives: Canada-wide Standards, guidelines, codes of practice.

6. CROSS-CUTTING INITIATIVES FOCUSING ON POLLUTION PREVENTION

Although this paper focuses primarily on the direct regulation of environmental pollutants, it is important to understand how the Federal Government's regulatory efforts, and those of Environment Canada in particular, operate within the context of a broader set of initiatives. Direct action by regulators will only be able to address a subset of high priority issues, and will not on their own foster fundamental change in long term production and consumption behaviour. Often working through inter-agency and public private partnerships, Environment Canada promotes practices such as pollution prevention, extended producer responsibility and design for environment. The Department also works with industry to promote the adoption of business management tools such as life cycle analysis, full cost accounting and corporate sustainability reporting. Together, these initiatives are intended to help Canadian business identify opportunities for reducing their ecological footprints while also enhancing their competitiveness and adding value to their bottom lines.

7. CONCLUSIONS

The management of risks from environmental pollutants in Canada is an evolving practice that is characterized by:

— A focus on environmental and human health risks;
— Increasingly sophisticated risk assessment protocols;
— Science-based, precautionary decision making;
— Inter-governmental collaboration;
— Extensive stakeholder engagement; and
— Use of an expanding tool box.

Much of this work occurs under the authority of the *Canadian Environmental Protection Act 1999*. When it was introduced, *CEPA 1999* established various new requirements and many new authorities for managing risks to the environment and human health from toxic substances and other pollutants. Although the Act provides one of the most complete regimes for managing toxic substances in the world, it is likely that the regime and the Act itself will continue to evolve over time. For example, through a provision that is relatively unique in Canadian law, *CEPA 1999* requires a standing committee of the House of Commons to review, every five years, the provisions and operation of the Act and to submit a report to Parliament recommending changes to the Act or its administration.

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ENVIRONMENT CANADA, Management of Toxic Substances website: http://www.ec.gc.ca/toxics/

Topical Session 3

DISCUSSION

D.B. CHAMBERS (Canada): I would be interested to hear from Ms. Power and Ms. Clark how they define "potentially significant effect" and whether reversibility fits into their definition.

L. POWER (Canada): From the environmental perspective, we look at characteristics such as persistence, bioaccumulation and toxicity for man-made substances.

So, from an effects perspective the policy at the federal governmental level will require us to virtually eliminate or work towards virtual elimination, recognizing that it is a long term goal.

M.E. CLARK (United States of America): The context for protection depends on the system within which you are operating or on your legal mandate. That will help to inform you about what the potentially significant effect is.

If applying a precautionary principle, any introduction of a stressor has a potentially significant effect. For compliance or for a cleanup, the "potentially significant effect" concept could be very different.

Given that there is an iterative loop — evolving knowledge — in all systems, there is potential for reversibility in all systems.

R.L. ANDERSEN (World Nuclear Association): Obviously a simplification of the framework for the radiation protection of humans is justification, limitation and optimization. Has Ms. Clark seen parallels in the frameworks which she has looked at for non-radiological aspects or generally for environmental protection aspects?

M.E. CLARK (United States of America): Justification for a practice would also be considered within the framework for environmental protection, so there is a clear parallel.

In the case of environmental protection there may be qualitative limits as well as quantitative ones. In other words, there may be evolving limits based on the legal framework or the ethical framework, but also in terms of what your objective is.

Obviously optimization fits within any of the frameworks, and the approach may be qualitative as well as quantitative.

A. JOHNSTON (Australia): In her presentation, Ms. Clark said that often measurements are made at the individual level and extrapolated to populations. How is that done?

M.E. CLARK (United States of America): The observations and analyses are generally performed in the laboratory. Then one extrapolates from a few individuals to a large group.

We are learning that there are problems associated with that — for example, bystander effects. Also, if you are looking at the total ecosystem there are other confounders. For example, if you are concerned about the introduction of a pesticide into an environment and are looking into the effect of the pesticide on — say — the bee in that environment, you may have laboratory data on the effect of the pesticide on bees. This will give you some indication of the effect of the pesticide on the bee population in a particular habitat.

There are other issues, however, because the pesticide may have an effect also on birds or other important species in that environment.

S. SAINT-PIERRE (France): I am reacting to one of the slides shown by Ms. Clark in her presentation.

If I understood the slide correctly, it referred to a scientifically based precautionary principle with the option of eliminating choices that create a risk. Without bringing up the whole low-dose issue, how do you deal with this?

What is Ms. Clark's interpretation of precautionary scientifically based risk in that context?

M.E. CLARK (United States of America): The application of the principle uses science. That was the implication of the slide.

I believe that Canada applies the precautionary principle in its decision making.

S. SAINT-PIERRE (France): I was not asking whether the precautionary principle is applied, but whether it is necessarily scientifically based.

M.E. CLARK (United States of America): For every approach there is a legal foundation, an ethical foundation and a scientific foundation. Whether the precautionary principle is based on science, on ethical values or on societal considerations is up to the relevant authorities of the country in question.

L. POWER (Canada): Regarding the precautionary principle in the CEPA context, the same scientific processes are applied for determining whether a substance is toxic.

If there is a suspicion of toxicity, we publish — through a public comment process — a risk assessment and then ask whether anyone has information additional to the data used in the scientific report, in order to inform the decision about whether the substance is toxic.

R.L. ANDERSEN (World Nuclear Association): One difference between radiological and non-radiological assessment approaches that is often mentioned is the notion of an ambient background level of the "contaminant", especially if you are dealing with populations.

How might the system for non-radioactive pollutants be applied in a radiation context, given that there is a natural variability in which populations exist and thrive?

M.E. CLARK (United States of America): With most chemical stressors there is no background. Metals are probably the most comparable to ionizing radiation, but there are obviously caveats — some metals are necessary for life and some are not, and the body has a way of regulating the amounts of metals which it contains.

L. POWER (Canada): Background levels have come up in discussions about mercury and other metals, but I would not attempt to draw a comparison between metals and ionizing radiation.

M.E. CLARK (United States of America): I would be happy to discuss with Mr. Andersen how risk assessments are being conducted for metals, the problems and data gaps, and the approaches that are being taken.

P.A. THOMPSON (Canada): In the assessments carried out in Canada for chemicals and radionuclides, the background is normally considered at the risk assessment stage, where levels of naturally occurring substances are considered in order to ensure that the benchmarks used are appropriate.

Once a determination has been made that a substance has to be managed, because of the health or environmental risks, the background radiation does not play such a role.

R.L. ANDERSEN (World Nuclear Association): I am intrigued by the fact that there is not only this difference of an ambient background that is universal but also the difference of transitioning from individual protection potentially to population protection.

My point was that populations seem less susceptible to variability in the background than individuals, and some arguments that are put forward about small incremental additions and their effect on individual protection may not apply when we shift to the context of protecting populations and the environment.

M.E. CLARK (United States of America): The uncertainties associated with extrapolating from individuals to populations are among the uncertainties identified also in the case of metals.

D.B. CHAMBERS (Canada): Irrespective of stressor, there can be very large variability in populations of non-human biota from place to place, from season to season and from year to year. How much of a variation in a population occurs naturally — all the time? How large would an incremental effect on the population have to be in order to become significant in the context of the natural variability?

L. POWER (Canada): As Ms. Thompson said, during a risk assessment there would be consideration of all these issues. We consider the sources, the receptors and the linkages between them.

For toxic chemicals, we are also guided by the pollution prevention principle throughout risk management actions.

M.E. CLARK (United States of America): I would add to what Ms. Power just said that in some cases there are safety factors built into the risk management decision. The safety factors can vary on the basis of all the different uncertainties. That is one way in which one accommodates some uncertainties in the management decision.

Round Table 2

DISCUSSION

D. CLEIN (Argentina – Chairperson): When I was starting my career in radiation protection, nobody spoke of consistency between the system of protection against the effects of radioactive materials and the system of protection against the effects of other pollutants. The reason was that the former system was so much more highly developed than the latter one. In the field of radiation protection, thought was given to protecting the environment by taking account of the recognized high radiosensitivity of humans.

During the past three decades, however, really impressive progress has been made in understanding the behaviour of other pollutants in the environment — so much so, that the false impression has been created that radiation protection has been lagging behind.

In my view, the two systems have now reached a similar level of maturity, so that it is perhaps time to think about consistency between the two.

A. SIMCOCK (OSPAR Commission): My interest is primarily in the marine environment, where there are few humans and where, therefore, the ICRP maxim that if you protect humans you also protect the environment is very questionable. Moreover, the marine environment is an environment where it is important to deal not only with radioactivity but also with other pollutants.

Initially, a distinction was made between radioactivity and other pollutants. Now, they feature together as a single factor in a list of factors which one should take into account when dealing with marine pollution. In 1998, when the OSPAR Commission was formulating strategies for the medium term, separate strategies were formulated for radioactive substances and hazardous substances — but only because different people were involved in their formulation.

Nevertheless, the two strategies have a great deal in common. For example, they both envisage — for the long term — a return to background for naturally occurring radioactive substances and other naturally occurring pollutants and environmental levels approaching zero for man-made pollutants, whether radioactive or not. As regards the short term, ending in 2020, it has been agreed that the OSPAR parties will — put in simple language — just do their best.

In trying to achieve consistency between the two strategies we have weighed up the benefits and disadvantages of various courses of action in a “prudential calculus”. In addition, we have taken account of “moral imperatives" (you should not treat the environment as a waste tip!), "absolute values" (what is pristine should remain pristine!) and "intergenerational equity" (one should not reduce future generations' scope for action!).

Furthermore, we have, in the area of "risk perception" taken account of what the United Kingdom Department of Health has called "fright factors" (for example, situations where the risk is perceived as being incurred involuntarily — as in the case of pollution — rather than voluntarily, as with dangerous sports or smoking, where the risk is perceived as being inescapable despite the taking of personal precautions, or where the risk is perceived as resulting from man-made rather than natural sources). Radioactivity scores high on the "fright factor" scale.

In the "risk perception" area we have also taken account of what might be called the "media multiplier" — the way in which the news media present information, perhaps emphasizing the human interest aspects and asking "who is to blame?", "has there been a cover-up?" and "are you at risk?".

In doing that, the OSPAR Commission has adopted rather different approaches to hazardous substances and to radioactive substances. In the case of hazardous substances, it considers the entire spectrum of chemicals on the market, tries to identify those chemicals which score high in terms of — for example — persistency, bioaccumulativeness and toxicity, tries to determine how they enter the marine environment and what they are doing there, and tries to determine what should be done about them. In the case of radioactive substances, it has had to focus much more on national plans for achieving the long term targets.

In this context, I would mention that the European Union has just made a proposal regarding a European marine strategy — to be implemented not only by the Member States of the European Union but by other European countries as well. The idea is to set long term objectives and divide up the work involved in achieving them among a number of organizations. I think this work will, over the next 18 months, involve a close look at radioactivity in the light of the "prudential calculus", "fright factors" and so on.

M. DOI (Japan): My answer to the question "Is consistency of regulations for ionizing radiation and other pollutants important?" is "Yes". For both human health and the environment, the system of protection against the effects of ionizing radiation should be consistent with the system of protection against the effects of other pollutants.

For the regulation of chemicals in the environment, a pragmatic framework has been developed for assessing both their human health consequences and their ecological toxicities in the context of sustainable development and/or the conservation of biodiversity. It is difficult to imagine something similar not being done for the regulation of radioactive substances.

Moreover, there is the risk of the bioaccumulation of environmental pollutants affecting humans, who are among the species most sensitive to ionizing radiation.

However, I would differentiate between the management of chemicals and of radioactive materials entering the environment. Some chemicals are, over time, reduced to non-toxic elements by chemical processes in the environment and by biochemical processes, so that their impacts may be regarded as acute transient disturbances. On the other hand, radioactive materials must await their own decay, and they may accumulate and their doses should therefore be integrated over time. This is equally true for some persistent and bioaccumulative chemicals, such as some organic pollutants. At all events, these factors must be taken into consideration when one is harmonizing the regulations for chemicals and radioactive materials in the environment.

That is not an easy task, but we can learn a lot from the management of chemicals in the environment. Through coherence and consistency between the management system for chemicals in the environment and radiation protection, we should be able to construct a comprehensive but simple system for protecting human health and the environment from the effects of radiation.

From the point of view of ecology, I would note that the environment is a self-organized, self-sustaining system of great complexity created by a web of interdependency among species. Its sustainability is based on intrinsic factors such as growth and carrying capacity, so that ecological responses to impacts emerge as “indirect effects”.

I say “emerge” because the scientific knowledge and the experience acquired in respect of any specific environment are very limited. Why are they very limited? One reason is that the ecological system is robust as a whole, and small impacts are compensated for without ever being detected.

Toxicology tests based on mortality, morbidity, reproductive success and observable DNA damage in reference species will be valid in most cases, but they are not infallible for both radiation and other pollutants. A precautionary, step-by-step approach is therefore the most effective method to prevent effects in the environment from emerging.

In this context, I would mention the precautionary principle. The general public in Japan may feel that safe air and water should be available free of charge. However, one sometimes has to pay for high air and water quality. It is therefore essential to consider the social, economic and other costs of environmental radiation protection. Who should pay those costs? In my view, the precautionary principle is reasonable only if the costs of alternatives are considered. Resources are very limited, and they must be distributed reasonably over the wide spectrum of risks. In some countries, specific social risks — for example, infant mortality and epidemic diseases — are matters of greater urgency then environmental radiation protection. So, international harmonization in the area of environmental protection must allow for local flexibility

U. FERNÁNDEZ GÓMEZ (Cuba): I believe that it is very important to achieve consistency of regulations for ionizing radiation and other pollutants.

In the necessary harmonization process, we must decide not only what has to be harmonized but also how and when the harmonization should be carried out, taking due account of different cultural backgrounds.

The nuclear industry, with a recognized high standard of safety performance, has from the outset considered environmental radiation protection from an anthropocentric point of view, focusing on the effects of ionizing radiation on human health and extrapolating effects observed at high doses and dose rates to the low dose range.

On the other hand, the growing need to assess the effects of human activities on different ecosystems in a more integrated manner has led to demands for the adoption of a holistic environmental view. In particular, industrial pollutants such as toxic chemicals have received increased attention in recent years, being explicitly mentioned among the top-priority issues highlighted at the World Summit on Sustainable Development held in Johannesburg last year.

As good examples of the harmonization of regulations, one might mention the application of risk assessment methodologies for the environmental impact assessment of the isolation of hazardous waste and the technological and process safety evaluation of industrial installations that handle large inventories of toxic and hazardous substances, using risk identification techniques developed by the nuclear industry. These two examples illustrate, in my view, valid applications of proven methodologies that could provide a useful tool for evaluating in a more precise and consistent manner the complex interactions between other, non-nuclear technologies and the environment.

However, when dealing with the problem of developing radiological protection criteria for the environment, we have to consider other important factors, such as the target definitions in terms of biosphere components, and also biological end points.

The temporal and spatial behaviour of many environmental variables poses an additional challenge, given the complex process of boundary definition and the intrinsic dynamics of environmental change.

Another factor to consider is the lack of scientific data for some radionuclides, species and ecosystems — an important factor since the composition of ecosystems may change with time.

Many of these issues can be resolved through the consolidation and interpretation of the available scientific data on the effects of ionizing radiation on biota and the behaviour of radionuclides in the environment and through the proper application of the main principles of environmental protection, incorporated into the most relevant international legal instruments providing for sustainability, biological diversity, conservation and environmental justice.

As regards the application of the precautionary principle, I would stress that the nuclear industry has proven credentials for facing the challenge of demonstrating, on a scientific basis, that all justified practices may from a radiation protection point of view be in compliance with the environmental protection objectives.

It is imperative that the nuclear sector, including regulators, establish close ties with environmental experts.

One of the main challenges in the area of environmental radiation protection will be the achievement of simplicity and practical applicability of the regulatory framework.

In the construction of the regulatory framework, it will be very important to conduct a thorough review of the models for transport and dosimetric calculations and to establish a proper monitoring system as a way of demonstrating compliance with the criteria or standards acceptable for each country.

In harmonizing the two types of regulations, we have a long way to go in terms of establishing a widely accepted regulatory system.

R.J. PENTREATH (United Kingdom): I would say that consistency of regulations for ionizing radiation and other pollutants is desirable. After all, the nuclear industry discharges non-radioactive pollutants as well as radioactive ones and other industries discharge radioactive pollutants as well as non-radioactive ones. Moreover, the radioactive and the non-radioactive pollutants are not discharged separately.

At present, the operators of a large industrial plant have to comply with a bewildering array of regulations relating to the protection of human health, pollution control, wildlife protection and so on. The different sets of regulations derive from different policies that have been translated into different objectives reflected in different ways in different legal instruments. I imagine that the plant operators — and the regulators — are driven mad by the complexity of it all, which makes for an inherently unsafe situation.

In my view, a large industrial plant should be required to have only two licences — one relating to the health and safety of the people working at the site and the other relating to the health and safety of the people living around the site and to the health of the near-site environment. I would be happy if — say — the European Commission were endeavouring to create such a situation, but I see no evidence that it is.

Plant operators clearly prefer regulatory simplicity, but regulatory simplicity may make for excessive prescriptiveness. The tension between simplicity and prescriptiveness results, in my view, from the lack of a clear common strategy for environmental management generally. You may think that there is somebody "up there" (for example, in the capital) who has the overall picture, but I have spent a lot of time looking for such a person and have found nobody either with the overall picture or interested in putting an overall picture together.

Can we learn something about consistency from the world of non-radioactive pollution control? I do not think so. Some objectives of non-radioactive pollution control relate to the protection of humans, others relate to environmental protection, and with still others the rationale has been lost in the mists of time — and in all cases there is a long and tortuous history.

Extensive use has been made of environmental quality standards, but it is not always obvious what they are for. There are environmental quality standards relating to mercury, cadmium, copper and zinc in water, for example. What are those standards meant to be protecting? In the case of mercury and cadmium, their purpose is to ensure that excessive concentrations of those two metals do not build up in fish — not for the sake of the fish, but for that of the humans who may eat them. In the case of copper and zinc, the purpose of the standards is to protect fish, which may choke to death owing to gill mucus irritation caused by copper and zinc. In addition, it is not always clear whether one is trying to protect individuals, populations, entire ecosystems or what, and with both humans and non-human species it is not always clear whether one is protecting them because there is a threshold value for deterministic effects that one does not wish to see exceeded or because one wishes to minimize the occurrence of a stochastic effect which one would only see at the population level.

I think it would be good to have an overall framework for dealing with the pressures on and threats to the environment generally, and I think that such a framework is more likely to be developed by those working to protect the environment from the effects of ionizing radiation than by those working to protect it from the effects of non-radioactive pollutants.

In the development of such a framework, one should not go too far and try to meet environmental management needs connected with issues such as environmental exploitation, nature conservation and habitat protection. The important thing is to do sound scientific work so that one can answer the questions asked by the people dealing with those issues, and, if the questions and answers converge, one will be able to simplify the legislative basis on which industries are run.

S.R. JONES (United Kingdom): I should be interested in hearing views about radioactivity judged against the criteria applied in the case of chemicals — persistence, bioaccumulativeness and toxicity.

A. SIMCOCK (OSPAR Commission): Before responding to Mr. Jones, I would recall that there are substances which, although not persistent, bioaccumulative or toxic, can affect reproductive success because they are endocrine disruptors. They may be important from the point of view of populations if not of individuals.

As regards the marine environment, the radioactive substances with which we are concerned are at present probably at levels well below the thresholds above which people would become worried because of persistence, bioaccumulativeness or toxicity.

When formulating policy, however, one has to allow for "fright factors" and the "media multiplier". People may refuse to buy fish if they think it is radioactively contaminated — a reaction similar to that which occurred in connection with BSE and beef.

R.J. PENTREATH (United Kingdom): Many radionuclides are fairly persistent and some bioaccumulate. However, the situation is less clear as regards toxicity, since there is no consistency as to what "toxicity" means for chemicals that we introduce into the environment.

The questions which are arising now are arising primarily because of the desire to maintain biological diversity. They are difficult to answer for many chemicals, but particularly difficult for radionuclides, because of what is known about the types of effect that radionuclides produce. I think that we shall have to put greater effort into trying to answer those questions, which are legitimate ones. I also think that we need not be afraid of the answers.

In my view, however, that is not the big issue. I believe that ultimately the big issue is trying to convince those responsible for deciding on and implementing policy that we have a sound scientific basis for managing difficult situations. If one could be sure that no nuclear facility was ever going to discharge more radioactivity than it is discharging now, there would be nothing to worry about. One cannot be sure, however, so we must provide appropriate scientific input for decision making.

R.L. ANDERSEN (World Nuclear Association): Clearly there is a difference between calculated risk and perceived risk. What can one do about that when one is formulating policy? I hope that nobody believes that one should tailor policy to people's unfounded fears about ionizing radiation.

R.J. PENTREATH (United Kingdom): Politicians and ultimately members of the general public become worried when scientists seem to be disagreeing among themselves. In the area of environmental radiation protection, the experts are not disagreeing among themselves. If they seem to be doing so, it is because they do not speak a common language. There is a lack of consistency in our approach that is very obvious when one compares that approach with the one adopted in human radiation protection.

In my view, we need to intensify the dialogue with those who are trying to manage the environment in an integrated manner. They have done a lot of serious thinking that is numerically based to an extent that would surprise many. They have developed advanced approaches with the focus on the protection of large areas rather than of rare species or habitats.

Some industries have gone quite a long way towards satisfying the requirements of those responsible for environmental management. The nuclear industry is lagging behind somewhat, partly because it has been so focused on human radiation protection.

A. SIMCOCK (OSPAR Commission): From the point of view of the media, bad news makes a better story than good news. That is a real problem for those involved in the formulation and implementation of environmental policy. How does one gain wide publicity for the fact that something has gone right? The opportunity to do so sometimes presents itself. When it does, it must be seized.

Something else that is essential is continuous monitoring, assessment and reporting. It is also important to demonstrate the existence and results of these actions to a wider audience.

The World Summit on Sustainable Development resulted in a programme that includes — as an important element — the ecosystem approach to managing human activities. In my view, that offers us a context for further work. However, the ecosystem approach needs to be given a firm numerical basis. Once it has that, we can demonstrate that the environment is being managed and monitored properly.

M. DOI (Japan): The fact that there is so far no evidence of harm due to the bioaccumulation of radioactive substances does not mean that there is no risk of such harm in the future. So what should one tell the general public?

In the case of chemicals, unexpected things have happened, and the relevant regulations have been changed as a result. Perhaps we should tell the public that there is no expectation of harm due to the bioaccumulation of radioactive substances and that, if we find evidence that their bioaccumulation is having an impact on an ecosystem, we shall make sure that the relevant regulations are changed.

At the same time, the public must know that we are monitoring the environment closely.

S. SAINT-PIERRE (France): Nobody can be opposed to the ecosystem approach mentioned by Mr. Simcock, but how does one distinguish between, on one hand, impacts of human activities and, on the other, natural variations in the environment? Will the ecosystem approach result in a major improvement?

A. SIMCOCK (OSPAR Commission): Application of the ecosystem approach is not easy. In the fisheries context, it has meant taking into account all the species in the environment of interest — not only the fish constituting the commercial catch but also, say, the sand eels which those fish eat; it has meant thinking about endocrine disruptors; it has meant considering the impact of gravel extraction on nursery beds — and so on. However, that is preferable to looking at fisheries issues separately from issues like gravel extraction.

In my view, the introduction of radioactivity raises problems of perception rather than of regulation, thanks to the success of the nuclear industry in minimizing radioactive discharges. However, more attention needs to be paid to, for example, the question of polonium accumulation when phosphogypsum is processed in fertilizer production and the question of radioactivity entering the sea as a result of offshore oil and gas extraction.

As part of an ecosystem approach, the OSPAR Commission is trying to formulate a consistent set of ecological quality objectives for everything from the oxygen budget to the size of commercial fish stocks which can be used as a basis for monitoring and assessment. So far, however, we have not yet addressed the question of how to integrate radioactivity into that set of objectives.

R.J. PENTREATH (United Kingdom): I believe that the ecosystem approach has a good future ahead of it, although there may be some lack of clarity about its present status.

Pollution control is essentially a matter of preventing undesirable things from happening. Some risks in life are inherently low and others are kept at a low level by constant vigilance. The trouble with constant vigilance is that it is very boring, and one might think that those who are exercising constant vigilance in the interests of pollution control and come up with a new approach are simply trying to break the monotony of their job. However, the ecosystem approach is not aimed just at preventing undesirable things from happening; it is aimed also at making desirable things happen. That is its great virtue, for in environmental management it is very difficult to ascertain what the policy-makers' positive objectives are.

Often difficult choices are involved — for example, between a sustainable fisheries or biological diversity in some marine environment or between high-yield monocrop agriculture and biological diversity in some terrestrial environment; or perhaps one would like to strike a balance between the two options. The history of pollution control has been a history of focusing on single substances in terms of what one does not want. The ecosystem approach enables one to consider what one is aiming for collectively.

I believe that the development of an ecosystem approach for both non-radioactive and radioactive pollution control will create an interface with those who are trying to manage the environment in terms of what they want to happen rather than not happen, and I also believe that such an approach can be developed.

S.M. AU (China): When considering the question of the consistency of regulations for ionizing radiation and other pollutants, one should perhaps ask whether the public is consistent in its attitudes towards the waste from nuclear power plants versus the waste from conventional power stations or towards the microwave “pollution” caused by mobile phones.

A. SIMCOCK (OSPAR Commission): The public certainly does not act on the basis of the “prudential calculus”. Hence the public attitudes to which Mr. Au just referred.

The waste from nuclear power plants is associated with “fright factors” in a way that the waste from conventional power stations is not, while the use of mobile phones is voluntary, so that the associated risk is considered acceptable.

The question of public attitudes in this context is a question of explanation. Policy-makers cannot simply say “We know best.” At least in Western Europe, paternalism in policy-making is very difficult to sell — even to those who might be the father-figures.

The public is irrational, but it is logically irrational — one can determine what has caused it to be irrational in terms of a narrow “prudential calculus”. Through risk analysis you can ascertain why people perceive different risks differently. Then you must respond in appropriately different ways.

R. NICKERSON (United Kingdom): As what you might call a representative of the lay public, I would say that there should be consistency of regulations for ionizing radiation and other pollutants, but I wonder how one would deal with the long term effects of radionuclides having half-lives of hundreds of thousands of years as compared to the long term effects of other hazardous substances.

R.J. PENTREATH (United Kingdom): I think the public needs to wake up to the fact that the radionuclides which Mr. Nickerson presumably has in mind exist as a result of the production of energy, not for some devilish reason, and that probably the greatest crisis looming ahead of humankind is an energy crisis — how to produce energy, what to use it for, and the environmental consequences of energy production and use.

I think the public will wake up to that fact in due course, and the attitude of the public — and of politicians — will then change very much.

U. FERNÁNDEZ GÓMEZ (Cuba): When talking about public perceptions of the risks associated with radionuclides, one should bear in mind the conditions under which the people in question are living. People without access to abundant energy supplies, and perhaps even to the most basic services, will perceive such risks differently from people who are more fortunate.

There are many countries with no nuclear facilities and hence no high-level radioactive waste that nevertheless have low- and intermediate-level waste requiring safe management. They do not see technological development in the nuclear field as a threat, but as something that may ultimately enable them to solve their radioactive waste management problems.

M. DOI (Japan): When considering the impact of very long lived radionuclides in the environment, it may be useful to study regions where there are high natural background radiation levels.

A. SIMCOCK (OSPAR Commission): As regards "intergenerational equity", to which I referred earlier, I do not think that radioactivity is any different from — say — some of the toxic metals. For example, as a result of the use of mercury in the production of chloralkali, large amounts of mercury have been introduced into the shallow seas, where they will remain for a long time, with serious impacts on many countries.

Mr. Fernández Gómez was in effect talking about another form of equity — equity as between rich and poor. The World Summit on Sustainable Development placed great emphasis on the importance of the availability of safe fresh water. In many countries, ensuring adequate supplies of safe freshwater will require vast amounts of energy and chemicals, which will raise the issue of justification that has featured so prominently in connection with practices involving ionizing radiation. There has been relatively little talk about justification with regard to the use of non-radioactive hazardous substances (one rare exception has been the continued use of DDT, justified on the grounds of the benefits it brings in tropical regions as opposed to the problems it causes in the polar regions), and I think there should be more.

B.E. CEDERVALL (Sweden): With regard to the problem of scientists being perceived by the public as disagreeing among themselves, after the Chernobyl accident a great deal of uncertainty arose in Sweden because some scientists said that there was no risk involved for individuals consuming various products while others referred to collective dose calculations. People did not understand the difference between individual risks and collective risks. Scientists must bear that kind of thing in mind when communicating with the public.

BUILDING ON CURRENT KNOWLEDGE

(Topical Session 4)

Chairpersons

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PROTECTION OF THE ENVIRONMENT
Current status and future work

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Abstract

There is already sufficient information to start introducing an overall framework for the systematic protection of the environment from ionizing radiation, drawing upon specialist reviews and interpretations of the large body of radiobiological and radioecological information that has been gathered over the last fifty years. The need to plug some gaps in our knowledge and to improve upon the existing data base is nevertheless recognized. Although the transfer of radionuclides is quite well known within some food chains, there are very little data on the behaviour of radionuclides in non-temperate zones and on uptake to species that do not form part of the human food chain. There is a need to develop both transfer models (flux, dynamic, ecosystem, etc.) and genotoxicological biomonitoring techniques that are capable of allowing impact assessments at a variety of species, population and ecosystem levels that could also deal with other environmental stressors. Mathematical models should be developed and applied to relate the effects of radiation on individuals (particularly with regard to early mortality, reproductive success, and cytogenetic damage) to potential impacts at the population level. Knowledge of the doses and effects of background radiation is lacking, as are dose-effect relationships, including information on relative biological effectiveness (RBE) for a variety of species, doses and dose rates. An understanding of the interaction between radionuclides and other stressors, including possible synergistic effects, is far from complete. The importance of various components of an environmental impact assessment can be explored, in a preliminary way, through the application of sensitivity and uncertainty analyses. These types of analysis, for semi-natural and marine systems, have demonstrated the importance of several radioecological parameters in the derivation of dose rates. However, although these analyses provide insight, caution should be practiced in interpreting their results. Further focused research is needed.

1. INTRODUCTION

The effects of ionizing radiation on plant and animals have been considered in numerous earlier reviews [1, 2], as have methodologies for performing exposure assessments for radionuclides in some environments, e.g. [3]. However, a broad and systematic approach to organize information in a consistent manner and to identify where knowledge gaps lie has never been undertaken. In 1999/2000 the IUR presented and promoted the idea of a system and a framework to address this issue and concluded that this was possible with existing knowledge and databases pertaining to radioecology and radiobiology. The key objective for IUR was to focus further development specifically on the need to improve the scientific basis for environmental protection. Furthermore, it was agreed that a broad and systematic approach was needed in order to develop a framework within which the majority — if not all — of the various approaches being applied to environmental impact assessment for radiation, e.g. [4, 5], could be accommodated. As development work has continued in the aforementioned projects and notably the EU-funded research projects EPIC and FASSET [6], great progress has been made with respect to the identification of areas of knowledge paucity and in methods that may be applied to improve our understanding of the systems under scrutiny. This has allowed the current status of the field to be addressed and has, furthermore, allowed priorities to be set in an attempt to focus future work and to further improve the scientific basis of the framework. Notwithstanding the advances being made with respect to the scientific basis for assessment, the development of ethical, legal aspects and consensus building also clearly require attention.

2. ENVIRONMENTAL PROTECTION FRAMEWORKS

The recent history of environmental protection and legislation illustrates three points to bear in mind when considering protection of the environment from radiation. First, some aspects of environmental protection are relatively new and still undergoing development. Second, the issue is a global one, deemed important by both governments and the public, and has therefore stimulated action on an international scale. And third, practical solutions are not without conflicts and controversy. Not withstanding these difficulties, examples of environmental law can be found in the national laws of every country. Although their scope and detail can vary considerably, progress during the last 30 years has led to a certain amount of agreement on what we mean by environment and its protection and which principles should guide that protection. In particular the principles of conservation, sustainability and (maintenance) of biodiversity have been identified as being particularly relevant in the context of environmental protection from radiation [7]. Such principles have to be interpreted and addressed by science, by ascertaining whether the principle is being maintained, through a current understanding of how radiation interacts with matter and causes effects upon biological systems.

A number of components can be identified that form the basis of a system for radiological protection of the environment. These include a planning stage wherein objectives and strategies require formulation before these are checked against legal frameworks and existing regulations and recommendations. Assuming this stage is finalized one enters a problem formulation wherein the assessment context is described providing details on factors including, but not limited to, source term identification, degree of simplification. The assessment part of the framework allows the assessor to quantify the exposure to the environment, or in most instances components of it, by the application of suitable methodologies, including for example, environmental transfer models, transfer factors, dosimetric models. The relationship between the probability of the effect and the magnitude of the exposure is then derived at the risk characterization stage before decisions are required through reference to the full procedure on the acceptability of the risk. The decision making management stage crucially requires input of a social, economic, legal and ethical nature. The emphasis for IUR work [8] has been mainly on the assessment stage of this framework and the discussion in the following section therefore reflect this predisposition. Several key areas requiring attention have been identified, the current status of the work in this area is summarized and future research priorities identified.

3. CURRENT STATUS

A detailed definition of the status of components of the assessment system would not be possible here. Instead a few indicators describing our current position under the thematic headings of transfer, dosimetry and effects are provided. In order to assess the possible impact of any consequent increase in the radiation exposure of the local wildlife, it is necessary to be able to quantify these radionuclide concentration distributions, using radionuclide transfer models, to provide the input data for the dosimetry models. Many such transport models have been developed for the purpose of human radiation exposure assessment and, in broad terms, their output has provided an initial basis for identifying the regions of the environment where the native flora and fauna are also likely to receive enhanced exposure, i.e., a basis for the selection of reference organisms, e.g. Ref. [9]. As many of these organisms are unlikely to be of direct importance as a source of human radiation exposure, there is currently a lack of the specific transfer rate data to model the accumulation of the radionuclides into both their tissues and their local environment. Some data exist in the literature and work has begun on organizing this information into an accessible format [10]. However, it is clear that future efforts must focus on providing information to bridge these knowledge gaps.

Numerous models already exist for the purpose of deriving absorbed doses to individual organisms including the analysis and solution of dose distribution functions, conservative approaches (whereby all radiation emitted by radionuclides within the organism are absorbed) and Monte Carlo methodologies, e.g. [3–5, 11]. Dose conversion coefficients have been derived for generic biota [12] and specific reference plants and animals [11]. For a limited number of cases, dose conversion coefficients are even available for organs within the body of selected organisms [13].

Numerous earlier reviews also exist on the subject of dose-effects relationships for flora and fauna (see Refs [2, 3]). Work has been conducted to organize such data under environmentally relevant end points and dose rates applicable to routine environmental impact assessments. The end points that have been considered to be of significance in an environmental context include: morbidity, mortality, reproductive capacity (encapsulating effects on fertility and fecundity), and cytogenetic damage [14]. In addition, some suggestions have been made for possible reference organisms in the European marine, freshwater and terrestrial environments in the projects FASSET and EPIC. Work on relative biological effectiveness (RBE) has been quite intensive, and it is noted that values for α-RBE range from low values close to unity up to several hundred, reflecting the fact that the measure is dose rate, end point and species dependent [15]. Recent work has suggested that alpha-weighting factors, derived in part from these studies, might be appropriately placed in the range 5–50 [11].

4. FUTURE RESEARCH NEEDS

4.1. Environmental pathways for radionuclide transport

It is important to emphasize that any new research should be initially tightly focussed on the specific requirements of estimating the radiation exposure of reference fauna and flora selected for inclusion in any environmental protection framework. Empirical approaches may be applied in order to derive transfer information (to organs as well as organisms) and/or provide input for appropriate models. The allometric approach, based on the observation that many metabolic parameters are related (as power functions) to the masses of organisms, may provide one of many ways forward. With respect to the consideration of non-equilibrium situations and in the derivation of equilibrium transfer values where no data are currently available, appropriate biokinetic models may provide some useful insight.

4.2. Natural background

There have been numerous assessments of the natural background radiation exposure of a variety of wild organisms (see [2] for a summary). A closer examination of the data shows that the assessments are probably partial in the sense that they do not appear to include all possible sources of internal and external exposure; this is particularly the case for the natural radionuclides taken up into the tissues of the organism, and even more so for the likely main contributor to the high LET component of the dose rate — ^{210}Po. These deficiencies arise mainly because the available data on tissue concentrations of the natural radionuclides in wild organisms are fairly limited (and many of the existing data were not obtained for the purpose of radiation dosimetry). This is particularly so for organs, such as the gonads, or the developing embryo, which are of significance from the viewpoint of possible radiation effects, and for the types of organisms that might be selected as reference flora and fauna within an impact assessment framework. It is important to identify these data gaps and take steps to fill them (some indication of the range and/or variation in the concentrations should also be obtained).

4.3. Absorbed dose (rate)-response relationships

Although it is likely that the lists of reference organisms identified in the initial stages of the system development are too long for practical application, they do provide an initial framework for organizing the available information on the effects of radiation that might be applicable in an environmental context. This is the approach that has been adopted in the FASSET project, and a stage has been reached at which significant gaps in the database have been identified. There is a clear requirement for further chronic (approaching the lifetime of the organism), low dose rate exposure experiments focusing particularly on environmentally relevant end points such as reproduction. The test species should be tied in with the choice of reference organisms discussed above and to be defined, in due course, by the ICRP. Extrapolations issues need also to be considered not least the derivation of information on effects at low dose rate from high dose rate information, the prediction of field biological effects derived from laboratory observation and modelling the effect at the population level of impacts on individual organisms.

4.4. Quantities and units

For human radiological protection practice, the RBE phenomenon is taken into account by applying dimensionless radiation weighting factors (w_r) to the absorbed doses from the different radiations, and summing, to give a quantity called the equivalent dose. It should be emphasized, however, that values of w_r defined for the purpose of human radiation protection cannot be applied without reservation to other organisms and biological end points. The derivation of appropriate "environmental" w_r s may require further focussed experimental studies, considering RBEs, once areas of data paucity have been identified.

4.5. Genotoxic techniques

The use of new cytogenetic techniques, or the adaptation of human cytogenetic techniques to non-human studies, offers the possibility for quantifying the effect of radiation on DNA at levels below that which cause obvious mortality or reduction in reproductive success, but which may cause chronic genetic effects in the individual or population. The use of such techniques in environmental research is already established with regard to some other genotoxins, particularly in the study of PAHs in aquatic biota, and may permit the comparison of the impact of environmental levels of radioactivity and other genotoxins, and in the determination of additive, synergistic or even possible antagonistic effects of radiation and other pollutants.

5. ASSIGNING PRIORITIES – SENSITIVITY AND UNCERTAINTY ANALYSES

Having listed a number of research areas that require further attention, it becomes quickly evident that some prioritization of tasks may be required owing to the fact that resources are not unlimited. The importance of the various components of the assessment can be explored in a preliminary manner by applying sensitivity and uncertainty analyses to existing model systems. In the following approach a generic (i) semi-natural terrestrial system and (ii) marine system have been considered.

5.1. Sensitivity and uncertainty analyses in the terrestrial environment

An uncertainty analysis of the exposure of biota in the food chain grass-rabbit-fox was carried out by performing probabilistic simulations with the FASSET model for terrestrial semi-natural ecosystems, FASTer [10]. The contamination scenario consisted of a chronic atmospheric deposition of 1 Bq/m^2 per year of ^{137}Cs and ^{239}Pu during a period of 50 years. Such a scenario is, for example, relevant for assessments of the environmental impact of normal releases from nuclear power plants. The probability distributions of doses to rabbit obtained are shown in Figure 1. Correlations between parameters were not taken into account, which partly explains why probability distributions with very long tails were observed. The 90% confidence intervals obtained for ^{137}Cs and ^{239}Pu where within 1 and 2 orders of magnitude respectively (from 2.5×10^{-5} to 1.9×10^{-4} μGy/h for ^{137}Cs and from 1.4×10^{-6} to 1.4×10^{-4} μGy/h for ^{239}Pu).

In order to understand which parameters have the greatest influence on model outputs, a sensitivity analysis was conducted by computing the Spearman rank order correlation coefficients between the input parameters and the calculated weighted absorbed dose rates. In Figure 2, a tornado chart is presented with the sensitivity indexes (correlation coefficients) showing the importance of different model parameters for the dose rate to a rabbit living in the area affected by ^{239}Pu deposition. According to these preliminary results, the Fractional Gut Uptake is the parameter that had the greatest influence on the predictions, followed by the radiation weighting factor (derived from RBE) and the grass biomass. Other parameters have an insignificant influence on the model predictions.

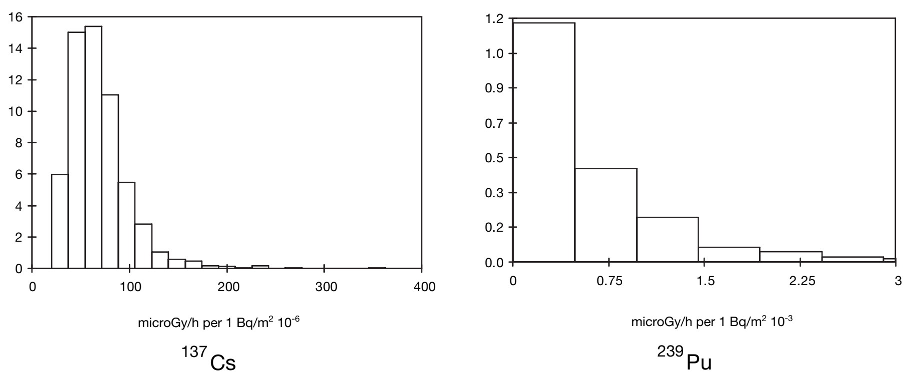


FIG. 1. Probability distributions of the weighted absorbed dose rates to rabbit generated by Monte Carlo Simulations (1000 iterations) using probability distributions for model parameters obtained from values reported in the literature.

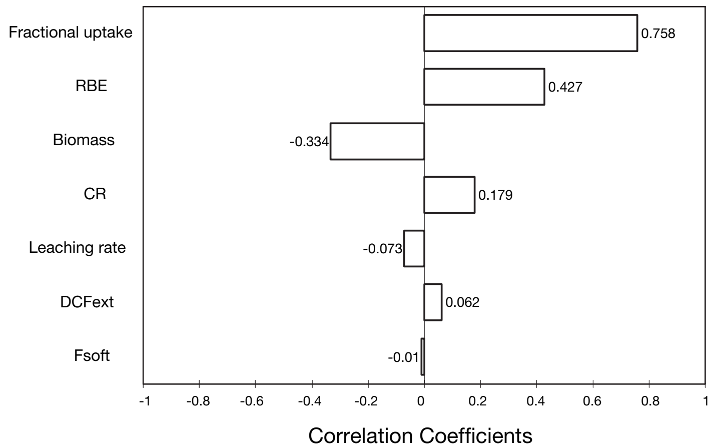


FIG. 2. Results of the sensitivity analysis presented as a tornado chart showing the Spearman rank order correlation coefficients between input parameters and the weighted dose rate from ^{239}Pu received by rabbit.

The sensitivity measure, described above, provides a ranking of the influence of each parameter on the assessment end point, but gives no quantitative feel for the contribution that each input is making to the output's uncertainty. To estimate this contribution, we conducted multiple simulations (10) with 1000 iterations. In each simulation, the uncertainty of one variable is removed and replaced by its expected (BE) value [16]. After each simulation the standard deviation was recorded as the measure of the uncertainty for that simulation. In order to give estimates of the percentage contribution of each variable to the output's uncertainty, the reduction in the output uncertainty for each simulation was divided by the sum of all the reductions. The results obtained for ^{239}Pu in rabbit are shown in Figure 3.

The results of the sensitivity analysis with the two applied methods indicate a different ranking of the parameters considered. The radiation weighting factor, being a multiplicative factor in the model, showed a relatively large influence on the assessed end point, but explained only 4% of the overall uncertainties. The parameter "weathering rate", in contrast, had a relatively high influence on the overall uncertainty, while it has a weak correlation with the considered output. This can be explained by the fact that a parameter with a high sensitivity may have a low uncertainty and vice versa. It should be noted that often different methods for sensitivity analysis give different results, sometimes contradictory ones, and it is therefore recommended to apply several methods when performing these analyses, e.g. see Refs [17–19].

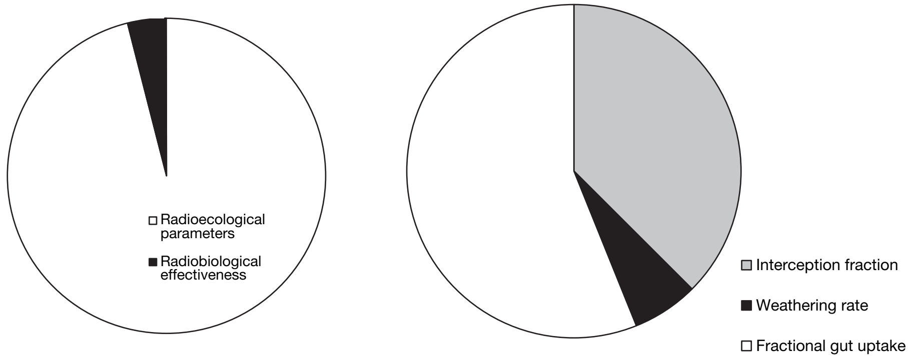


FIG. 3. Results of a special type of a sensitivity analysis, sometimes called uncertainty analysis, showing how the uncertainty in the results influences the uncertainty in the predictions. The figure shows that the overall uncertainties in the doses to the rabbit from ^{239}Pu are dominated by the uncertainty in the radioecological parameters.

One, if not the most important, step in an uncertainty analysis, is the assignment of probability distributions to the parameters and inputs used in the assessment. The probability distributions for uncertain parameters must be carefully constructed if the uncertainty estimates for the assessments are to be meaningful. In the present study, preliminary distributions were used and the results should therefore be seen as an illustration of the potential value of the approach.

5.2. Sensitivity and uncertainty analyses in the marine environment

An exposure assessment for marine flora and fauna has to cover whole processes such as dispersion of radionuclides in oceanic space, transfer of radioactivity between sea water and sediments, uptake of radionuclides by biota and, finally, dose calculations. Here, the modelling approach for environmental impact assessment described in [20] is applied to a generic marine box. The following sensitivity and uncertainty analysis was provided on the basis of the sensitivity index, $S^{(L)}$ [21]. Parameters which were chosen for sensitivity and uncertainty analysis represent different processes of dose formation:

— Water-sediment interaction represented by sediment load SSL sedimentation rate SR and sediment distribution coefficient K_d.
— Bioaccumulation is described by a concentration factor, CF.

— Doses to biota are derived using dose conversion factors for internal and external exposure DCF-I and DCF-E, and radiation weighting factors (based on RBE) for alpha and beta radiation particles/photons RBE-A and RBE-B.

Calculations were provided for following reference organisms: phytoplankton, zooplankton, macroalgae, mollusc, crustacean, pelagic fish, benthic fish, seabird and mammal. Results indicate that for ^{137}Cs reference organisms can be divided into two groups defined by habitat, i.e. pelagic and benthic organisms. Organisms from the same group exhibit similar sensitivity to changes in specific parameters. Typical results are shown in Figure 4. Sedimentation rate, sediment distribution coefficient and external dose conversion factors are most significant for molluscs, whereas concentration factor and internal dose conversion factors are most important for pelagic fish. For ^{239}Pu external doses and influence of sediment are low in comparison to ^{137}Cs. Therefore, all dose rates for reference organisms exhibit a similar response to change in parameters as exemplified by pelagic fish (Figure 5).

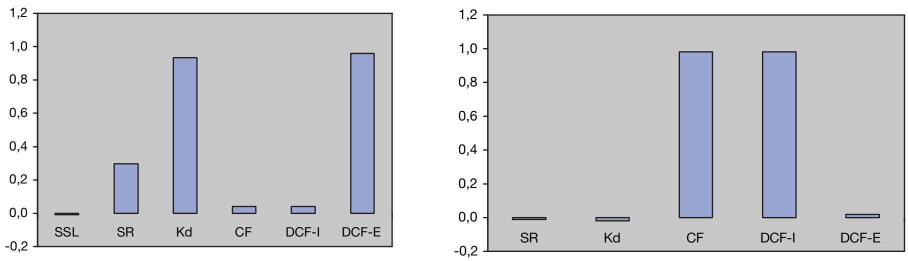


FIG. 4. Local sensitivity index for ^{137}Cs – (a) dose rate in mollusc; and (b) dose rate in pelagic fish.

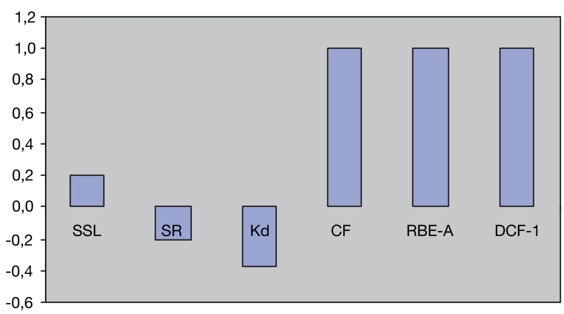
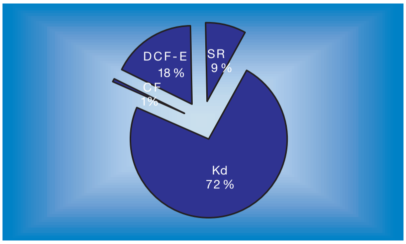
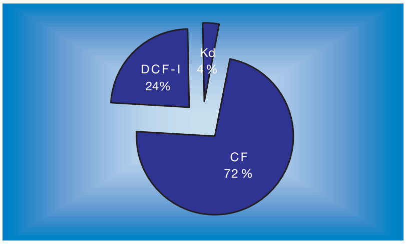


FIG. 5. Local sensitivity index for dose rate in pelagic fish from ^{239}Pu.

Results for uncertainty analysis, conducted for parameters associated with water-sediment interaction (SR and K_d), bioaccumulation of radionuclides in biota (CF) and dose calculations (DCF-I, DCF-E and RBE-A, RBE-B) are shown on Figures 6 and 7. Results of uncertainty analyses confirm the results of the sensitivity analysis about the influence of parameters for different reference organisms and radionuclides: for benthic organisms, in the case of ^{137}Cs, parameters for water-sediment interactions and external dose conversion factors are most important, whereas for pelagic organisms concentration factors and internal dose conversion factors are most significant. For ^{239}Pu concentration factors, internal dose conversion factors and alpha weighting factors are the most important parameters.



(a)



(b)

FIG. 6. Results of uncertainty analysis for dose rate in (a) mollusc, and (b) pelagic fish from ^{137}Cs.

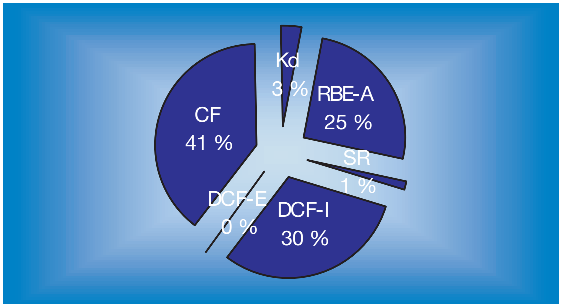


FIG. 7. Results of uncertainty analysis for dose rate in mollusc from ^{239}Pu.

6. CONCLUSIONS

The sensitivity analyses described above demonstrates the importance of several radioecological parameters that are important in relation to exposure estimates. The relative importance of the various parameters, in terms of model sensitivity and their addition of uncertainty to the assessment, is dependent on numerous factors including model structure, scenario, radionuclide and organism habitat. It is therefore not possible to draw any concrete conclusions without further detailed analyses. On the other hand, it is clear from this exercise that there are large uncertainties associated with many of the parameters that we require to perform an impact assessment. Several research themes have been discussed in the first part of this paper. In view of the numerous deficiencies identified, it seems prudent to conduct further focussed research in order to underpin the environmental impact assessment system that is currently being developed.

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THE FASSET AND EPIC PROJECTS
Development of conceptual and practical approaches to environmental assessment and protection

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Abstract

A total of 16 organizations (including regulators, research institutes and industry) in eight European countries (Finland, France, Germany, Norway, Russia, Spain, Sweden and UK) have for the past three years been collaborating in two research projects on environmental assessments and protection that are funded by the EC 5th Framework Programme. The FASSET project aimed at creating a Framework for ASSessment of Environmental impacT of ionizing radiation, and involved 15 organizations in seven countries. The EPIC project targeted Environmental Protection from Ionising Contaminants in the Arctic, and involved four organizations in three countries. Both projects concerned development of approaches and tools for assessing impact on biota and ecosystems, to support efforts to protect the environment from harmful effects of radiation. The frameworks developed under the projects make use of a generalized ecological risk assessment methodology, incorporating elements of assessment frameworks developed for other hazardous substances, e.g. genotoxic chemicals. Whereas FASSET focused on major ecosystems across Europe; three aquatic (marine, brackish, freshwater) and four terrestrial (semi-natural ecosystems including pasture, agricultural ecosystems, wetlands and forests), EPIC focused on the Arctic regions, in particular northern Russia. Both projects have made extensive surveys of the literature on biological effects, observed in laboratory and field experiments, as well as in contaminated sites affected by accidental releases of radionuclides. The survey has focused on general 'umbrella' effects that, when manifested in an individual, may have an impact at population level or at higher levels of biological hierarchy. The four effects categories are: morbidity (well-being in a general sense), mortality (death directly attributable to radiation), reproductive success (changed number of offspring) and mutations. A FASSET Radiation Effects Database (FRED), holding ca 25 000 data entries from over 1000 literature references is freely available at the project's website, www.fasset.org.

1. INTRODUCTION — OBJECTIVES OF THE FASSET AND EPIC PROJECTS

The limitations in applying the existing International Commission on Radiological Protection (ICRP) doctrine, in essence expressing that the dose limits in place for man ensure that flora and fauna are protected from the effects of ionizing radiation [1, 2], has over the last decades been increasingly challenged. The criticism has been based on several factors, inter alia:

— Whilst measures to protect man may be *protective* of the environment, direct demonstrations of *protection* due to such actions are scarce, partly because of lack of assessment methodologies and lack of agreement on proper assessment end points;
— Environmental protection is considered essential also when humans exposure is negligible, with the obvious example of environments where no humans live; and,
— The doctrine fails to address stakeholders' concerns in cases of, e.g. siting of contentious facilities.

The need for expanded or alternative approaches to radiological protection has been debated and a number of approaches have been developed [3–9], including a recent account from the ICRP itself on the ethics and conceptual basis of environmental assessments and protection [10], to provide input to the Commission's ongoing revision of its general recommendations, due 2005.

Against this background of international development, the projects "Framework for Assessment of environmental impact "FASSET"" and "Environmental Protection for Ionising Contaminants in the Arctic "EPIC"" have been financially supported by the EC. Both projects have an aim to develop a (mutually-compatible) system for the protection of the environment from ionizing radiation. FASSET adopts a generic approach with the intention of providing guidance on environmental impact assessment methodologies that are applicable within a broad geographical (primarily at a European scale but intentionally tailored for application on larger scales) and temporal context. FASSET is a collaboration between 15 organizations from seven countries.

The approach adopted in EPIC places more emphasis on "case study" whereby the practical application of a system for assessing the impacts of radiation on the environment can be tested over a limited area. EPIC is primarily concerned with the (European) Arctic region only, but draws on the methods developed by Russian scientists within a wider setting, in the process of developing their country's own basic standards and criteria to protect the environment from ionizing radiation. EPIC is a collaboration of four organizations in three countries with the main input, in terms of resources and manpower, coming from Russian scientists.

Within the general objectives of developing an assessment framework to guide decision making and support stakeholder dialogues, the projects have a number of specific objectives:

— To review existing frameworks for environmental assessment used in different environmental management or protection programmes;
— To select a reference set of critical target organisms by considering inter alia their ecological sensitivity, their intrinsic sensitivity and their ecological significance;
— To provide applicable models and databases for reference organisms that can be used to simulate the transport to and uptake by these organisms, the concomitant absorbed (or weighted) doses and relevant dose-effects relationships;
— To compile and critically examine existing dose-effects data that can be used to evaluate the potential effects (see below) of a range of exposures (low level chronic → high level acute) on wild organisms.

2. GENERAL ASPECTS ON ASSESSMENT/MANAGEMENT FRAMEWORKS

The FASSET project has reviewed a total of 20 pathway based assessment frameworks, developed within 14 organizations, in order to explore commonalities within and between systems used for radionuclides (nine in total) and other hazardous substances (11 in total), as well as to identify problems in using a common approach [11]. The aim of the exercise was to take advantage of, and integrate into the FASSET framework, aspects of existing systems dealing with environmental risks from radioactive or hazardous substances. A general conclusion was that assessment frameworks for radionuclides can and should incorporate many of the elements used in impact assessments for other hazardous substances. Two advantages with a common approach are obvious; it allows for drawing on experience gained within a large range of applications; and, it facilitates the risk communication with the public and with stakeholders in a general sense.

Furthermore, a number of issues were considered in order to define the *assessment context* of the FASSET project. A systematic approach to the formulation of the assessment context has been described by the IAEA BIOMASS project, with special emphasis on waste repositories [12–14]; a

TABLE 1. DEFINING THE FASSET ASSESSMENT CONTEXT

Factor to be considered in defining the assessment context	FASSET assessment context
Purpose of the assessment	Present an estimate of environmental impact that is as realistic as possible, while still using general or generic information, to guide decision making
Identification of source term and initial hazard analysis	Flexible in terms of sources, environmental properties, and effects of different nuclides, and to provide a means to prioritize
Identification of the spatial and temporal scale	Consider acute and chronic exposures for the relevant environment
Appropriate level of simplification	Use generalized data for seven European ecosystems (three aquatic and four terrestrial), use a set of 'reference organisms' as basis for impact analysis
Consideration object of protection	Analyse the ecological significance and characteristics of organisms towards protective measures should be directed, if not already prescribed in national legislation
Consideration of what biological effect in the environment that needs to be considered	Compile and assemble in a database information on effects of ionizing radiation on different wildlife groups, organized in four 'umbrella' categories, morbidity, mortality, reproductive success, and mutation, as a basis for estimating impact on individuals
Consideration of data availability and data requirements	Use 'realistic' data if available and extrapolate with reasonable caution when data are missing

number of those issues considered within FASSET are briefly reviewed in Table 1.

3. THE FASSET FRAMEWORK

Following the definition of the assessment context, as outlined in Table 1, the FASSET project has developed an assessment framework that starts with sources for radionuclides in the environment and delivers an estimate of effects in affected organisms through an in-built effects analysis. The framework has so far not considered risk characterization and managerial issues, which will be subject of future research and developments. The framework is outlined in Figure 1. Note that the assessment methodology used and developed in EPIC is similar; the description here will focus on FASSET but also consider a few peculiarities of the EPIC project.

3.1. Source and hazard analysis

Within frameworks of ecological risk assessment, a screening methodology is often adopted to identify the contaminants of potential concern that may require further investigation, or even to take early decisions on acceptability of an activity, intervention needs, etc. In general, the approach involves an initial analysis of the source term (quantitative and identity of hazardous substances), physical characteristics (e.g. half-life in the case of radionuclides), environmental fate (e.g. mobility, surface reactivity), and toxicity. For FASSET and EPIC a full source characterization and hazard identification were not performed before the radionuclides, for which tools are to be developed within the project, were chosen. Instead, sub-sets of radionuclides were considered, on the basis of:

— Radionuclides routinely considered in both regulatory assessments of waste disposal and releases from different facility types, and emergency planning for accidental releases;
— Existing contamination in e.g. the Arctic;
— A range of environmental mobilities and biological uptake rates;
— Both anthropogenic and natural radionuclides; and
— Representatives of α, β and γ emitters.

The sub-set of radionuclides from 20 elements was selected for consideration within the development of the FASSET framework on the basis of these criteria and also data availability [FASSET, 2001b]. The framework designed to assess these radionuclides should be sufficiently robust as to be readily applicable to the consideration of others.

3.2. Ecosystem description

Europe includes a range of ecosystems from Mediterranean systems in the south to Polar Deserts in the north. The frameworks developed under FASSET and EPIC need to be able to assess exposure of biota in potentially any of these ecosystems. In order to evaluate the radioecology of European ecosystems they have been considered in a number of broad groups:

Source and hazard	Ecosystem							Reference organism			Exposure assessment	Effects assessment
	Terrestrial				Aquatic			Biological Component	Reference geometry	Example		
	S	A	F	W	F	B	M					
Radio-nuclides of 20 elements			X					Tree	Type 1	Pine	Use the appropriate environmental concentrations, transfer factors and dose conversion factors for the assessment	Screen against the FASSET Radiation Effects Database, FRED
	X	X	X					Burrowing mammal	Type 2	Mole		
					X	X	X	Pelagic fish	Type 2	Salmon		
								Etc.	Etc	Etc.		

FIG. 1. Elements of the FASSET framework for assessment of environmental impact of ionizing radiation.

Note: S, A, F, W, F, B, and M signify the seven ecosystems considered in the FASSET project: S, semi-natural ecosystems including heathland; A, agricultural ecosystems; F, forests; W, wetland; F, freshwater ecosystems; B, brackish ecosystems; M, marine ecosystems. For reference geometries, Type 1, Type 2, etc. signify the different sizes and shapes of organisms that are further discussed in the main text.

- Forests Communities dominated by trees. The Food and Agriculture Organization of the United Nations defines forest as land with tree crown cover of more than 10%, an area of more than 0.5 ha and with trees which are able to reach a minimum in situ height of 5 m at maturity;
- Semi-natural pastures and heathlands. A broad range of ecosystems including mountain (e.g. Alpine pastures) and upland grasslands (e.g. those characteristic of many upland areas of the UK), heath and shrub lands (e.g. Mediterranean Garrigue), salt marshes and some Arctic ecosystems. These ecosystems are termed ‘semi-natural’ since, whilst they comprise natural species not introduced by man, they have been influenced by human use, for instance by the grazing of livestock.
- Agricultural ecosystems, including arable land, intensively managed pastures and areas used for fruit production.
- Wetlands. Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt.
- Fresh waters. All freshwater systems including rivers and lakes.
- Marine ecosystems.
- Brackish waters. In Europe only the non-tidal, shallow Baltic Sea; organisms are immigrants from either marine or freshwater systems.
- Arctic ecosystems.

The FASSET project has considered all but the Arctic ecosystem in some detail [15] whereas the Arctic is described in EPIC. The ecosystem descriptions have been performed in order to identify the relevant exposure pathways for biota, the potential of bioaccumulation along these pathways, and other relevant information to inform the selection of reference organisms as well as compilation of relevant transfer factors for particular environments.

3.3. Reference organisms

A special feature of the assessment frameworks developed within the projects is the focus on reference organisms. This approach is analogous to the Reference Man concept that has been adopted within radiological protection to provide a standard set of models and datasets. The projects' working definition of the reference organism is:

> "a series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects".

The approach is now widely recognized, as it allows for simplification of assessments in order to avoid them being unmanageable, facilitates comparisons, allows for pooling of data and focused future data gathering, and allows for some extrapolation (using scientific data and expert judgements to substantiate the extrapolations and assess uncertainties) to other organisms or organizational levels. It should be noted that the ICRP has set up a second Task Group on environmental protection, where one of its tasks is to provide a data base for a limited number of reference animals and plants, yet again expanding from the Reference Man concept.

The initial work on exposure in different ecosystems was concerned, in FASSET, with the identification of reference organisms from the point of view of radioecological sensitivity. The factors determining radioecological sensitivity are:

— Whether the habitat or feeding habits of the organism are likely to maximize its potential exposure to radionuclides, based on an understanding of the distribution of the different radionuclides within the ecosystem;
— Whether the organism exhibits radionuclide-specific bioconcentration which is likely to maximize internal radionuclide exposures in particular circumstances;

— Whether the position of the organism within the food chain (e.g., top predator) is such that biomagnification of radionuclides up the food chain may lead to enhanced accumulation.

Several other selection criteria including intrinsic radiosensitivity to acute radiation, distribution and amenability to research have been applied in the EPIC project [16]. Tables 2a and 2b summarize the reference organisms considered by FASSET, EPIC and the ICRP, in the latter case by permission of the ICRP Task Group chairman, Dr. Lars-Erik Holm, Sweden. Whilst FASSET considers ca 30 generic 'biological ecosystem components' as base for assessments, the EPIC project — being more 'case study oriented' — is more specific with regard to organisms.

Further information with regard to these organisms has been compiled and will be generated in future work. This refers to so-called life history data, examples of which are life cycle, reproductive pattern, size, occupancy, etc., comprising information that is vital to judgements on sensitivity, exposure situations, and dose rates and accumulated doses during different life cycle stages as well as during the entire life span.

Furthermore, certain geometric characteristics will have to be attached to the reference organisms, in order to calculate doses resulting from internal and external exposure. Table 3 gives examples of geometric characteristics for a number of reference organisms used for computing external dose rates.

3.4. Exposure analysis for various reference organisms

The projects have compiled current information on radionuclide concentrations in the ecosystems, based on unit deposition (rates). Dispersion models were not considered, as these would be the same as those used for estimates of human exposure. From FASSET outputs and an assessment of the uses to which it may be put, it is clear that there is varying completeness and relevance of available data on radionuclide intake and transfer. In particular, there are many gaps in our ability to predict transfer of many radionuclides to natural freshwater and terrestrial biota, whereas the FASSET output for agricultural ecosystems appears sufficient and our ability to predict transfer in marine ecosystems is reasonable [18].

As an example of project activities in this area, a review of available models for considering transfer of radionuclides in terrestrial Arctic ecosystems has been undertaken within EPIC. There are no models that have been specifically designed to simulate the transfer of a suite of radionuclides to various organisms within Arctic ecosystems. The ECOMARC model which has been previously used to estimate exposure of Arctic human populations

TABLE 2A. REFERENCE ORGANISMS SELECTED FOR FURTHER STUDY AND CHARACTERIZATION – TERRESTRIAL ECOSYSTEMS

Organism/ecosystem component	FASSET	EPIC	ICRP
Soil			
Soil microorganisms	X	X	Annelid
Soil invertebrates	X	X	
Plants and fungi	X		
Grasses, herbs, crops	X		
Herbaceous layer	X		
Bryophytes	X	X (+lichens)	
Grasses, herbs, crops	X	X (monocots, dicots)	Grass
Shrubs	X		
Invertebrate	X		
Herbivorous mammal	X	X	Rodent
Carnivorous mammal	X	X	
Reptile	X		
Vertebrate egg	X	X (bird)	
Amphibian	X		Frog
Bird			Duck
Insect			Bee
Mollusc			Gastropod
Canopy			
Tree	X	X (Gymnosperm)	Pine
Invertebrate	X		

considering both radiocaesium and radiostrontium in the EC-Copernicus project AVAIL [19] has been used as a basis for further development. This semi-dynamic model is an adaptation of the ECOSYS-87 agricultural food chain model [20] with the inclusion of some Arctic-specific parameters. Work has been carried out to adapt and parameterize this model so that it may be used to derive concentrations in selected reference organisms. The model has been used to predict activity concentrations of ^{137}Cs and ^{90}Sr in reindeer muscle following a single deposition of 1 Bq m^{-2} of each isotope occurring in June. Predicted ^{137}Cs and ^{90}Sr activity concentrations in reindeer muscle have subsequently been used to predict the ^{137}Cs and ^{90}Sr activity concentrations in wolves, hypothetically consuming reindeer as their sole dietary intake.

In order to estimate the external exposure, within FASSET, Monte-Carlo calculations have been made for various reference organisms, using details on

TABLE 2B. REFERENCE ORGANISMS SELECTED FOR FURTHER STUDY AND CHARACTERIZATION – AQUATIC ECOSYSTEMS

Organism/ecosystem component	FASSET	EPIC	ICRP
Sediment			
Benthic bacteria	X	X	Annelid
Benthic invertebrates	X (‘worm’)	X (e.g. *Polychaeta*)	Gastropod
Molluscs	X	x	
Crustacea	X		Daphnia
Vascular plants	X	x	Grass
Amphibians	X		Frog
Fish	X	x	Flat fish
Fish eggs	X	x	
Wading birds	X	X	Duck
Sea mammals	X		
Water column			
Phytoplankton	X	X	
Zooplankton	X	X	
Macroalgae	X	X	Brown alga
Sea mammals	X	X	Salmonid

the assumed exposure conditions, e.g. as given in Table 2. In all cases, relatively simplified geometries for the target organisms as cylinders and ellipsoids were assumed. In order to estimate the impact of the distribution of the radiation source, calculations have been made for various distributions of the radioactivity in soil. Planar sources on the top of the soil, at depths of 5 cm and 20 cm, as well as a homogeneous volume source to a depth of 50 cm have been considered. The calculations have been made for a number of monoenergetic γ-energies.

For estimating internal exposures to biota, a set of organisms, sizes and energies were defined that allow the assessment of exposures to a wide range of possible species. The most important quantity to assess internal exposures is the fraction of energy absorbed in the organism; this depends on the radiation type, the energy and the size and geometry of the reference organism.

Similar approaches have been applied within EPIC in order to derive internal and external dose conversion coefficients. On the basis of developed algorithms, a computer program DOSES3D was created. The program allows doses of external (α particles, photons) and internal exposure (α, β particles, photons) in biological objects of the any size and form to be calculated. Doses

TABLE 3. ION OF EXTERNAL EXPOSURES AS USED IN FASSET; SEE FURTHER [17]

<table>
<tr><th>Targets</th><th>Example</th><th>Shape</th><th>Length, cm</th><th>Diameter, cm</th><th>Location relative to soil surface, cm</th><th>Shielding layer, cm</th></tr>
<tr><td>Soil invertebrate</td><td>earthworm</td><td>cylinder</td><td rowspan="3">10</td><td>0,5</td><td>0, –5, –20</td><td>0</td></tr>
<tr><td rowspan="2">Small burrowing mammal</td><td>mole</td><td rowspan="2">ellipsoid</td><td>5</td><td>0, –15, –25, –35</td><td rowspan="2">0.1</td></tr>
<tr><td>mouse</td><td rowspan="2">3</td><td>0, –10, –25</td></tr>
<tr><td>Reptile</td><td>snake</td><td>cylinder</td><td>100</td><td>0, –25</td><td>0</td></tr>
<tr><td rowspan="3">Herbivorous mammal</td><td>rabbit</td><td rowspan="7">ellipsoid</td><td>30</td><td>12</td><td>0</td><td>0.1</td></tr>
<tr><td>roe deer</td><td>60</td><td>27</td><td>40</td><td rowspan="2">0.3</td></tr>
<tr><td>cattle</td><td>150</td><td>70</td><td>50</td></tr>
<tr><td rowspan="2">Carnivorous mammal</td><td>fox</td><td>30</td><td>12</td><td>30</td><td>0.1</td></tr>
<tr><td>wolf</td><td>60</td><td>27</td><td>20</td><td rowspan="3">0.3</td></tr>
<tr><td>Herbivorous bird</td><td>pigeon</td><td>10</td><td>3</td><td>300</td></tr>
<tr><td>Carnivorous bird</td><td>hawk</td><td>30</td><td>12</td><td>1000</td></tr>
</table>

can be calculated for any radionuclide although, in the present version of the program, an initial data set for 42 radionuclides is used [21].

In order to enable a comparison of exposures to biota from anthropogenic radionuclides with the background in the specific habitats of the reference organisms, data on the levels of natural radionuclides in different environmental compartment such as marine waters, freshwaters and soils have been collected. Special emphasis was placed on the radionuclides ^{238}U, ^{232}Th, ^{230}Th, ^{228}Ra, ^{226}Ra, ^{222}Rn, ^{210}Po and ^{40}K. Details of the calculations for deriving dose conversion factors and the treatment of background have been published 22], and data have been compiled in look-up Tables, available both in a FASSET report [18] and from the website (www.fasset.org).

3.5. Biological effects of ionizing radiation

Within FASSET a consensus has been reached that, although in many cases protection could be legitimately directed at the population level, this objective could be achieved by focusing on the effects in individuals, to which the great preponderance of relevant information relates, and to which protective legislation often apply. The effects of radiation exposure would, however, be examined with due recognition of their implications for the maintenance of healthy populations. This led to the definition of four umbrella categories of radiation effects in individuals that are relevant for the population [22]. These are:

— morbidity (including growth rate, effects on the immune system, and the behavioural consequences of damage to the central nervous system from radiation exposure in the developing embryo);
— mortality (including stochastic effect of somatic mutation and its possible consequence of cancer induction, as well as deterministic effects in particular tissues or organs that would change the age-dependent death rate);
— reduced reproductive success (including fertility — the production of functional gametes, and fecundity — the survival of the embryo through development to a reproductive entity separate from its parents);
— mutations (i.e. indication of mutation induction in germ and somatic cells).

It is recognized that these four categories of effect are not mutually exclusive — e.g., effects leading to changes in morbidity may result in a change in the age-dependent death rate, and an increase in mutation rate may lead to changes in reproductive success. They simply provide a convenient means of summarizing the available information in a structured way that is meaningful within the objectives of the FASSET project.

One much debated aspect of radiation effects is that of the relative biological effectiveness of radiation, and the associated weighting factors, that may be used in impact assessment on biota. Depending on assessment end points, a very large range of RBEs has been reported in the literature [22], with values up to several hundreds for alpha radiation. However, FRED identifies only 78 papers that relates to RBE. Of these, 65 papers (including 1736 observations) were judged to be relevant to FASSET. At the present and on the basis of reviewed information, FASSET does not recommend use of a single weighting factor for alpha radiation. It is suggested that a precautionary approach should be applied to weighting of alpha radiation when a sensitivity analysis indicates that this is an important factor for the outcome of the assessment. If deemed important, expert judgement will have to be applied to take effectiveness into account; some guidance and some examples can be found in the FASSET deliverables [17, 18, 22]

An ACCESS® database (The FASSET Radiation Effects Database, FRED) has been created within FASSET for the summarization of the radiation effects data from the literature [22, 23]; this allow for data to be sorted by umbrella category of effect, reference organism type, acute or chronic exposure, dose rate, total dose, and so on. The database provides a suitable means of organizing vast quantity of raw data and facilitates subsequent information extraction and synthesis during the process of critical review and report writing.

Within EPIC a database on dose-effects relationships is also being developing in Microsoft Excel, with accompanying text abstracts (Microsoft Word files with detailed description recorded effects) accessed using hyperlinks. The emphasis for this data compilation is on studies conducted in the former Soviet Union and on studies in the Russian literature to avoid substantial duplication of the work being undertaken in FASSET [24]. The database is subdivided into radiation effects on terrestrial and aquatic organisms. The database allows dose-effect relationships to be established for different end points, which correspond to those “umbrella” end points discussed above within FASSET. Reconstruction of doses or contamination levels has been performed for those studies that require it.

4. OUTLOOK

While the organization of existing knowledge into an assessment framework has clearly demonstrated that impact assessment on biota can be performed with reasonable confidence, the projects have also revealed a number of deficiencies in existing scientific support for the assessments. Thus, there are large gaps in, e.g., environmental transfer data for key radionuclides in several ecosystems, and in our knowledge on biological effects and radiosensitivity for large groups of ecologically significant organisms. Furthermore, and outside the scope of the FASSET and EPIC projects, there is a general lack of scientific knowledge underpinning an ecologically relevant risk characterization, where the impact of radionuclides can be estimated and compared to other hazards in a multicontaminant context. Also, management and decision making on the basis of environmental assessments has received relatively little attention, and environmental protection (outside human exposure pathways) from ionizing radiation has not been extensively debated in a larger stakeholder community.

Currently, and within the EC 6th Framework Programme, these issues are being addressed with the view of formulating a new research programme to fill scientific gaps and extend the framework to include risk characterization, risk management and stakeholder interaction. The overall objective is to provide and apply an integrated approach of addressing scientific, managerial and societal issues surrounding environmental effects of ionizing contamination, at a European Community level, with emphasis on biota and ecosystems. A number of specific objectives can be identified under this general objective, such as:

— To provide an assessment tool;
— To provide risk characterization methodologies for ecologically meaningful estimates of risk;
— To provide managerial guidance together with stakeholder involvement in support of the protection of the environment from ionizing radiation;
— To apply and test, in case study scenarios for different sites, the assessment frameworks.

Such programme would be well suited to provide technical input to support and substantiate the conceptual and technical developments by the ICRP and the IAEA, while also taking advantage of experiences from other frameworks, as review previously in this paper.

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RADIONUCLIDE BIOACCUMULATION PATTERNS IN MARINE ORGANISMS

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Abstract

Accurately assessing the radiation dose received by contaminated marine biota requires precise knowledge of the levels and location of the bioaccumulated radionuclides. Furthermore, understanding the factors that govern the rates of radionuclide bioaccumulation and elimination in these organisms is important for estimating transfer factors used in dose assessment models. Several examples are presented of the various ways in which radionuclides are concentrated, distributed and retained in marine tissues following uptake by different pathways. A review of the literature shows that many environmental and physiological parameters can affect bioaccumulation patterns, and that resultant tissue distributions of most radionuclides (both artificial and natural) are neither constant nor homogeneous in many marine species. These observations highlight the need to take into account such information in order to refine dose models. Suggestions are made about what information is needed to help fill the existing data gaps.

1. INTRODUCTION

Assessing the impact and effects of radiation on organisms in the environment involves a sound understanding of the physical and metabolic association of both natural and artificial radionuclides within the organism. Moreover an accurate estimation of the attendant dose rates received requires knowing the exact location and concentration of the radionuclides incorporated in a given species. Acquired concentrations of accumulated radionuclides are often transient therefore necessitating additional information on pathways of radionuclide uptake and corresponding rates of bioaccumulation and excretion. These transfer parameters of course will vary with the type of organism, the radionuclide and a wide variety of environmental and biological factors. Several in depth reviews of the subject are found in the literature [1–6], and the reader is referred to those for specific information for a given species or environmental setting. Furthermore, no attempt is made here to compile a listing of artificial radionuclide concentrations in different marine species as such levels are transient, in some cases site specific, and in most areas are changing due to radioactive decay and/or varying ambient concentrations. In this review, I highlight only various examples of radionuclide bioaccumulation patterns and trends, as well as the processes and factors affecting them, which are fundamental to assessing the doses from incorporated radionuclides. A major shortcoming of some proposed dose models has been the assumption of homogeneous radionuclide distribution throughout the organism [7]. As will be evident from the following discussion, this is rarely the case for most radionuclides.

2. ACCUMULATION FROM WATER

Radionuclide uptake from water occurs either by adsorption of the radionuclide onto the organism's surfaces, absorption in body surfaces such as cell membranes, gill and gut, or active transport across surfaces mediated by enzymatic activity. For heterotrophs an alternative mode of accumulation is via the intake and assimilation of contaminated food. The relative ability of organisms to concentrate radionuclides can be expressed as a concentration factor (CF), defined as the ratio of the amount of radionuclide per unit fresh weight of tissue to that dissolved in an equal weight of sea water. Since these ratios take into account only the radionuclide concentration in water and the organism, they give no information on the relative importance of the different uptake pathways, nor do they reflect the influence of speciation of the radionuclides in the water on bioavailability. Radionuclide concentrations in marine species are not constant but in a state of dynamic equilibrium which is the net result of both uptake and elimination processes. These dynamics are controlled by many factors such as exposure time, the physico-chemical form of the radionuclide, salinity, temperature, competitive effects with other substances, life cycle of the organism, physiology, feeding habits, etc. For this reason, concentration factors are best viewed as general ranges rather than as absolute values.

Depending on the organism and the radionuclide, concentration factors range from roughly 10^0 to 10^6 [8]. In many marine species, especially the smaller ones, radionuclides of Pb, Ru, Zr, certain lanthanides and transuranics are normally concentrated more than physiologically important nuclides such as Zn, Fe, and Co. This occurs since many of these non-essential elements are particle reactive in sea water and are more apt to sorb to surfaces, especially those of smaller organisms with high surface area to volume ratios [1, 5]. On the other hand, radionuclides which are less particle reactive and behave more conservatively in sea water such as ^{137}Cs and ^{99}Tc typically display much lower concentration factors, although exceptions have been noted. For example, some experimental studies have demonstrated very low technetium concentration factors (~10^0–10^2) in phytoplankton, bivalve molluscs and small crustacea when the organisms were exposed to 95^{m}Tc in sea water either as the pertechnetate anion (VII oxidation state) or in a reduced form (IV) [9, 10], whereas similar laboratory experiments as well as field data have indicated that lobsters and brown algae can reach Tc concentration factors as high as 10^3–10^4 and 10^5, respectively [11, 12]. Thus, despite the very conservative behaviour of ^{99}Tc in sea water, the uptake from sea water can be an important vector in certain organisms.

Phytoplankton, because of its large surface area to volume ratio, quickly takes up radionuclides and reaches extremely high concentration factors (Table 1). The biphasic process involves rapid sorption to the cell surface

TABLE 1. SELECTED RADIONUCLIDE CONCENTRATION FACTORS (NUCLIDE/G WET ANIMAL DIVIDED BY NUCLIDE/G WATER) FOR PHYTOPLANKTON AND CRUSTACEAN ZOOPLANKTON [8, 15]

Radionuclide	Phytoplankton	Microzooplankton**	Macrozooplankton+
^{60}Co	2×10^3	7×10^3	6×10^3
^{59}Fe	4×10^5	3×10^5	2×10^5
^{65}Zn	1×10^4	1×10^5	1×10^5
^{99}Tc	4×10^0	1×10^2	1×10^2
$^{239+240}$Pu	9×10^4–1×10^5	4×10^3	1×10^2
^{241}Am	2×10^4–1×10^5	4×10^3	1×10^3
^{144}Ce	9×10^4	6×10^3	—
^{106}Ru	2×10^5	3×10^4	—
^{238}U	2×10^1	3×10^1	—
^{232}Th	2×10^4	2×10^4	—
^{230}Th	8×10^3	4×10^3	—
^{228}Th	2×10^4	6×10^3	—
^{226}Ra	2×10^3	1×10^2	—
^{210}Po	7×10^4	3×10^4	1×10^4

+ Euphausiids
**Mainly copepods

followed by slower diffusion across the cell membrane and subsequent binding within the cell [13, 14]. Equilibration is generally rapid (minutes to hours) and there is evidence in the case of transuranic and other particle-reactive nuclides that uptake is a passive process [13, 14]. In general, interspecific differences in bioconcentration factors are relatively small compared to inter-radionuclide differences [14].

Despite the wide variety of different species in the zooplankton community, most data on radionuclide bioaccumulation by zooplankton relate to micro- or macrocrustaceans such as copepods and euphausiids [5, 14]. Heterotrophic zooplankton obtain elements directly from sea water and also accumulate them through their food. Direct uptake from sea water occurs both by adsorption onto body surfaces and absorption across surfaces, such as gills or gut linings. Once across the cellular boundaries radionuclides are translocated to other organs and tissues by either active or passive processes where they are stored or eventually eliminated. Uptake rates strongly depend on the nuclide, with reported equilibration times ranging from several hours to several days [16], and resultant concentration factors in zooplankton vary greatly ranging over several orders of magnitude (Table 1). As with phytoplankton, the highest concentration factors are noted for 'particle reactive' radionuclides, whereas concentration factors are typically low for the those nuclides which behave more conservatively in sea water.

Macroalgae, macroinvertebrates, and fish also absorb radionuclides from water, but the degree of relative uptake is usually much less than that of smaller organisms since the role of surface area in total accumulation is far less important in larger species. Uptake is generally non-linear and often biphasic with an initial rapid component representing surface adsorption followed by a slower rate of radionuclide bioaccumulation into internal tissues [3, 5]. The uptake rate generally decreases until a steady state is reached between the radionuclide in the water and the organism's tissues. Because in larger species internal tissues are often isolated from the surrounding sea water, equilibration times based on radionuclide absorption from water are normally much longer (days to weeks) than those observed for plankton.

The importance of the initial component of uptake depends to some extent on the surface characteristics of the organism. Hard shelled, calcareous animals may deposit much of the radionuclide in the shell during growth. Indeed, substantial concentrations of radionuclides are present in mollusc shells and exoskeletons of crustaceans and echinoderms [17–20]. Soft bodied organisms with no hard, external covering are able to equilibrate their internal tissues more rapidly. Mucus coating the surface of many of these species, including fish, is important in the initial complexing of the radionuclide and often contains relatively high radionuclide levels. When the radionuclide has diffused through the epithelium, the blood or haemolymph circulation in invertebrates is the principal vector for radionuclide transfer to the various tissues. The degree of radionuclide accumulation in these tissues depends on the chemistry of the radionuclide, the number of binding sites, retention time in a tissue, and general physiology of the organism. Often liver and kidney of invertebrates and vertebrates contain the highest concentrations of radionuclides accumulated from water, whereas muscle normally concentrates radionuclides to a much lesser extent [3, 5, 21]. An example of the distribution of alpha emitters in tissues of crabs and cuttlefish from contaminated and non-contaminated waters is shown in Table 2. The most notable feature is the order of magnitude difference in concentrations between some tissues.

The degree of radionuclide uptake from water largely depends on the physical and chemical form of the element. It has been shown that radio-iron hydroxide particles readily sorb to the surface of diatoms, a mechanism that may enhance the uptake of other particle-reactive radionuclides since metal

TABLE 2. TISSUE DISTRIBUTION OF ALPHA EMITTERS IN CUTTLEFISH AND CRABS (Bq/kg WET) ESTIMATES OF CONCENTRATION FACTORS ARE GIVEN IN PARENTHESES [4]

Tissue	Cuttlefish (*Sepia officinalis*)	Crab (*Cancer pagurus*)		
	^{210}Po Mediterranean	^{239}Pu La Hague, France	^{239}Pu Windscale, UK	^{241}Am Windscale, UK
Exoskeleton		0.083 (170)		
Gills		3.77 (7850)	104	292
Muscle	1.04	0.019 (40)	3.7	22.2
Caecae	8.51			
Hepatopancreas (entire)	707	0.071 (150)	7.4	55.5
(liver)	833			
(pancreas)	20.7			
Gonads		0.021 (40)		
Intestinal tract		0.081 (170)		
Hemolymph		0.013 (26)		
Remainder	4.44	0.014 (30)		

hydroxides are known to scavenge other elements in sea water. The response of other organisms to different chemical forms of radionuclides varies greatly for certain radionuclides. With radionuclides like ^{60}Co, the response can be varied; for example juvenile lobsters take up four times more ionic radio-cobalt than when the nuclide is complexed as cobalamine [22]. In contrast, phytoplankton and fish show a strong preference for radio-cobalamine over the ionic form of radiocobalt [23]. In the case of plutonium, differences in the uptake response to different oxidation states of the radionuclide appear to be minimal for a variety of marine organisms [17]. For fission products like radio-ruthenium and chromium, ^{106}Ru chloride complexes are far more bioavailable than the ^{106}Ru nitrosyl-nitrato forms [24], and hexavalent ^{51}Cr is taken up in preference to the trivalent ion by certain molluscs [25]. Although relatively few studies have addressed the question of exactly how chemical forms of anthropogenic radionuclides in sea water affect uptake processes, it is evident from the literature that this single factor may largely govern the initial transfer of the radionuclide from water to tissue and, hence, the eventual dose to the organism.

As a general rule, for many marine organisms the uptake of radionuclides from water is proportional to their ambient concentrations. This holds true particularly for plankton, macroalgae and certain marine invertebrates [5, 25]. On the other hand, radionuclides of several biologically essential elements (e.g., ^{65}Zn, ^{59}Fe, ^{54}Mn) may be physiologically regulated so that internal concentrations in certain species would show little variation in response to changing levels in their surroundings. This would result in concentration factors for those radionuclides being inversely related to dissolved ambient radionuclide concentrations [26].

Environmental factors also affect bioaccumulation of radionuclides from sea water, and temperature and salinity probably exert the strongest effect. Generally speaking, radionuclide uptake rates correlate positively with temperature in a variety of species; however, there are exceptions indicating that temperature has little or no effect. In the case of crustaceans that normally molt more frequently at higher temperatures, radionuclide loss with the molts leads to lower levels than those in animals exposed at lower temperatures [5]. Uptake rates and resultant concentration factors of many radionuclides in marine species generally show an inverse correlation with salinity [4]. This effect, attributed to lesser amounts of competing ions in low salinity waters and chloro-complexation of some elements, would be most noticeable in estuaries and coastal waters receiving runoff.

3. ACCUMULATION FROM FOOD

The absorption of radionuclides from ingested food takes place in the gut and accumulation in tissues depends on the assimilation efficiency and the amount retained. Once assimilated, many of the same factors mentioned above determine the fate of the residual ingested radionuclides. The radionuclides of biologically essential elements such as Zn, Fe and Mn are rapidly absorbed and assimilated into tissues of many marine species, although quantitative differences may occur in the tissue distribution compared to that following uptake from water [5]. In contrast, radionuclides of non-essential elements, or those that are particle reactive like Ru, Ce, Pu and Am, are often poorly assimilated and rapidly excreted. Exceptions to this are the high assimilation efficiencies and strong retention of Pu, Am and Tc in crabs, starfish and lobsters due to a specialized digestive metabolism [19–21]. In the case of fish, radionuclides absorbed from food generally accumulate to a high degree in the liver, with elasmobranch livers taking up more of the assimilated radionuclide than those of teleosts [3]. It is evident from the literature that radionuclide assimilation into tissues is highly dependent both on species and element. As with bioconcentration factors, assimilation efficiencies vary greatly with the physiological state of the animal, the food type, and diverse environmental conditions; hence ranges of assimilation efficiencies should be considered for any given combination of animal and radionuclide.

The degree to which the food pathway for radionuclide uptake predominates in the natural environment will depend on many parameters, in particular, the length of radionuclide exposure and food availability and density. As a general rule, for radionuclides with high assimilation efficiencies, such as those that form activation products, the food pathway will be significant. However, despite measured assimilation efficiencies ranging from 50–90% for these elements, direct absorption from water may still play a large role in obtaining equilibrium radionuclide distributions in the organism's tissues [5, 20].

The general public often holds the view that biomagnification of contaminants in aquatic organisms is a common occurrence in nature. For radionuclides, the phenomenon is rare and at present has only been demonstrated for a few radionuclides. Biomagnification of ^{137}Cs has been observed in both freshwater and marine fish food chains and is thought to result from a very high assimilation efficiency as well as the high percentage of body weight (> 50%) represented by fish muscle coupled with its high caesium concentration [3, 27, 28]. In top marine mammalian predators such as seals and porpoises, ^{137}Cs accumulates mainly in muscle and the concentration tends to increase with body weight and/or age of the predator. Nevertheless the question of biomagnification in these mammals at the top of the food chain is still unclear; for example, seals from the Irish Sea were found to contain ^{137}Cs concentrations 3–4 times higher than those in the local fish, their main source of food [29], whereas seals from the high Arctic showed little difference between their ^{137}Cs concentration factors and those in their prey [30]. More data for complete, well-defined food chains with top mammalian predators would help clarify this issue.

Although to date radiocaesium is the only anthropogenic radionuclide that has been demonstrated to biomagnify, radionuclides of certain other elements should be examined in specific food chains. For example, high assimilation and subsequent strong retention of certain activation products (e.g. ^{65}Zn, ^{60}Co, ^{110m}Ag) are known to occur in tissues of starfish [31], thus, there is potential for these radionuclides to biomagnify in echinoderms. For natural radionuclides, ^{210}Po also concentrates more in copepod zooplankton than in the phytoplankton they consume, and is believed to result from high assimilation efficiencies and very slow rates of loss in copepods [32]. Because of the high alpha dose delivered by incorporated ^{210}Po [33], the bioaccumulation and tissue distribution of this radionuclide has been studied in a variety of species [34, 35].

4. ACCUMULATION FROM SEDIMENTS

The ultimate marine sink for radionuclides is usually the sediments, and correlations between radionuclide concentrations in marine species and in the surrounding sediments demonstrate that sediments are also a source of radionuclides for benthic organisms [5]. The accumulation process occurs either by organisms ingesting contaminated sediment and organic particles therein, or by direct uptake of the radionuclide from the sediment pore water. Depending upon the source term, subsequent radionuclide bioaccumulation occurs by the same processes as described above for water and food.

In general, accumulation of radionuclides from sediments by in fauna is highly dependant upon the relative degree of binding to the sediments (i.e. Kd), but it is also a function of sediment type. For example, worms and clams exposed to Atlantic and Pacific deep sea sediments labelled with americium took up two to five times more americium from siliceous-rich Pacific sediments than from the carbonate-rich Atlantic sediments, despite the fact that the Kd values for Am in the two sediments were nearly the same. Subsequent geochemical leaching techniques indicated that in the Atlantic sediments far more of the bioavailable Am (62%) was present in a highly resistant form than that in the Pacific sediments (12%), a fact which explains the similar relative differences in bioavailability to the organisms [36]. It thus seems clear that for some radionuclides and certain organisms, the sediments can serve as an enriched source of radionuclides for benthic food chains. Nevertheless, both field and experimental data indicate that radionuclide bioavailability from contaminated sediments is typically low, with transfer factors being generally less than 1.

5. RADIONUCLIDE ELIMINATION

Regardless of the mode of bioaccumulation, the subsequent elimination of radionuclides through excretion is a competing process and acts to maintain radionuclide equilibrium within the organism. Elimination occurs by passive desorption or ion exchange, active excretion of the soluble radionuclide, and particulate loss via feces, crustacean molts and reproductive products. Following contamination by radionuclides, subsequent loss often leads to a different radionuclide distribution within the organism's tissues. Most often radionuclides are lost from the organism more slowly than they are accumulated. Loss rates are rarely constant; hence, there are biological half-times characteristic of the various individual radionuclide pools within the organism. Biological half-times vary from hours to days for plankton and from months to years for certain radionuclides of Cs, Co, Ag and transuranics in large invertebrates such as starfish and cephalopods [5, 20, 31, 37]. The important point is that following an acute contamination, radionuclide distribution in an organism's tissues will change due to variable loss from the individual tissues, and may be dependent upon the time lapsed since the initial bioaccumulation. This fact and the retention time have clear implications for calculating the dose received.

6. NATURAL RADIONUCLIDES

In the marine environment in order to assess the biological effects of artificial radiation, a sound knowledge of the total radiation dose rate regimes experienced by marine biota is an essential prerequisite. This requires precise quantitative information on the levels and distribution of key natural radionuclides in the organism so that the actual dose received from artificial radionuclide contaminants can be accurately assessed. It should be noted that whereas such measurements have been made in a great diversity of marine biota, complete data sets of natural radionuclides for a single species, or even groups of organisms, are rare or non-existent. Furthermore, less information is available on concentrations and distribution of natural radionuclides within the organism's tissues.

Based on present literature ^{40}K and ^{210}Po generally display the highest concentrations in most of the organism groups examined. With respect to incorporated radioactivity in phytoplankton, zooplankton and pelagic fish, ^{210}Po is the main source of the natural dose with ^{40}K contributing most of the remainder. The alpha-emitter ^{210}Po is of particular interest because of its non-homogeneous distribution within tissues of many marine species. For example, it is found in very high concentrations in crustacean hepatopancreas and fish viscera [33], a fact that results in extremely high doses of alpha radiation delivered to individual organs or tissues. Clearly, an expanded data base on polonium levels in marine organisms and their tissues will help refine dose estimate calculations.

7. INFORMATION GAPS AND SUGGESTED FUTURE STUDIES

To fully understand potential impacts of radioactivity on the marine ecosystem, ideally radionuclide bioaccumulation and tissue distribution data are needed for all key species (or "reference organisms") in the ecosystem. At present coverage is far from complete and several important gaps in knowledge are evident. For example radionuclide concentration data for the ubiquitous plankton pertain mainly to zooplankton with lesser amounts available for phytoplankton, and virtually no information about levels in bacterioplankton although the latter is a primary link in all marine food chains. Concerning zooplankton, present information on radionuclide bioaccumulation is largely derived from crustaceans although they are often not the only common zooplankton species. Soft-bodied or gelatinous forms such as chaetognaths, polychaetes, salps, medusae and larvaceans are other important members of the pelagic ecosystem for which comparable information is largely lacking.

Marine mammals are considered to be at or near the top of the marine food chain, however radionuclide concentration data are extremely limited for mammals when compared to other marine organisms, and we know even less about the processes that control radionuclide bioaccumulation processes in these species [8]. It is noteworthy that since marine mammals obtain their radionuclide body burden principally from food and that some mammals feed at very different levels of the food chain, radionuclide levels and tissue distributions are likely to vary considerably within any one group of mammals. Such variability might occur in some cetaceans; for example, concentrations in whalebone whales that consume plankton may differ markedly from those in carnivorous toothed whales. Given the difficulties and restrictions related to sampling marine mammals and the near impossibility of controlled experimentation with them, making use of samples obtained for other purposes would help enhance the mammalian radioactivity database.

In terms of marine heterotrophs in general, much evidence points to the overall importance of food chain transfer in the bioaccumulation of radionuclides in many species. Yet our data base on the assimilation of radionuclides from food, the subsequent tissue deposition sites, and the physiological and environmental factors that affect them is relatively sparse. Additional information on assimilation of key radionuclides affecting radiation dose will greatly help refine dose models for organisms of interest.

When considering radionuclides in the marine environment, far less effort has been put into defining the physical chemical form of the bioavailable fraction than has assessing bioaccumulation and concentration factors based on the total radionuclide concentration in water. Nevertheless, available data show the importance of the chemical and physical form of the radionuclide in determining the bioaccumulation, retention and tissue distribution in an organism, yet this information is known for only a limited number of radionuclides in very few species. This is a area clearly requiring additional study.

Calculating the impact of radiation dose received from artificial radionuclides must also consider the natural internal radiation dose. For this, knowledge of natural radionuclide concentrations, in particular ^{210}Po and ^{40}K, is required for all organisms. Augmenting the limited existing database for natural radionuclides in marine organisms and their tissues would substantially enhance models used to assess biological effects of radiation on marine organisms and ecosystems.

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ECOLOGICAL SYSTEMS — DATA REQUIREMENTS AND AVAILABILITY

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Abstract

A review of available data for the many potential radionuclide-biota combinations which may be required for environmental assessments highlights the many data gaps for terrestrial species. We review the different approaches which have been suggested to compensate for these data gaps. All the reviewed approaches have merit. However, there is a requirement for transparency in methodology and data providence which is not always present. Furthermore, there is a need to validate the various methodologies to enable their use with confidence.

1. INTRODUCTION

An essential step in being able to quantify the doses to biota is the estimation of radionuclide transfer between ecological compartments to allow the quantification of internal dose. Higley et al. [1] suggest that for most radionuclides, the most important predictor of biota dose is the method used to estimate internal tissue concentrations.

Assessment of exposure via these transfer routes may be needed for a large number of both natural and anthropogenic radionuclides for a variety of objectives including screening assessment for routine releases and application of legislation regarding the protection of habitats and species. Therefore, there are an enormous number of potential radionuclide/biota combinations for which quantification of transfer may be required and it is obviously impossible to parameterize all of these through measurement or experimentation. To reduce the scale of this task the 'reference organism' concept has been adopted [e.g. 2, 3]; reference organisms for terrestrial ecosystems are typically at trophic or biological order to kingdom level (e.g. carnivorous mammal, herbivorous bird, shrub, tree etc.). However, this still leaves a requirement for a potentially large number of radionuclide-reference organism transfer values. For instance, Strand et al. [3] consider 189 radionuclide-reference organism combinations for natural terrestrial ecosystems. A challenge in providing estimates of transfer is to devise approaches which are credible and transparent to ensure that they are acceptable to the wider community, but not overly restrictive and resource demanding for industry and regulators

In this paper, we consider available data for estimating transfer in terrestrial ecosystems (aquatic ecosystems are considered by Fowler [4] and Saxén et al. [5]). We then consider the different approaches which have been taken to accommodate the problem of the large number of radionuclide/biota combinations. We critically evaluate the various options and make recommendations on the way forward.

2. DATA AVAILABILITY

Many groups have compiled available data on transfer of radionuclides to biota [e.g. 1, 2, 6–8]. A common comment in these compendia is the lack of specific available data for the transfer of many radionuclides to wild species. For instance, Strand et al. [3] reviewed available data on the transfer of 17 radionuclides to nine reference organisms typical of semi-natural pastures/heathlands. Due to the scarcity of data, it was not possible to differentiate between the wide variety of different types of semi-natural ecosystems. For most groups, the data is dominated by Cs and Sr, although this is not always the case (Table 1). Many more data were available for plants and herbivores (mostly Cs and Sr) than for carnivores and burrowing mammals. Of the other radionuclides for which transfer values could be calculated, from the whole dataset 235 were for Pb, 132 for Ra, and less than 100 values for each for Po, Th, U, Ni, with less than 10 values for Pu and Am.

Despite the acknowledged lack of data, some compendia present comparatively comprehensive tables of transfer parameters. In such circumstances, it is essential that the derivation of recommended transfer values is adequately explained. However, in some works this is not the case with little transparency of how the numbers have been derived and relevant source references are not given.

3. APPROACHES TO ESTIMATING TRANSFER

In comparison to wild species, there is much more comprehensive data for agricultural species and therefore some authors (e.g. Ref. [6]) have relied on these data to provide missing empirical transfer parameters for wild species.

TABLE 1. SUMMARY OF AVAILABLE CONCENTRATION RATIOS (RATIO OF THE ACTIVITY CONCENTRATION IN REFERENCE ORGANISM TO THAT IN SOIL) FOR DIFFERENT REFERENCE ORGANISMS TYPICAL OF SEMI-NATURAL PASTURE/HEATHLANDS [3]

Group	No of nuclides	Number of CR values	% Cs and Sr data
Lichen and bryophytes	7	807	92
Grasses and herbs	2	869	100
Shrubs	7	777	92
Worms / detritivores	6	165	11
Mammals – herbivores[a]	9	2386	71
Mammals – carnivores	7	46	43
Mammals – burrowing	4	59	0

[a]Reindeer comprise nearly 80% of the data.

Whilst this may be acceptable it needs to be justified and data provenance should be obvious to the reader.

Copplestone et al. [7] describe a sequential approach to deriving "realistic, and conservative" transfer values for terrestrial animals and plants in the absence of data for specific species as follows:

(i) Use of available transfer values for a reference organism of similar ecology;

(ii) If the above is not available a transfer (organism:soil) value of 1 is recommended as being generally conservative for terrestrial environments. The authors acknowledge that there may be exceptions where this assumption is not conservative (e.g. some soil to biota transfers for caesium are greater than 1) but suggest that data will generally be available for some organism groups for these radionuclides on which an expert judgement can be based. The approach is not applicable to radionuclides for which the transfer is generally calculated from air concentrations (e.g. ^{3}H, ^{32}P, ^{14}C, ^{35}S);

(iii) Where transfer values cannot be attributed to organisms by these approaches, they suggest that available values for "analogue" radionuclides as recommended by the EA [9] should be used; "analogue" being defined here as the use of parameters for a well defined radionuclide being applied to assessments of those for which data is lacking. The use of analogue radionuclides may lead to highly conservative CR values being applied. For instance, ^{137}Cs transfer values were suggested for application in assessments of ^{41}Ar and ^{85}Kr [9]. Subsequently, a more realistic evaluation of these two isotopes has recommended that there is negligible transfer to biota as they are noble gases and that internal doses are not important [10].

For a number of radionuclides which have natural stable isotopes the potential exists to utilize stable element data to derive transfer parameters for radionuclides. Whilst these data have been used in approaches to estimate radionuclide transfer in aquatic systems [e.g. 11] it has been somewhat neglected in terrestrial systems. An exception to this is the approaches developed to estimate the transfer of ^{3}H and ^{14}C to wild species [e.g. 12].

A potential generic approach to estimating transfer to wild plants is to identify whether the mineral element composition of plants correlates with easily observable, or known, species characteristics. Plant mineral concentrations correlate with evolutionary (phylogenetic) and ecological attributes of plant species. Using meta-analyses and direct experimentation, phylogenetic variation in leaf concentrations have been demonstrated for radiocaesium in agricultural species [13], for several metals [14, 15] and for nutrient elements including C, Ca, K, Mg and Na [16]. The phylogenetic variation of certain pairs of elements is similar (e.g. Ca and Mg, K and Cs, Ni and Zn). The elemental concentrations of plant leaves also correlate with ecological attributes of plants, for example, fast growing annuals have higher leaf mineral contents than slower growing perennials [17]. Phylogenetic and ecological correlates of leaf mineral contents potentially provide an opportunity to estimate the soil-to-plant transfer of a large number of radionuclides to a wide range of plant species. Similar approaches have been used to identify phylogenetic influences on leaf mineral concentration in species from Central England, despite large differences in the substrate conditions within the region [18].

Higley et al. [19] suggest a kinetic-allometric approach to predicting radionuclide concentrations in animals. Allometry, or more properly biological scaling, is the consideration of the effect of size on biological variables. The dependence of a biological variable Y on a body mass M is typically characterized by allometric equations of the form:

$$Y = aM^{b} \qquad (1)$$

There are publications summarizing allometric relationships for a wide range of biological variables (e.g. Ref. [20]). Allometric relationships for the biological half-life and dietary transfer coefficient for some radionuclides have also been derived [19, 21–23]. Along with many other biological parameters most of these scale to quartile values. Higley et al. [19] suggest the use of allometric relationships including long component of radionuclide (Cs, Sr, I, Co and H) biological half-life, food intake, inhalation rate, water intake and life expectancy for use in the modelling of internal exposure of wild animals. Elsewhere, the same authors also present allometric relationships for the biological half-life of Am, Eu, Pu, Ra, Sb, Tc, Th, U, Zn and Zr [21]. The approach suggested by Higley et al. [19] was used to determine soil-biota transfer values for Arctic mammals and birds by Beresford et al. [8]. Where comparison was possible, predicted values generally compared well to the available measurements (e.g. Table 2) confirming the potential of the approach for use within the modelling of the exposure of wild animals to ionizing radiation. The obvious advantage of using such relationships is that they allow extrapolation to species for which there are no data. Allometric biological half-life relationships have also been used within dynamic source-soil-plant-animal models [3, 8]. However, some of the available allometric biological half-life relationships are based upon studies described within ICRP 30 [24] which consider only a limited number of species.

TABLE 2. COMPARISON OF ALLOMETRICALLY PREDICTED AGGREGATED TRANSFER VALUES (m^2 kg^{-1} FRESH WEIGHT) WITH OBSERVED DATA FOR ARCTIC SPECIES (ADAPTED FROM BERESFORD ET AL. [8])

Species		Radionuclide		
		Cs	Sr	U
Vole+	Predicted	2.4×10^{-2}	5.8×10^{-2}	9.9×10^{-6}
	Observed	4.5×10^{-2}	n/a	3.3×10^{-5}
Rangifer tarandus	Predicted	1.0×10^{-1}	3.6×10^{-1}	6.8×10^{-5}
	Observed	1.3×10^{-1}	4.5×10^{-2}	n/a
Fox	Predicted	9.9×10^{-2}	1.2×10^{-1}	3.7×10^{-7}
	Observed*	8.3×10^{-3}	n/a	n/a

+ *Microtus* spp., *Clethrionomys* spp. and *Eothenomys* spp. (observed data also includes *Lemmus* spp.)

* *Vulpes vulpes* and *Alopex lagopus*

n/a = not available.

MacDonald [22] derived an allometric relationship describing the transfer of caesium from feed to animal tissues (F_f, d kg^{-1}):

$$F_f = 8.89M^{-0.72} \qquad (2)$$

On the basis that MacDonald also derived an allometric relationship for the transfer of I from diet to feed with a similar exponent, Sheppard [25] hypothesized that the derivation of relationships for other radionuclides required only the estimation of the multiplicand. This hypothesis is supported by the observation that the exponent for many biological half-life relationships (including Cs, Sr, Co, U and organically bound ^{3}H) is close to 0.25; because of the relationship between F_f and biological half-life it is to be expected that if F_f scales to –0.75 then the biological half-life will scale to 0.25.

Animal dry matter intake is also one of the biological parameters which varies with mass, scaling to an exponent value of circa 0.75. By algebraic derivation, Beresford [26] suggested that there should be no effect of animal mass on the ratio between the activity concentration in body tissues and feed (for some radionuclides), as the combination of allometric relationships for either biological half-life or F_f with that for dry matter intake removes any mass dependent component from the resulting expression. Whilst not proving the hypothesis, available data reviewed for radiocaesium transfer to wild species provides some initial support [26]. If we can understand why some radionuclides scale to exponents of circa 0.25 for biological half-life and –0.75 for F_f, and conversely why some do not, we can derive generic transfer values for a given radionuclide on the basis of measurements for comparatively few species. This could perhaps be based upon the more abundant data available for farm animals, although high productivity rates of farm animals may have an impact on observed tissue to diet concentration ratios [27].

The suggestion that animal live-weight is not an important factor determining radionuclide concentrations in tissues is supported by the results from the dynamic model of radionuclide transfer to wild animals described by Strand et al. [3]. This demonstrated variation in transfer (expressed as the ratio of the activity concentration in animals to that in soil) of generally less than 100% over a range of two orders of magnitude in live-weight for all 12 radionuclides considered (including actinides). However, Higley et al. [28] observed that organism weight was the principle factor dominating radionuclide transfer from soil to animals. Clearly, there are important implications of this issue and it requires further investigation.

The adaptation of human food chain models to predict radionuclide transfer to biota has been attempted for Arctic [8] and wider European semi-natural ecosystems [3]. These have combined the soil-plant components of published models [29, 30] with allometric approaches to estimating transfer to herbivorous and carnivorous mammals. However, a current weakness of these approaches is that the soil-plant models are parameterized predominantly for agricultural systems and relatively few reference organism groups have been considered. The approaches discussed above have all been designed to provide empirical equilibrium transfer values. A potential advantage of attempting to adapt human food chain models is that they are mechanistic and allow temporal predictions during the simulation of different release scenarios. Predictions of chronic release scenarios demonstrate a potential problem in the assumption of equilibrium transfer; equilibrium assumptions tending to underestimate activity concentrations in biota compared to mechanistic predictions because of the lack of consideration of pathways such as direct deposition to plant surfaces and resuspension [3].

4. DISCUSSION

There is a lack of appropriate data to enable the assessment of the transfer of those radionuclides which need to be considered in environmental impact assessments to many terrestrial biota groups. It has been suggested that uncertainty in transfer parameters is the largest contributor to the overall uncertainty in assessments of dose to biota [31]. As discussed above, there are a number of approaches which have been developed to overcome this problem, some of which are currently being used in assessments. All of the approaches reviewed here have a logical basis. However, there is a requirement for transparency in methodology and data providence which is not always present. Furthermore, there is a need to validate the various methodologies to enable their use with confidence; consistency in terminology would also reduce potential misuse of data and/or allow their full exploitation.

Assessments may require the consideration of the protection of specific species, this raises the question as to if the reference organism concept will be adequate under site specific circumstances. As an example, Copplestone et al. [7] had to consider 81 species (from all habitat types) protected under the European Union Wild Birds and Habitats Directives at sites potentially impacted upon by radioactive substances authorizations in the UK. Terrestrial species included birds (which contributed 68% of the species), mammals (bat species and *Lutra lutra*), flying (with aquatic larval stages) and ground invertebrates, amphibians, reptiles and plants. To accommodate this diversity, any reference organism list used in such assessments needs to be comprehensive; some of those currently suggested would not be sufficient to have covered the range of required species [e.g. 3]. Furthermore, there may be a requirement to consider the ecology of a specific species to assess if default reference organism values are appropriate (e.g. would a default transfer value for a 'terrestrial bird' based predominantly on herbivorous bird data be applicable to an insectivorous species?).

There is considerable understanding of the environmental factors controlling the behaviour of some radionuclides (e.g. the influence of soil properties on radiocaesium mobility [32]). Currently, we are not taking this knowledge into account when modelling radionuclide transfer to biota. It might be argued that often these environmental factors are not allowed for in the current human food chain assessment models and therefore they would not be required in assessments for biota. Clearly, the need to include such variables will depend on their impact. It is possible that their influence may be greater for wild species than for humans, as environmental impact assessments may often be considering extremes of environment and consequently radionuclide mobility.

Uncertainty analyses of the parameters involved in radiological environmental impact assessments is now being assessed by some groups [e.g. 31]. This process will help to compare uncertainties in transfer with those in dosimetry (e.g. the value of RBE) and end point effects, and hence help to identify those areas which most require further research. However, we have many data for the transfer of some radionuclides (namely radiocaesium and, to a lesser extent, radiostrontium) and very few for others (e.g. the actinide elements and technetium). When conducting uncertainty analyses we should therefore be cautious of being overly pessimistic with regard to those radionuclides for which we have considerable data and hence observed variability, or overly optimistic with regard to those for which we have little data and hence little observed variability.

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Rapporteur's Summary 2

CONTRIBUTED PAPERS ON ENVIRONMENTAL TRANSFERS AND DOSIMETRY

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1. INTRODUCTION

This summary covers 34 contributions that were submitted as posters to the current Conference. They cover a wide range of topics. The papers included in this review focus on the following topics:

- — Evaluation of results from monitoring and screening programmes .... 5 papers
- — Experiments on the transfer of radionuclides in the environment .... 13 papers
- — Effectiveness of countermeasures .... 2 papers
- — Development of models to estimate the radionuclide transfer in the environment and/or the exposures to biota .... 6 papers
- — Derivation of dose conversion factors for biota .... 2 papers
- — Dose estimations for biota .... 6 papers

The main findings for these papers are summarized below.

2. RESULTS

2.1. Monitoring and screening programmes

The papers on monitoring covered a wide range of programmes to monitor radionuclides in the terrestrial, freshwater and marine environments. The general usefulness of screening and monitoring measurements was outlined by Yoshida et al. [1] and Andjelic et al. [2]. Examples showed that results of environmental monitoring might help to identify bio-indicators.

Styro et al. [3] monitored ^{137}Cs and ^{90}Sr in the Baltic Sea. ^{137}Cs-levels dropped by a factor of 2 in the period from 1987 to 2000, whereas the ^{90}Sr dropped only by less than a factor of 1.5. The radioactivity levels are more persistent than originally expected due to the continuous input of ^{137}Cs and ^{90}Sr with the river water.

Pryhodzka [4] monitored ^{137}Cs and ^{90}Sr in water supplies of Belarus. A pronounced seasonality was observed for ^{137}Cs and ^{90}Sr in macrophytes. It is also interesting to note that the ^{137}Cs and ^{90}Sr levels are influenced by the fluctuation of the potassium and calcium concentrations in water, which underlines the potential importance of analogous elements for the behaviour of radionuclides in the environment.

Bondarkov [5] presented results on contamination levels in the "Red Forest". ^{137}Cs and ^{90}Sr-levels were found in the range of 75–150 MBq/m^2 and 40–85 MBq/m^2, respectively. Furthermore considerable amounts of ^{154}Eu (0.5–1.1 MBq/m^2) and ^{241}Am (1–2.5 MBq/m^2) were found. The migration to deeper soil layers was slow. In general, most of the activities were still in the layer above 10 cm. Only in cases where there was evidence of burrowing animals, a larger proportion of the activities deposited was below a depth of 10 cm.

2.2. Studies on the transfer of radionuclides in the environment

Two papers reviewed root uptake of radionuclides in Asian countries. Beitollah et al. [6] measured the uptake of ^{226}Ra in a region of high radioactivity in Iran, Jalil at al. [7] investigated the uptake of ^{137}Cs in Bangladesh. In both cases, soil to plant transfer factors were determined that are very similar to those observed in temperate climates.

The foliar uptake of ^{125}I by typical Chinese vegetables is presented by Shang [8]. Contamination levels subsequent to deposition of particulate iodine were compared with the uptake of ^{125}I from soil via the roots. The results underline the high potential of foliar uptake.

Dulama et al. [9] performed uptake studies in temperate environments for caesium, cobalt, protactinium, uranium and manganese. The TF determined are within the range of the expectations.

A number of papers investigated the interaction of radionuclide speciation and uptake by plants. Ishii et al. [10] investigated the uptake of technetium by bacteria in a rice field. It was found that technetium is metabolized by bacteria both under anaerobic and aerobic condition, whereby under well aerated conditions, the metabolization is faster and more effective. The speciation of uranium in soil and the uptake was investigated by Vandenhove [11], the results underline the importance of the pH and the carbonate concentration on the uranium behaviour. Homidov [12] found that the mobility of manganese, cobalt and nickel is influenced by the pH value. Furthermore, the mobility of these elements can be considerably enhanced by the amendment of EDTA, which indicates the potential of complexing agents to accelerate the migration.

Aggregated transfer factors for ^{137}Cs and ^{90}Sr for wild animals were determined by Gaschak et al. [13]. Those data are also very useful for the derivation of allometric relationships which were presented by Beresford [14]. These relations enable the estimations of transfer parameters for animals for which no data are available by interpolation taking into body mass.

Two papers focused on the behaviour of ^{3}H and ^{14}C in the environment. Kim et al. [15] monitored levels around a Korean nuclear power plant. Pine needles were identified to be a good bio-indicator for OBT. Due to the relatively long lifetime of pine needles — in the order of 3–5 years, there is obviously enough time to accumulate OBT in amounts that are easily detectable. Galeriu et al. [16] assessed the concentrations of ^{3}H and ^{14}C in wild animals for continuous releases. For ^{14}C, a specific activity model was used, whereas for ^{3}H, HTO and OBT were distinguished. The model was adapted to different climatic conditions to estimate the impact of climate. However, only minor variations were found.

An interesting paper was submitted by Joensen [17], who derived integrated transfer factors for milk [unit: Bq a/L per Bq/m²] for the Faroe Islands from monitoring measurements performed from 1964 to 1996. For milk, values of 0.03–0.06 Bq a/L per Bq/m² were reported. It is interesting to note that the integrated transfer factor appears to decrease in proportion to the amount of rainfall. The annual amount of precipitation was between 1200 and 2300 mm at the locations studied. Under such conditions, the activity is deposited predominantly with rain. The interception of wet deposits also decreases with the amount of rainfall. The ecological half-life of ^{137}Cs in milk at different locations varied between 3 and 5 years.

One paper, by Saxén et al. [18], focused on the determination of transfer factors in the aquatic environment. Concentration factors for sea birds and a variety of aquatic biota were presented for ^{137}Cs, ^{90}Sr, $^{239/240}Pu$ and uranium. The data on the latter elements were particularly useful, since the database for such isotopes is very poor.

2.3. Work on countermeasures

Two papers reviewed agricultural countermeasures. Maskalchuk et al. [19] discussed the possibility of the application of sapropel to reduce the availability of ^{137}Cs and ^{90}Sr in soil. Sapropel is sediment that is rich in clay, in organic matter and in calcium and potassium, so it also acts as a fertilizer.

Therefore it may affect the mobility via the increase of the sorption capacity of soils as well as by the increase of analogous elements. An advantage of sapropel is its low cost, in addition to the fact that no extra machinery is needed for its application.

Putyatin [20] investigated the possibility of the use of plants to remove ^{137}Cs and ^{90}Sr from soil. However, the effectiveness of this possible measure was relatively low. For ^{137}Cs and ^{90}Sr, a maximum of 0.07 and 4% per year of the total inventory in soil could be removed with the harvested biomass. This removal rate was negligible for ^{137}Cs but maximal as to the radioactive decay for ^{90}Sr. This development clearly showed that this option cannot be regarded as an effective countermeasure. Another problem was the large amount of contaminated plant material that would have to be disposed, if this countermeasure were to be successful.

2.4. Model development

Several models were presented that were developed to estimate exposures to biota. Iospje [21] simulated the dispersion in the sea with a box model which enabled the estimation of radionuclide concentrations in marine habitats as well as in marine biota. Models that estimated exposures to both terrestrial and aquatic biota were presented by Kerekes et al. [22] and Yu et al. [23].

A model for environmental impact assessment was developed by Robles et al. [24]. It estimates the activity concentration of 34 radionuclides in nine agricultural targets, which included plants and animals. These results can be used for the exposure assessment.

The outline and features of the ECOLOGO model was presented by Avila et al. [25]. ECOLEGO provides a Mathlab toolbox that enables to model dynamic systems and to perform risk assessments. A graphical user interface can be used to set up a mathematical model from a conceptual model and an interaction matrix. Both deterministic as well as stochastic modelling are thereby enabled.

Börretzen et al. [26] developed a biokinetic model to estimate the transfer of ^{137}Cs and ^{239}Pu in marine food chains consisting of 4 trophic levels including phytoplankton, zooplankton, polar cod and the harp seal as the top predator. The transfer of plutonium to higher trophic levels was very low, whereas for caesium a pronounced accumulation in higher trophic levels was predicted, such as for cod and for harp seal.

2.5. Derivation of dose conversion factors for biota

Battle et al. [27] described the derivation of dose per unit concentration values (DPUC) that are based on the semi-empirical theory by Berger on absorption of photons and electrons, involving the deduction of simple mathematical functions for energy deposition in water by photons and electrons from point isotropic sources, taking account of the 'point isotropic specific absorbed fractions'.

Absorbed dose fractions were calculated for each individual ellipsoid using a Monte Carlo calculation, based on Berger's point specific absorbed fractions, that was repeated for different energies ranging 0.005–1.5 MeV for electrons and 0.015–3 MeV for photons to yield the fraction of energy absorbed within each ellipsoid. The following assumptions were made in the Monte Carlo calculations: a) organisms are represented as ellipsoids; b) density differences between the organism and the surrounding media are ignored; c) radionuclides are distributed uniformly through all tissues of the animal or plant; d) the resulting absorbed doses, both internal and external, are calculated as an average throughout the volume of the organism.

Sundell-Bergmann et al. [28] discussed the application of weighting factors for the different types of radiation in exposure assessments for non-human biota. Whereas an RBE-value for α radiation in the dosimetry for humans of 20 was used, it is thought that this value is not a priori applicable to biota. Weighting factors are the result of a complex interaction of the radiation type, the stage of development at which the organ or organism is exposed and the end point considered.

2.6. Dose assessment for biota

A number of papers presented dose estimations for a variety of terrestrial and aquatic biota. The results are summarized in Table 1. The exposures were given in some cases as unweighted absorbed doses, in some cases as weighted doses. When the authors gave weighted doses, most authors assumed a weighting factor for α radiation of 20.

TABLE 1. SUMMARY OF EXPOSURES ASSESSED FOR TERRESTRIAL AND AQUATIC BIOTA

Ecosystem	Location	Organism	Exposure (mGy/a)	Remark	Reference
Marine	Baltic Sea	Pelagic fish	^{137}Cs 0.28 ^{226}Ra 0.39 (α=20) Sum: 0.67		[29]
		Benthic fish	^{137}Cs 0.28 ^{226}Ra 5.1 (α=20) ^{239}Pu: 0.005 (α=20) Sum: 5.4		
Freshwater fish	Arctic	Pike	^{3}H 0.0001 ^{40}K 0.28 ^{210}Pb 0.00001 ^{210}Po 0.32 (α=20) ^{232}Th 0.12 (α=20) ^{238}U 0.16 Sum 0.88		[30]
Terrestrial	Chernobyl area	Small mammal (muscle)	^{137}Cs 24-57	^{137}Cs: 1 MBq/m²	[31]
		Small mammal (bone)	^{90}Sr 4-10	^{90}Sr: 0.4 MBq/m²	
Marine	Black Sea	Mussels	^{210}Po 0.014-1.1 (α = 1) ^{210}Po 0.28-22 (α = 20)		[32]
Marine	Generic background	Plankton, molluscs, fish, etc.	0.4-6 (unweighted)	^{40}K, ^{210}Po $^{226/228}Ra$ $^{228/230/232}Th$ ^{238}U	[33]
Fresh water	Generic background	Plankton, molluscs, fish, etc.	0.4-4 (unweighted)		
Fresh water	Finland	Perch 1987 2000	^{137}Cs 3 0.3		[34]

In the investigations considered, the unweighted natural background exposures were at their highest about 5 mGy/a — in most cases the exposure was well below this value. Weighted doses may be considerably higher depending on the weighting factor assumed. In the aquatic environment, ^{210}Po is a very important contributor to background exposure; in the terrestrial environment ^{40}K is important due to the combined external and internal exposure.

Exposures of biota in the vicinity of the Chernobyl reactor may be considerably higher. It is obvious that the exposures vary widely due to the very heterogeneous conditions. As reported in [13], exposures may be in the order of up to a few tens of mGy/a.

3. SUMMARY AND CONCLUSIONS

This report summarizes the findings of 34 papers that were submitted to this conference on the topics of “environmental transfers, uptakes, and dose assessment methodologies”. The papers covered a wide and heterogeneous range of topics. The results that are considered most important have already been summarized. The more general findings are summarized below:

- Monitoring is a necessary but not necessarily exciting task. However, if appropriately designed in terms of selection of samples and of temporal and spatial distribution, valuable results may be obtained. Especially, long term monitoring may help to deepen and to confirm scientific hypothesis.
- Some papers looked into the determination of transfer factors in arid and tropical conditions. The results were very similar to those obtained for temperate environments.
- Some studies reported on the speciation of radionuclides in soil. The results indicated that speciation was a key issue for the understanding of the behaviour of radionuclides in soil.
- Allometric relationships may be an appropriate approach in assessments to species for which no experimental data are available. More work needs to be done to fill gaps and to improve their reliability.
- For selected aquatic and terrestrial biota, background exposures were assessed. Unweighted doses did not exceed 5 mGy/a, weighted doses may have been much higher, if α-emitters were involved.
- In estimating exposures due to α-emitters, the most sensitive parameter was the weighting factor for α radiation. Many assessors apply a factor of 20, as used in dose assessments for humans. However, this factor has been

derived for stochastic effects, whereas this end point is less important in environmental dosimetry. More work is needed to find agreement on weighting factors that are appropriate for dose estimations for biota.

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Rapporteur's Summary 3

CONTRIBUTED PAPERS ON BIOLOGICAL EFFECTS AND POPULATION AND ECOSYSTEM STUDIES

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1. INTRODUCTION

In order to prepare a system for the protection of species other than the human being from the harmful effects of ionizing radiation, it is essential to gain understanding on the relevant biological end points for flora and fauna, as well as their dose response and the dose rate effects. The FASSET [1] and EPIC [2, 3] databases have identified well over one thousand references on a variety of end points in plants and animals. A number of basic experiments on radiation sensitivity of different species were carried out in the 1950s and 60s, such as those determining lethal doses for acute and protracted irradiation. Moreover, species other than human, such as mice and Drosophila, have been applied in laboratory experiments on mutagenicity and carcinogenicity. This information has been applied for the extrapolation of radiation risk from animals to humans. In fact, our understanding of the genetic effects of radiation lies almost solely on animal experiments, as there is little direct information on humans.

Based on the literature databases, it is now possible to identify knowledge gaps regarding individual species and different types of effects. On the other hand, current knowledge on the structure and function of genome and the evolutionary relationships between species, as well as modern molecular biological methods and bioinformatics could well provide new dimensions to our understanding of the effects of radiation on biota, including man as part of nature.

2. WHAT IS THE RELEVANT LEVEL OF PROTECTION?

The papers on biological effects presented in the Topical Session 3, The scientific basis for environmental radiation assessment, cover several organizational levels. In addition to the substantial reviews [1–3] that cover a wide range of species and end points, effects at the following levels were discussed:

— Radiobiological effects in cell cultures derived from animals and plants [4, 5];
— Bioindicators of radiation exposure in flora and fauna [6, 7];
— Developmental effects in exposed animals [8, 9];
— Effects on plant and animal populations in contaminated territories [10–12];
— Ecosystems [13, 14].

2.1. Are there ecological effects of ionizing radiation?

The ultimate aim of environmental protection is to protect natural populations and ecosystems. In the paper of Skarphédinsdóttir et al. [14], possible ecological effects of ionizing radiation from radionuclides were discussed and evaluated in terms of how individual level effects are translated to risks at the level of the population and higher. They concluded that the ecological effects of ionizing radiation at the level of population and above can be caused by two different mechanistic routes. Firstly, the detrimental effects of radiation on the individuals, such as increased mortality, morbidity, and decreased fertility can, depending on their magnitude have implications on population dynamics and thereby also potentially on community and ecosystem properties. Secondly, ionizing radiation may cause genetic damage, which can have effects at the population level, affecting the genetic structure and genetic diversity of populations.

2.2. Effects on individuals and populations

As the health and well-being of individuals is seen as the basis for any relevant effects on the population and ecosystem level [14], and the biota in general and fauna especially share a lot of common features with man, like DNA as the primary target for radiation effects, I consider here man as the model organism for biota and discuss the observed effects in terms of deterministic and stochastic (probabilistic) effects (Figure 1). This classification of effects has been very useful in the radiation protection of man, and could provide a holistic approach for the radiation protection of biota as well.

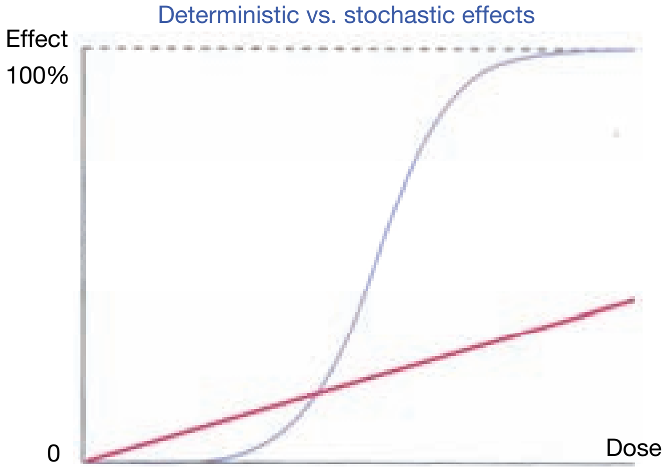

FIG. 1. Deterministic effects of ionizing radiation have a threshold and, as the dose increases, the number of individuals affected increases (the S shaped curve). The probability of stochastic effects increases with dose in a linear manner, without an apparent threshold. However, even after large doses, only a fraction of the exposed individuals will be affected.

2.2.1. Deterministic effects

The deterministic effects occur at high doses and dose rates and they are based on extensive cell killing that affect the function of organs. The deterministic effects have a threshold, below which these effects are not seen. Above the threshold, both the prevalence and severity of the effects increases. In humans, examples of deterministic effects are acute radiation sickness, reduced fertility, sterility, skin burns, lens opacity and developmental defects of irradiated foetus (central nervous system). These are most often seen after an acute dose in a radiation accident, and protraction of the dose over a prolonged period reduces the effect. Even a very large dose of the order of several sieverts may not cause deterministic effects in case it is protracted over a long period (years).

In the extended reviews on the effects of ionizing radiation [1–3], examples of deterministic effects in biota are: mortality, shortening of life span, radiation sickness, changes in blood, decrease in immunological function, sterility, reduced fertility and pathology of different organs and abnormalities in developing embryo and foetus.

In their preliminary scale for dose-effect relationships in aquatic organisms [2], Sazykina and Kryshev conclude that acute exposure of 5–10 Gy results in high mortality of fish and fish eggs, 100–200 Gy results in mortality of some zooplankton species and a decrease of biodiversity in zooplankton associations, and 200–500 Gy in total mortality of zooplankton, mortality of some phytoplankton species and stimulation of bacterioplankton. Comparable estimates were reached in the microbial test tube ecosystem of Tetrahymena, Euglena and E.coli of varying radiosensitivities, where gamma exposure of 500 Gy led to disruption of the microecosystem [13]. The computer simulation revealed that the first species that became extinct, was the most radiosensitive one (E.coli strain). This led to the extinction of Tetrahymena which used E.coli as its prey. Tetrahymena died even though it was the most radioresistant.

With protracted doses, the threshold dose rates for the first effects in the aquatic organisms [2] were at the level of 0.5–1 mGy/d, with accumulated doses above 0.05–0.2 Gy. At this level, first changes in fish blood and early signs of immunosuppression appeared. This appears to be very much the same threshold as that reported [3] for the first changes in blood of terrestrial animals (0.1–1 mGy/d after α, β exposure). In humans, the first changes in blood count (reduction in lymphocyte count) are seen after 0.5 Gy of acute low LET radiation. For effects in blood, fish and terrestrial animals seem to be more sensitive than humans.

As the reports [1–3] generally refer to the dose rate only, without giving information on the integrated (total) dose, it is difficult to make comparisons between species or with man. Further difficulties are related to types of radiation and the fact that there may be significant variation in RBEs depending on species and cell type.

As the deterministic effects do have a threshold, it is important to note that the window between no effect and a full effect may be quite narrow. This is exemplified by the experimental long term exposures of fish to low dose rate gamma or alpha radiation [9]. A gamma dose rate of 1000 μGy/h had no effect on the number of eggs laid or the viability of eggs of zebrafish, whereas exposure to a dose rate of 7400 μGy/h resulted in total failure to lay any eggs after 20 weeks.

2.2.2. Stochastic effects

Stochastic health effects are caused by mutations in the genome of individual cells. These effects appear both at high and low doses, apparently without a threshold. As the dose increases, the prevalence — but not severity — of these effects increases. The manifestation of an effect requires a clonal proliferation of cells carrying the mutations. If the mutation is in a germ cell taking part in fertilization, the mutation will be cloned to all cells of the developing individual which may lead to hereditary effects. A mutation in a somatic cell may provide the cell with growth advantage which leads to clonal proliferation and, ultimately, cancer.

Genetic effects were addressed in two papers. Gudkov et al. [12] have conducted studies on aquatic organisms in the Chernobyl NPP exclusion zone. In 1997–2000 the doses to the organisms were in the range of 1.6 mGy/a to 3.5 Gy/a. They continue to observe a variety of morphological changes in plants (bur reed) a long time after the Chernobyl accident, even though the doses have decreased considerably and in some areas are practically similar to the pre-accident situation. They conclude that the observed effects are hereditary.

Ulyanenko and Filipas [11] studied the development of resistance to pesticides in pests exposed to ionizing radiation. The sensitivity of spring grain aphid and corn thrips collected from different sites in the 30 km zone around Chernobyl to two groups of pesticide, did not show any trend in resistance in relation to the contamination. However, as these contaminated lands have not been cultivated for long periods and therefore pesticides have not been used, there has been no selective pressure towards resistance. The laboratory experiments suggested that radiation increased the tolerance of the offspring of spring grain aphids, whereas it had no effect on the resistance of the offspring of red spiders.

2.2.3. Biological indicators of radiation exposure

Somatic mutations, like chromosomal aberrations, can be used as sensitive biological indicators of radiation exposure. However, sporadic somatic mutations as such do not necessarily cause any harm to the cell or tissue function, or indicate greatly increased health risk to the individual.

Tradescantia stamen-hair assay was applied to study the effects of chronic radiation in situ at radioactive waste deposits in Brazil [6]. The radiation exposure rates ranged from 1.6 μR/min (control) to 750 μR/min. Three out of nine test sites showed slight, but statistically significant increases in the mutation rate. As the time of exposure was only 24 hours, the lowest effective dose (corresponding to an exposure rate of 33 μR/min) was just 0.47 mGy. As the control dose rate was elevated (0.96 μGy/h), the Poços de Caldas Plateau presumably is an area with exceptionally high natural background radiation.

Chromosomal aberrations have been observed in cells of several aquatic organisms, both plants and animals, in the Chernobyl NPP exclusion zone [12]. In the organisms from the most contaminated water reservoirs, the rate of chromosomal aberrations was as high as 10% during the years after the accident.

Donnik and Khaibullin [7] reported elevated levels of chromosomal aberrations (anaphase bridges) in the medulla (bone marrow) of cattle in a radon-prone area in the Urals. However, the radon concentrations in the surface air were not remarkably high (1 Bq/m^3 and 52 Bq/m^3 in control and study areas, respectively), but more or less in the range of global background for radon in outdoor surface air. Studies on chromosomal aberrations in peripheral lymphocytes of humans exposed to much higher concentrations of radon have failed to show any increase in aberration rate.

2.2.4. Stimulatory effects and adaptation

In addition to harmful effects, some of the papers also reported mild stimulatory effects of chronic irradiation at low doses, like the higher viability of seeds of the Manchurian alder [10] and the increased nervous-muscular activity of Drosophila imago after irradiation during the larval development [8]. Such effects deserve attention for several reasons. First of all, stimulation may be regarded as an adaptive response to environmental stress. Adaptation can take place either as a direct enzymatic response in the exposed individual, like proposed here by Pozolotina et al. [10]. Alternatively, in more long term, adaptation of the population could take place via genotype selection for more efficient polymorphic enzyme alleles (examples of the latter, concerning radical detoxifying enzyme alleles, have been reported for plants growing close to the Semipalatinsk nuclear test site at dose rates below 1 mGy/d).

The reported behavioural changes due to the radiation induced apoptosis in the central nervous system of developing larvae also raise concerns, even though the Drosophila scientists apply the activity test as an anti-aging indicator. Could radiation induced apoptosis during the brain development of other species be a mechanism for subtle intellectual or behavioural changes later in life, not necessarily all positive?

In the ecological context, effects that can be classified as stimulatory or positive at the individual level, increasing the fitness, may turn out to be negative for other species in the ecosystem. What is good for one, may be bad for the other. This can also be exemplified by the acquired pesticide resistance discussed by Ulyanenko and Filipas [11] — while is it very positive from the point of view of the pest, it is not desirable for the plants or the farmer.

2.3. In vitro studies

Many of the radiobiological effects that have been observed in human and mammalian cells, are relevant also for other species. Mothersill and Seymour [4] report their observations of radiation induced bystander response in explants of salmonid skin and in cultures of haematopoietic tissue from *Nephrops norvegicus*. The fact that vertebrate cells from two classes (Pisces and Mammalia) can respond to a bystander signal produced by completely unrelated species in a different phylum, point to common cellular mechanisms and evolutionary origin. The biological meaning of the bystander effect is still under investigation, but several investigators now assume that is has a role in the adaptation of cells to radiation exposure.

Also apoptosis, programmed cell death, is a ubiquitous phenomenon in higher biota, and has important roles both in radiation response and organ development. Watanabe et al. [5] describe radiation induced cell death in cultured Japanese cedar cells. This cell death has same features as apoptosis in mammalian cells. The Japanese cedar cells were also as sensitive to apoptosis as the mammalian cells.

3. CONCLUSIONS AND RECOMMENDATIONS

A variety of biological effects on biota were reported in the individual papers as well as the large literature databases collected in the FASSET and EPIC projects. Based on these reviews and the knowledge of radiation effects in man it can be concluded that man is an example of a radiation-sensitive organism, but not the most sensitive species for all biological end points.

— The fact that man is not the most sensitive organism for all biological effects casts further doubt on the prior ICRP assumption that when man is protected, the environment is also sufficiently protected.
— The systematic collection of information on effects of radiation on non-human species enables the identification of gaps in knowledge. More research is needed on the effects of low doses and low dose rates of radiation on natural biota and on hereditary effects.

A general conclusion seems to be that the relevant level of protection is the individual, and the effects on individuals are the basis for any effects on the population and ecosystem level.

— If the individual of the population is protected, the population and ecosystem is protected.

As an analogy to the radiation induced health effects in humans, the effects on biota can also be classified in deterministic and stochastic (probabilistic) effects. The deterministic effects occur at high doses and dose rates: they are based on extensive cell killing that affect the function of organs. The deterministic effects have a threshold, below which these effects are not seen. Above the threshold, both the prevalence and severity of the effects increases. Examples of deterministic effects in biota are: mortality, shortening of life span, radiation sickness, changes in blood, decrease in immunological function, sterility, reduced fertility, pathology of different organs and abnormalities in developing embryo and foetus.

— The recommendation is to protect biota from deterministic effects of ionizing radiation.

Stochastic health effects are caused by mutations in the genome of individual cells. These effects appear both at high and low doses, apparently without a threshold. As the dose increases, the prevalence — not the severity — of these effects increases. Manifestation of an effect requires a clonal proliferation of cells carrying the mutations. If the mutation is in a germ cell taking part in fertilization, the mutation will be cloned to all cells of the developing individual which may lead to hereditary effects. Most new gene mutations are harmful, some have no effect and a small proportion (perhaps less than 1/1000) may be beneficial. While it is recognized that radiation may actually increase genetic diversity of a population by introducing new mutations, the net effect is likely to negative. However, due to the non-threshold nature of genetic effects, it is not possible to prevent them totally. A mutation in a somatic cell may provide the cell with growth advantage which leads to clonal proliferation and, ultimately, cancer. In non-human species, radiation induced neoplastic diseases could lead to a shortening of lifespan by a few percentage points. However, this may not be among the end points that would jeopardize biodiversity of the population, as cancer is typically a disease encountered at old age and, unlike man of the modern society, animals in nature seldom die of old age. Moreover, cancer is not a relevant end point for plants or lower organisms.

— When deterministic effects are prevented, the large doses are avoided and stochastic effects are therefore limited to a great extent. When a safe dose rate limit for the prevention of deterministic effects has been set, the prevalence of stochastic effects at that level and below should be estimated and judgements on the additional harm to the biota assessed. This assessment requires knowledge on total dose in addition to the dose rate. If necessary, additional precaution should be introduced by further limitation of the dose rate.

Somatic mutations, like chromosomal aberrations, can be used as sensitive biological indicators of radiation exposure. However, sporadic somatic mutations as such do not necessarily cause any harm to the function of the tissue or possess a health risk to the individual.

— Somatic mutations can potentially be applied as an early indication of levels of radiation that are approaching levels that could have harmful effect on the population. Methods will need standardization.
— In vitro studies on cell cultures add information on mechanisms of radiation effects. Why are some species more sensitive or resistant than others?

The future ICRP recommendations will be built on multiples of natural background radiation. While this is not quite straightforward even for humans, it is much more complicated for the biota. The dose from the background radiation for different species and habitats varies much more than the natural background for man. Examples of extremes could be represented by a fish which is shielded from cosmic and terrestrial radiation by large volumes of water, and a burrowing animal or an earthworm in a radon-prone area, where the concentration of radon in the porous ground air may be as high as hundreds of thousands of Bq/m^3.

— A systematic review of the natural radiation background to non-human biota should be carried out.

Finally, here are some practical comments on the radiation protection system of biota.

— From the practical point of view (how to prove compliance with the recommendations), protective limits should be based on dose rate and derived radionuclide concentrations rather than dose to the organism.
— Environmental assessment of effects on all possible species in the ecosystem is not feasible. Site specific assessments should be based on reference organisms.
— Optimization for radiation protection of biota has a number of aspects that need further consideration. For example, in an accident situation the protective countermeasures aiming at decontamination of environment may introduce more harm than benefit to the biota. This may lead to a conflict with the needs of the society and the protection of man. When it comes to a choice whether to protect man or nature, man should be given

priority. This does not imply that man, while carrying out measures in order to protect nature, should not receive any dose at all.

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RADIATION WEIGHTING FACTORS FOR BIOTA

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Abstract

Dosimetry models are needed to assess the impact of environmental radioactivity on biota and to demonstrate compliance with biota radiation dose guidelines. Realistic dosimety models for biota are much less well developed compared to human dosimetry. A number of factors contribute to uncertainty in biota dosimetry, among them, organism, population relevant end point(s), the range of doses under consideration and the choice of a modifying factor for application to absorbed dose used to account for the relative effectiveness of different types of radiation. This modifying factor is alternatively referred to as radiation weighting factor, relative biological effectiveness (RBE), and ecodosimetric weighting factor among others. It remains to be decided whether this modified dose should be called "dose equivalent" or something else; also whether it should be measured in grays, sieverts, or some new unit specific to biota. Reference or guidance doses (or dose rates) for the protection of biota are generally based on exposures to X rays or gamma rays as the reference radiation. If an organism were exposed to a source radiation of a different quality, say high LET radiation, then the absorbed dose to the organism would be multiplied by a radiation weighting factor to determine if the dose guideline has been exceeded. This paper describes the basis for biota radiation weighting factors, reviews of available data, and suggests ranges of alpha radiation weighting factors for use in environmental evaluations.

1. INTRODUCTION

In the past, the prevailing view has been that if humans were adequately protected, then other living things are also likely to be sufficiently protected [1]. More recently, a caveat has been added that "individual members of non-human species might be harmed but not to the extent of endangering whole species or creating imbalance between species" [2]. Over the past several years, there has been considerable and increasing effort to develop a framework for assessing potential radiological doses to non-human biota (here after biota) (e.g. Refs [3–10]).

In 1999, the International Atomic Energy Agency (IAEA) prepared a discussion document on this topic [6] which gave impetus to the idea that it was important to specifically address the issue of whether or not biota are protected when people are protected. Amongst other national and international agencies, the International Commission on Radiological Protection (ICRP) has shown much increased interest in this subject also [7].

While the focus of this paper is the protection of biota from ionizing radiation, it is important to recognize that radiation is only one of many physical, chemical or biological stressors to which biota may be exposed and that there are no obvious reasons for there to be different sets of ethics and principles for the protection of non-human species against radiation produced by industrial activities and against similarly produced hazardous chemicals.

In order to assess the potential risks to biota from ionizing radiation, it is necessary to develop, or at least to formalize procedures to estimate "doses" to biota from radioactivity in the environment and, once having estimated the "dose", to assess the potential hazard arising from the "dose". As shown in Table 1, one element of the dose calculation is the selection of an appropriate weighting factor that can be applied to the absorbed dose from internally deposited (α) radiation such that the resulting "number" can be compared to a dose criterion based on X or γ radiation.

The selection of an appropriate weighting factor is the subject of this paper. To date, there is no firm consensus as to just what value(s) should be assigned to this weighting factor. What is agreed however is that the data are sparse, uncertainties abound, and judgement is required in selecting an appropriate weighting factor. Although similar discussions apply to discussions of relative biological effectiveness (RBE) for tritium beta particles, for reasons of size limitations, the focus of this paper is alpha particle RBE.

2. PROTECTING POPULATIONS OF BIOTA

In general terms, the ultimate objective is to protect populations of non-human biota. In order to do this, we need to establish a framework such as that illustrated in Table 1. In addition, however, we need to be able to answer the question of "just what is a significant effect?" This is a difficult question to answer for many reasons. First, the focus of existing data on individual biota, usually the more sensitive individual, derives from controlled laboratory testing. However, in the natural environment, the collective response of individuals (i.e., the response of a population) determines the response of the community as a whole. It is not necessarily evident how to relate effects on individual biota to the population. The situation is further complicated by the fact that all natural systems are inherently variable. Moreover, what level of anthropogenic stress, here above background levels of radiation and radioactivity, results in a change that can be distinguished from natural

TABLE 1. ROLE OF THE (ALPHA) RADIATION WEIGHTING FACTOR IN BIOTA PROTECTION

- The objective of protecting a population of (reference) biota;
- Selecting *population relevant end points* for the assessment;
- Estimating the dose (rate) to an *individual member* of the biota population
  - a. exposure pathways;
  - b. uptake by organisms;
  - c. non-uniform distribution among (and within) organ;
  - d. absorbed dose (rate) (whole body or by tissue/organ);
  - **e. radiation weighting factor;**
  - f. weighted dose (rate);
- Reference dose (rate)
  - g. from experiment;
  - h. from nature (variable).

variation over time and space. In addition to year-to-year variability, natural systems evolve over time as the result of succession or long term changes to the physical environment, which further complicates the separation of changes arising from anthropogenic stressors and natural causes.

A committee of the International Joint Commission (IJC), in discussing the health of an ecosystem has defined an ecosystem objective as “a desired state of the system and integrating over all aspect of the system” [11]. The committee selected the Lake Trout, “a top predator and therefore the controlling compartment of the steady-state community” within the Great Lakes as a key indicator species. Subsequently, the IJC identified the bald eagle as another ecosystem indicator and with fecundity, survival of the young and contaminant body burdens as specific measures of the species sustainability. There are many characteristics or properties that could be measured; however, in practice it is only possible to measure a subset of potential indicators of ecological significance. To be of use, such indicators (end points) need to be defined in a manner that allows assessment through measurement or prediction. Unfortunately, as noted previously, our ability to assess population-level effects directly is limited and most often it is necessary to extrapolate from observed or predicted effects in individuals to population level effects. The recent FASSET report on radiation effects in plants and animals [12] provides a succinct review of such issues. Even assuming the uncertainties in such extrapolation can be managed, it is necessary to decide at what level a population effect arising from an anthropogenic stressor becomes significant. For example, is a 5% per annum increase, or a 10% per annum increase in mortality of Lake Trout a significant effect, when the typical natural mortality is about 20% per annum [13]. A discussion of what determines ecological significance is beyond the scope of this paper; however, it is perhaps useful to note that spatial scale, temporal scale and reversibility have been put forward as a “risk topology” for addressing ecological significance [14].

In any event, the primary focus of environmental risk assessments (ERAs) is on population level effects rather than effects to individuals [3, 4, 9, 12, 15–18], recognizing however that the focus might shift to protection of individual members of endangered species, or species valued for other reasons. For protection of populations, non-stochastic population relevant end points are generally considered of greatest relevance.

3. SOME FACTORS AFFECTING RADIATION WEIGHTING FACTORS

Radiation effects on biota depend not only on absorbed dose, but also on the type or “quality” of the radiation. For example, alpha particles and neutrons can produce observable damage at much lower doses than beta or gamma radiation. Thus, the absorbed dose (in Gy) is multiplied by a modifying factor — alternatively called the relative biological effectiveness (RBE), quality factor, radiation weighting factor, ecodosimetric weighting factor — in order to account for the differences in the radiation’s effectiveness in producing biological damage. For present purposes, we refer to this factor as RBE with the understanding that we are actually referring to an ecological radiation weighting factor. At present, there is no universally accepted name for this factor in the context of dose to biota. The focus of this paper is radiation weighting factors (RBE) for alpha radiation.

The concept of RBE can be understood as the “inverse ratio of absorbed doses of different quality radiations, delivered to the same locus of interest, that produce the same degree of a given biological effect in a given organism, organ or tissue” all other factors being equal [19], namely:

$$\text{RBE} = \frac{\text{Dose of reference radiation needed to produce a given effect}}{\text{Dose of the test radiation needed to produce the same biological effect}}$$

RBE depends on many factors, among them, the type of cell or tissue irradiated, dose and dose rate, the distribution of LET or lineal energy, the end point (effect) of interest, and other factors [20]. Barendsen [21] indicates that in addition to cellular processes, RBE depends on other factors such as "*multicellular interactions, immunological, hormonal, and possibly other system factors*".

Amongst the other factors, RBE depends on Linear Energy Transfer (LET) which is the amount of energy absorbed by the target tissue per unit path length. Low LET radiations such as X rays, gamma rays or electrons of any energy have an average LET of about 3.5 keV/μm (of water) or less [19, 22]. In many systems, the RBE increases with increasing LET until the LET reaches about 100 keV/μm and then begins to decline. This phenomenon is shown for example in the impairment of regenerative capacity of cultured human cells inactivated by monoenergetic particles (e.g. Figure 4 of [23]). The peaking of the RBE at an LET of about 100 keV/μm can perhaps be explained by noting that it only requires a few tens of keV of energy to break a single stand of DNA and that a single particle with a LET of 100 keV/μm is sufficient to produce a double strand break which is prone to imperfect repair and may result in the death of the cell. Thus at LETs greater than 100 keV/μm, there is sufficient energy to ensure a double strand break in target DNA and additional energy is simply wasted.

Consider the two dose response curves show in Figure 1 for a standard reference radiation A (assumed low LET) and the radiation of interest B (assumed high LET). In this instance, we assume the reference radiation follows a linear-quadratic dose response relation of the form "Effect = $\alpha_A D + \beta_A D^2$" when D is the absorbed dose and that radiation B follows a linear dose response relation of the form "effect (E) = $\alpha_B D$".

In this instance, the RBE is defined as:

$$RBE_B = \frac{D_A(E)}{D_B(E)}$$

where $D_A(E)$ and $D_B(E)$ are the absorbed doses of radiations A and B which cause the same effect E.

It is clear from the figure that the calculated RBE depends on both the level of effect and the absorbed dose of the two radiations needed to produce that effect. In general terms, RBE increases with decreasing dose and reaches a maximum value which, following ICRP practice, is referred to as RBE_M for stochastic effects and RBE_m for deterministic effects [23]. At the origin, as the dose approaches zero, the RBE does not become infinite but is equal to the ratio of the initial slopes of the two dose response curves.

Gamma rays from ^{137}Cs or ^{60}Co and 250 kVp X rays have been used as the "standard" or "reference" radiation. In looking at the literature, it is important to understand that ^{60}Co gamma rays are less effective than 250 kVp X rays

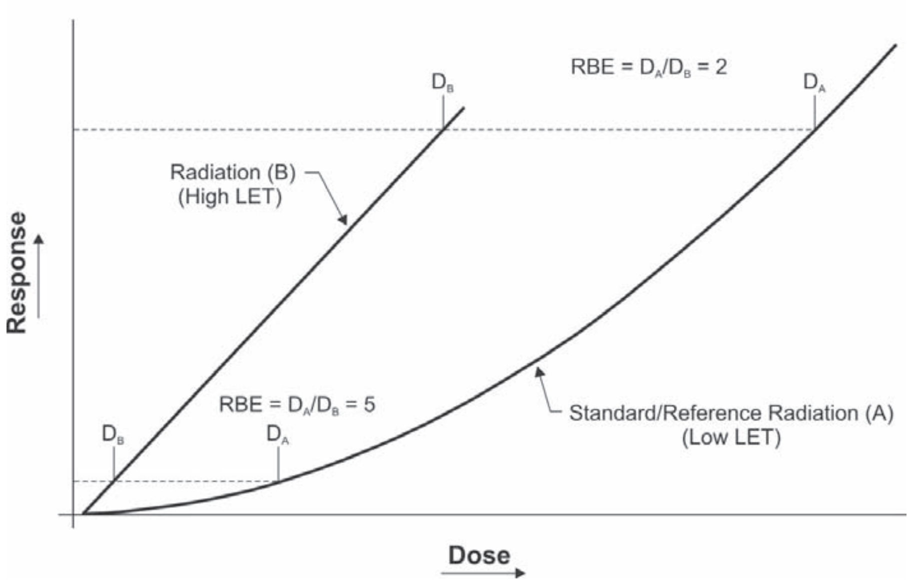

FIG. 1. Dose response and relative biological effectiveness (RBE).

including radiobiological effects. At high doses, the difference is small (RBE = 0.86 for ^{60}Co relative to X ray as the standard); however, the difference is larger at lower dose rates [24]. Overall, the difference in the relative effectiveness of ^{60}Co gamma rays and 250 kVp X rays is about a factor of 2 [22–24].

The selection of the relevant (target) tissue is also an important consideration. For example, for radiation induced bone cancer in beagles, the RBEs for bone seeking radionuclides relative to Ra-226 for ^{231}Pu, ^{225}Th, ^{228}Ra and ^{90}Sr respectively have been estimated as 6, 8, 2.5 and 0.07 to 0.24. This is explained by the different pattern of energy deposition of the radionuclides which leads to different irradiation of sensitive tissues. For alpha emitters, "surface seekers" are more toxic than "volume seekers" and β radiation is less effective than alpha radiation in inducing bone cancer [20].

Early reviews of RBE deserve some mention. For example, a 1967 report of the NCRP [19] provides extensive discussions of radiation from internal emitters, including discussions of radiobiological mammalian RBEs for somatic effects and RBE data from dose-effect curves for a variety of radiological data. In discussing these data, the NCRP notes that data for animals larger than mice are sparse and that even for a small animal, the physical dosimetry presents a severe problem. In discussing RBE, the authors of the NCRP report suggest that the increase in RBE with potential exposure reflects a relative "lack of dependence of high LET radiation on dose rate for the life shortening effects, and a relative dependence of low LET radiation on dose rates.” In commenting on radiological data for plants, mammalian organs and single cell populations, the authors comment that if “dose-effect curves for two low LET radiation are compared, or if a comparison is made with a high LET radiation for the same effect, that the RBE will vary with the degree of effect (dose) and dose rate”. Experimental curves of RBE versus LET are presented for a variety of test organisms and end points including for example T1 bacteriophage in broth, haploid yeast survival in air, *artemia* eggs hatching or emerging, various mammalian tissues, broad leaf bean root effects on growth and survival and others suggest a maximum RBE of (about) 10, at an LET of (about) 300 keV/μm for human cells in culture.

According to the ICRP, deterministic effects arise from the “collective injury to substantial numbers or relatively large proportions of cells in effected tissue” [23]. For deterministic effects, relevant to population end points, the dose-response relation for many specific end points shows a threshold below which there is either no effect or the effect is so small it is undetectable. The ICRP also indicates that RBE values for high LET radiation at doses below the threshold for deterministic effects are necessary to assess the effects of exposure to mixed high and low LET radiation. The ICRP go on to note these RBE_m can be estimated by extrapolation from information at higher doses [23]. Nevertheless, questions remain about the interpretation of RBE_m for doses below the threshold.

4. CURRENT EVALUATIONS OF ECOLOGICAL RADIATION WEIGHTING FACTOR

Several authors have reported data and evaluations of published data on RBE [3–5, 12, 15, 17, 25–29]. Nominal values from these reviews are summarized in Table 2. In considering these values, it is important to understand that data are limited; that experimental RBEs are specific to the end point studied; the biological, environmental and exposure conditions (e.g. reference radiation, dose rate, dose, etc.) and other factors. Thus, as noted in a recent FASSET report [12], it is a challenge to develop a generally valid RBE for use in environmental risk assessment. For such reasons, the ACRP [3] and FASSET [12] have proposed ranges of RBE values for such general application. Coincidentally, the ACRP and FASSET both selected an alpha RBE of 10, as a notional central value of the RBE and “in order to illustrate” the impact of RBE for an internally deposited alpha emitter in the case of FASSET.

TABLE 2. RBE FOR INTERNAL ALPHA RADIATION (RELATIVE TO LOW LET RADIATION)

Source	Nominal Value	Comment
NRCP [26]	1	Built-in conservatism in dose model
IAEA [16]	20	Keep same as for humans
Barendsen [31]	2–10	Non-stochastic effect of neutrons and heavy-ions
UNSCEAR [17]	5	Average for deterministic effects
Trivedi and Gentner [29]	10	Deterministic population relevant end points
UK Environment [15]	20	Likely to be conservative for deterministic effects
Environment Canada [5]	40	Includes studies with high RBEs
ACRP [3]	5–20 (10)	5–10 deterministic effects (cell killing, reproductive) 10–20 cancer, chromosome abnormalities 10, nominal central value
FASSET Deliverable #4 [12]	5–50 (10)	10 to illustrate effect of α RBE

It should be noted that a number of studies such as those shown in Table 3 propose to show much higher alpha RBEs. As discussed in the report of the ACRP [3], these studies are flawed, the most serious issues being the estimate of alpha radiation dose. These studies all suffer from a number of methodological flaws, the most serious being the estimate of α radiation dose. Most studies assumed that the alpha emitting radionuclides were uniformly distributed throughout the organ of interest. However, in the dose ranges reported (0.1 to 10 mGy), only a few cells will receive very high doses; the vast majority of cells receive no dose at all. This effect can distort the apparent RBE towards very high values. Consider for example, the paper by Samuels [28] which reports an estimate of dose to mice oocytes from intake of Po-210 based on the number of alpha particles absorbed by a certain volume of tissue times the 5.3 MeV energy of Po-210 alpha particles. The major source of error lies in estimating the number of alpha particles originating and being absorbed in the specific tissue being assessed. This estimate relies on the results of a radiochemical assay. Samuels assumes a uniform gross distribution of Po-210 within the ovary (as opposed to microscopic localization in follicle cells) and further assumes that all the particles are absorbed within the ovary (track length for

TABLE 3. SUMMARY OF SELECTED STUDIES WITH ALPHA RBE VALUES GREATER THAN 20[a]

RBE	Author(s)	End point	Comment
377	Samuels (1966) [28]	Cell killing in mouse oocytes	Based on single point; author urged caution, suggested only 50–100.
250–360	Jiang, Lord and Hendry [29]	Fœtal haemopoetic stem cell deficit in mice	Assumed uniform dose distribution. A repeat experiment gave 150.
245	Rao et al. [32]	Sperm head abnormalities in mice	Assumed uniform dose distribution. Poor statistics.
50–100	Brenner et al. (1991) [33]	Lens opacification in rats	For argon ions. Relevance to survival not clear.
65	Brooks et al. (1995) [34]	Micronuclei in rat lung fibroblasts	Conversion from WLM to mGy α dose was suspect.
37–60	Martin et al. (1995) [35]	Transformation of Syrian hamster embryo cells	Poor statistics

[a] In accordance with Ref. [3].

alpha particles is 37 μm). The large uncertainty in the dose estimate also reflects uncertainty in the radiochemical assay, which may be quite inaccurate at low dose rates [28].

Samuels [28] used the results from his experiments on the effects of Po-210 on mice ovaries to estimate RBE values. His estimates suggest that "in some cases the RBE for Po-210 alpha particles may be as high as 50 or more" and provides error bars on the estimates as a function of the total radiation dose. As far as can be ascertained from the paper, the error bars reflect the uncertainty in the radiochemical analysis, but not the uncertainty in the assumption of uniform Po-210 distribution in the ovary. Removing this assumption and using a heterogeneous distribution (as observed) would imply higher doses to targeted tissues (in this case the follicle cells) and therefore would imply a lower RBE.

There are also some new data entering the literature. Tracey and Thomas [30] measured the RBE of ^{210}Po alpha particles versus 250 kvp X rays in producing injury to bovine endothelial cells. Primary cultures of endothelial cells were harvested from bovine aortas. Cells were X rayed at the Saskatoon Cancer Clinic and alpha irradiated by addition of ^{210}Po citrate to the culture medium. Radiation effects on cells were measured by a number of different assays; however, all of the measured RBEs fell in the range of between 8 and 14.

In addition, Knowles [36] reports on experimental studies of groups of zebra fish which were exposed from an early age to different dose rates of γ and α radiation (^{210}Po). Among the gamma irradiated fish, only those in the highest dose rate group (7400 μGy/h) showed radiation related damage. No groups of alpha irradiated fish showed evidence of radiation induced reduction in egg production even though autoradiographs showed concentrations of ^{210}Po in testes and ovaries. Since the highest alpha dose rate (214 μGy/h) showed no effect, comparison with the γ radiation dose rate of 7400 μGy/h which caused egg production to cease, only upper limits to the RBE were calculated and were found to be in the range of <7 to <20. The authors suggest the RBEs derived from their work provide the best available estimates of RBE for fish.

5. OVERALL CONCLUSION

Based on all of the above, it seems reasonable to conclude that a nominal alpha RBE of (about) 10 would be adequate to protect biota in most cases. However, it is also clear that there is considerable uncertainty in this value and a range of from 5 to 20 (or so) might be reasonable for purposes of sensitivity analysis.

6. POSTSCRIPT

As a postscript, I feel that future evaluation would benefit from a more structured approach to evaluation of experimental data on RBE. One suggestion from an ongoing study is to “value” the literature on experimental data by asking and attempting to answer a series of questions shown below, perhaps an ecological risk assessment version of Hills postulate[1].

— What is the end point of interest?
— Are the results of the study relevant to biological end point of interest?
— Have the experimental observations been reproducible?
— How relevant are the experimental dose rates?
— Have temporal variations been adequately taken into account?
— How accurate is the experimental dosimetry?

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[1] An independent review of alpha RBE data is currently being conducted by R.V. Osborne and M.W. Davis. This review is expected to be completed by the end of 2003.

— How certain are the values obtained experimentally?
— Is the test radiation relevant to the selection of a weighting factor for alpha particle dose?

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EFFECTS OF IONIZING RADIATION ON THE INDIVIDUAL
An overview

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Abstract

Effects of ionizing radiation on non-human biota can be measured at several levels, from DNA to cell, tissue, organ, individual, population, and up to ecosystem, if doses (or dose rates) are high enough. Scientific literature also shows that for non-human species knowledge decreases, with increasing uncertainty, as you move from measurements of effects on DNA to ecosystem. This paper provides an overview of the research that has been undertaken on the effects of ionizing radiation on the sub-individual and individual levels. It will show the vast range of effect studies that exist for a wide range of non-human species. However, whilst there is a lot of information, there are problems with data gaps for wildlife groups and a number of studies are not directly applicable for the purposes of regulation in an environmental context. The paper concludes that describing the effects of ionizing radiation on the individual is suitable for the purpose of regulation in environmental protection.

1. INTRODUCTION

Radiation transfers energy by its interactions with the electrons of irradiated biomolecules resulting, potentially, in damage to tissues, organs or whole-body. In the course of these interactions, the atomic structure of the molecules may be disrupted due to excitations (the transition of orbital electrons to higher energy levels in the atoms) or ionization (the separation of orbital electrons from the parent atoms). The timescales differ greatly between the initial excitation and ionization events, and the final expression of the induced biological damage. High linear energy transfer (LET) radiation is more effective than low LET radiation in inducing complex damage in DNA and chromatin. Clusters of DNA damage present an increased challenge to the repair processes operating in the cell, and have been postulated to be largely responsible for the difference in biological effectiveness of different radiation qualities [1].

The influence of radiation quality on biological systems is quantified in terms of Relative Biological Effectiveness (RBE). The RBE for a specific type of radiation, R, is defined as:

$$\mathrm{RBE(R)} = \frac{\text{Dose of reference radiation required to produce a given biological response}}{\text{Dose of radiation R required to produce an equal response}}$$

where the reference radiation may be 250 kVp X rays, or ^{137}Cs or ^{60}Co γ rays.

The total dose received by an organism is the sum of internal and external exposures to ionizing radiation [2]. Organisms may be internally and externally exposed to differing extents dependent upon contamination scenarios. The exposure received by an organism is dependent on how radionuclides are distributed within an ecosystem and how a species may interact with different parts of that ecosystem. The internal exposure of biota is proportional to the concentration of the radionuclide inside the organism, which is related to, among other factors, the availability of the radionuclides for biological uptake (bioavailability) and the capacity of the organisms to concentrate radionuclides with respect to the surrounding media or their foodstuffs (bioaccumulation).

2. EFFECTS AT THE SUB-INDIVIDUAL LEVEL

Regardless of the source, and the exposures to differing types of radiation, the initial effect of ionizing radiation on all biota will primarily be on DNA. The major types of DNA damage, induced by radiation, are single- and double-strand breaks (SSB and DSB), base damage, and strand cross-links. The type and degree of damaged DNA can influence the development of, variously, the cell, tissue, organ, and potentially the survival of the individual.

Complex damage in DNA occurs as a result of clusters of ionization events; these include not only prompt double strand breaks, but also clusters of non-DSB damage such as multiple single strand breaks of varying complexity, or multiple base lesions. It has been demonstrated that the clustering of damage can arise from the passage of a single ionizing particle and, therefore, may occur at any dose with no possibility for a dose threshold effect.

2.1. Aberrations

At the molecular level, many different types of chromosomal aberrations are produced after irradiation; some are lethal to the cells and others are not. Dicentrics represent an asymmetrical exchange between two separate, broken chromosomes. The resulting chromosome contains two centromeres. One or two acentric chromosome fragments remain after the formation of the dicentric, and these may develop into micronuclei. Cells having dicentric chromosomes and micronuclei are non-viable and will die at a subsequent mitosis due to the presence of unbalanced gene complements in the two daughter cells. The scoring of dicentrics or micronuclei represent the most commonly used methods for biological radiation dosimetry.

Deletions and translocations are examples of symmetrical exchanges found after irradiation. The formation of translocations involve breaks in two different chromosomes and the two fragments generated by the breaks are exchanged between the two chromosomes. Each translocated chromosome retains a single centromere and cells carrying translocations will survive and potentially, if they occur in germ cells, transfer the aberrations to subsequent cell generations. In the case of deletions, radiation produces two breaks in the same arm of a chromosome. When the ends of the chromosome rejoin, the intervening fragment between the two breaks may be omitted from the repair, and then be lost in a subsequent mitosis. Cells having symmetrical translocations and small deletions may persist for many years after the original exposure and can be also used in bio-dosimetry (biomarkers).

2.2. Mutations

Mutations comprise a mixture of rearrangements from point mutations, e.g. base changes, to large deletions or insertions. This may result in either the alteration or loss of information but most chromosomes and genes are present in two copies, except in the case of the non-homologous sex chromosomes, e.g. the X- and Y-chromosomes in male mammals. Radiation may induce small point mutations, e.g. single base changes, but it seems that the majority of radiation induced mutations entail rather large genetic changes. The tolerance of genetic change may vary between different regions of the genome, and consequent cell lethality will limit both the frequency and the apparent size of induced mutations. The induction of mutations per unit absorbed dose of low LET radiation is reduced when the dose rate is decreased below ~6×10^3 μGy/h [3], a situation applying to all environments contaminated by authorized discharges of radionuclides [4].

In terms of their possible consequences, somatic mutations have to be distinguished from those induced in germ cells. Somatic mutations may contribute to cancer induction and, hence, influence the survival of individuals in the present generation. Mutations in germ cells may be transmitted to the offspring and thereby enter the gene pool of the species concerned (genetic load); these inherited mutations may affect the fitness (survival potential) of individual descendants. For non-human organisms there is usually a strong natural selection pressure against individuals deviating from the phenotypic norm (i.e. those less fit or well adapted); this, coupled with a reproductive surplus (often large), results in the rapid disappearance of detrimental mutations. Only when mutations confer a selective advantage with respect to a particular environmental state will they spread in the population. They may speed up adaptation and microevolution in such situations or facilitate the development of resistance to certain genotoxic agents.

A large fraction of the genome consists of non-coding DNA sequences that are, to a large extent, of a repetitive nature. Some of these multi-copy sequences are found in tandem repeat arrays such as mini- or micro-satellite loci. Minisatellites show a high germline mutation rate and various studies have indicated that mini- (or micro-) satellites may serve as hypersensitive biomarkers for germ line mutations after irradiation.

2.3. Cell deaths

DNA damage results in response mechanisms, which include the processes of DNA repair, cell cycle checkpoint arrest and apoptosis. The latter two processes serve to prevent the proliferation of damaged cells that have failed to undergo successful repair.

Two recognizable modes of cell mortality are apoptosis (programmed cell death) and mitotic death. Apoptosis has been recognized as an important element in the regulation of organ development and tissue maintenance, and to restrict growth in many normal cells (e.g. erythroblasts) and tissues. It is believed that the balance between cell proliferation and apoptosis is crucial to the correct development of organisms. The apoptotic process is genetically controlled and the resulting death of the cell follows a characteristic sequence of morphologic events. Radiation induced apoptosis appears to be different from the normal apoptosis through the involvement of different signalling pathways and differs between different types of cells. There are findings to indicate that apoptosis is independent of both dose rate and LET. Mitotic death means that cells die at cell division due to chromosome damage (see above). This mode of death is most common after irradiation and there seems to be a close quantitative relationship between mitotic death and the induction of dicentrics (non-transmissible chromosomal aberrations).

2.4. Other less targeted effects at cell level

It has become increasingly apparent that radiation, besides causing aberrations, mutations or inactivation of cells, can also induce less targeted effects such as genomic instability and bystander effects. Genomic instability appears in the progeny of cells (cell clones) that had previously appeared to have survived the radiation dose unharmed. Many cell studies, mostly of cell cultures (i.e. in vitro), have demonstrated the effect but the underlying mechanisms are not fully understood. The dose responses commonly appear to consist of a rapid rise at low doses followed by an extended plateau, and high LET (Linear Energy Transfer) radiation seems to be more effective than low LET radiation. Nevertheless, not enough is known about the effects in vivo that might lead to implications for radiation protection.

A bystander effect refers to the detection of responses in cells that have not been directly hit by radiation. Numerous in vitro cell culture studies have demonstrated this effect for a variety of biological end points such as cell survival, mutation, cell transformation, apoptosis, gene expression and induced genomic instability. The effect has been observed after very low, acute doses and there is evidence to indicate that the effects after high and low LET radiation may result from different mechanisms. Experiments using medium transfer from irradiated to un-irradiated cells have indicated that cell-cell contact is not required to produce the effects after γ ray and microbeam α particle irradiation. In contrast, other studies using α particle radiation have indicated that the gap junction-mediated transfer of biochemical signals between cells is a prerequisite for generating the effect. The confirmed existence of radiation induced bystander responses in vivo would be likely to have profound implications for extrapolation issues. As both genomic instability and bystander effects have only been observed directly in cell culture, there is still needed research to establish and observe on how their influence may be distinguished in whole organisms.

Pre-exposure of cells with a low radiation dose has been shown to modify the response to a subsequent larger (challenge) dose. This mechanism, called the adaptive response, has been observed in numerous experiments on different cell types using low LET radiation. It has been suggested that a low incidence of DNA breaks will act as a trigger for a response mechanism leading to accelerated repair of damage. The response is not universal, however, and some cells do not show an adaptive response. There appears to be a minimum dose rate for its induction at low doses of low LET radiation, and high LET radiation does not seem to stimulate any adaptive response in cells. Irradiation of whole animals (mice) has produced convincing evidence for the existence of an adaptive response after low LET irradiation in vivo. For example, exposure of mice in utero at low dose rates of low LET radiation resulted in a significantly lower yield of chromosome aberrations in males after birth. Other studies have shown increased radioresistance in germ cells in mice following irradiation but the response did not have any influence on the offspring.

3. EFFECTS AT THE INDIVIDUAL LEVEL

A radiobiological end point has been defined as a consequence of the absorption of radiation that has relevance for the health of the individual organism and may have implications for the population. There are a large number of end points that have been used to describe radiation impact and construct dose/response relationships. Many of the earlier studies have been on the determination of LD_{50} values for comparative radiosensitivity purposes i.e., acute radiation exposures (usually in 10s of seconds or at most a few minutes) were employed to determine the resultant short term mortality (again, usually within 30 days). It is important to note, however, that the often used 30 day period for assessing the mortality is not relevant to all organisms due to the influence of metabolic rate — 30 days is appropriate for most mammals, but a longer period is probably necessary for poikilotherms. Experimental studies on the effects of low dose rate, chronic radiation exposure have provided data not only on mortality (frequently, a relatively minor effect), but also on such end points as fertility, fecundity (or their combination as total reproductive performance), growth rate, somatic and germ cell mutation rates, and so on. As a result, FASSET grouped these observations into four umbrella end points [5].

— **Morbidity** describes loss of functional capacities generally manifested as reduced fitness, which may render the organisms less competitive and more susceptible to other stressors, thus reducing the life span.
— **Mortality** includes the stochastic effect of somatic mutation and its possible consequence of cancer induction as well as deterministic damage in particular tissues or organs that might influence the age-dependent death rate.
— **Reproductive capacity** describes any effect that would reduce the number of offspring, including fertility (the production of functional gametes) and fecundity (the survival of the embryo through development to an entity separate from, and independent of, its parents).
— **Mutation** relates to the whole range of DNA damage (see above), and the induction of which, in somatic and germ cells, is of potential consequence for the affected generation and its offspring.

It is recognized that these four categories of effect are not mutually exclusive, e.g., effects leading to changes in morbidity may simply result in a change in the age-dependent death rate, and an increase in mutation rate may lead to changes in reproductive success. However, they provide a convenient means of summarizing the available information in a structured way that is meaningful within the objectives of the FASSET project. This resulted in the production of the FASSET Radiation Effects Database (FRED) that represents the beginning of a summary of the available research results on the effects of radiation on a wide range of wildlife groups.

A list of experimental observations studied under each end point is shown in Table 1 [6, 7]. This means that a number of specific effects may contribute to each group of effect, but also that some specific effects may be included in more than one effect group. For example, mutations, such as those that might initiate benign tumours, are unlikely to reduce the success of an organism other than by creating physical abnormalities that impede movement or reduce the organism's chances of being successful during courtship. However, mutations that occur in gonads, particularly in germ cells, may have profound effects on the reproductive success of individuals and their offspring.

The assessment of mortality as an umbrella end point is generally restricted to studies of acute toxicity. Chronic exposures to radiation at dose rates relevant to authorized disposal situations ($<\sim 100\ \mu$Gy/h) are highly unlikely to result in significant increases in death rate. Mortality is therefore only likely to apply as an end point in the wild under accident conditions

TABLE 1. SPECIFIC MEASUREMENTS RECORDED IN STUDIES ON THE EFFECTS OF CONTAMINANTS ON A RANGE OF WILDLIFE [6]

Morbidity	Biomass (shoot, root, plant) *tp;* immunocompetence *f, m;* vertebral abnormalities *f;* shell length and deposition *mc;* plant height *tp;* leaf length *tp;* number of leaves per plant *tp;* photosynthetic rate *tp;* tumour development m; weight decrease a, aqi, aqp, c, f, i, m, mc, r, sf, tp; change in biochemical parameters (e.g. hormone changes) *m;* soil respiration *sf*; percentage of substrate used *sf;* histo-pathological changes *aqi, b, c, f, m, mc, r, sf;* visual detrimental effects *a, aqi, aqp, b, c, f, I, m, mc, r, sf, tp*
Mortality	Survival rates *a, aqi, aqp, b, c, f, I, m, mc, r, sf, tp*; life span reduction *a, aqi, aqp, b, c, f, I, m, mc, r, sf, t*
Reproductive capacity	Seedling emergence *tp;* changes in sex hormones *f, m;* number of dead offspring per litter *m;* visual detrimental effects *a, aqi, aqp, b, c, f, i, m, mc, r, sf, tp;* seedling growth *tp;* seed productivity per cone or per plant *tp;* pollen viability *tp;* pollen tube growth *tp;* length of inflorescence *tp;* nesting success *b;* hatchability success *b, f, i, mc, sf;* number of oocytes *b, f, m;* number of spermatogonia b, m; average number of eggs laid *aqi, b, f, i, mc;* defective sperm *m;* mean litter sizes *m;* morphological and histopathological changes of gametes and gonads *m, r;* fertilization success *f;* altered reproduction rates *aqi, c, sf*
Mutation	Seedling emergence *tp*; sister chromatid exchange *aqi, m;* comet assay *a, c, f, m, mc;* visual detrimental effects *a, aqi, aqp, b, c, f, i, m, mc, r, sf, tp;* mitotic index *tp;* chlorophyll mutation frequency *tp;* production of stress proteins *sf, m;* frequency of chromosome aberrations *a, aqi, aqp, b, c, f, i, m mc, r, sf, tp;* frequency of cell aberrations *a, aqi, aqp, b, c, f, i, m, mc, r, sf, tp*

Key: a = amphibians; aqi = aquatic invertebrates; aqp = aquatic plants; b = birds; c = crustaceans; f = fish; i = insects; m = mammals; mc = molluscs; r = reptile; sf = soil fauna; tp = terrestrial plants.

resulting in acute exposures to radiation (>~5 Gy), or more extended exposures at high dose rates (>10 000 μGy/h).

It is important to assess reproduction as an end point when investigating the impacts of ionizing radiation on non-human biota because successful environmental protection requires the maintenance of ecosystem function. This is inherently linked to the success of organisms, at a population level, that occupy the different niches within that ecosystem. Therefore, any reduction in reproductive success or fitness that is passed on to the progeny as a result of genetic mutation in the germ cells may be an important effect in terms of ensuring the long term survival of a population and, therefore, in maintaining ecosystem function.

From the foregoing, it may be reasonably concluded that the initial damage to organisms from ionizing radiation is independent of species, i.e. a large part of the initial damage is to the DNA as organized into genes and chromosomes. The consequence of this initial damage is, however, modified by the extra-chromosomal, but genetically determined, complexity of the biochemical machinery of the cells (including the number and efficiency of DNA repair mechanisms, and the efficiency of the mechanisms for eliminating (e.g. apoptosis) and/or replacing, damaged cells). All of these factors are likely to vary between species, and between life cycle stages within species, leading to the observed variations in radiosensitivity of different species.

4. RESEARCH ON EFFECTS OF IONIZING RADIATION ON NON-HUMAN SPECIES

FRED shows that publications are heavily weighted (2:1) towards acute data, as compared with low chronic exposure regimes [8]. For the acute exposures, and across all organisms, the effects on reproductive capacity have been most commonly studied. For chronic exposure regimes, morbidity has been the most commonly studied end point, closely followed by reproductive capacity and then to a lesser degree by mutation and mortality.

Table 2 provides an overall summary of the availability of data relating to chronic exposure conditions, i.e. those that are most relevant to environments contaminated by authorized releases of radionuclides. The table shows that there are no, or very few, data from which relevant conclusions can be drawn for many wildlife groups and umbrella end points. In addition, experimental data tend to relate most often to dose rates above 10^3 μGy/h, i.e. at levels that are only very occasionally approached in environments contaminated by authorized waste management practices, for which dose rates are generally less than ~10^2 μGy/h [4]. Although the publications frequently give graphical dose rate/response relationships (or the corresponding data in tabular form), these are for so many different species, and for particular end points that it is difficult to provide a concise general summary.

To illustrate the limited and varied type of research amongst non-human species, effects of different dose rates of chronic ionizing radiation on soil fauna and insects are summarized in Table 3. Data on soil fauna are mainly from field experiments, where soil activity has been increased artificially or due to a nuclear accident (e.g. [9]). Reduced numbers of earthworms were observed after a dose rate of 100 μGy/h of alpha radiation (^{226}Ra) and increased chromosomal damage occurred in scorpions exposed to gamma radiation in this low dose rate range.

TABLE 2. OVERALL SUMMARY FOR CHRONIC EFFECTS DATA FOR THE WILDLIFE GROUPS, BASED ON THE FASSET RADIATION EFFECTS DATABASE (FRED) [8]

Wildlife group	Morbidity	Mortality	Reproductive capacity	Mutation
Amphibians	Too few data to draw conclusions.	No data available.	No data available.	Too few data to draw conclusions.
Aquatic invertebrates	No data below 10^3 μGy/h. No effects on worm growth at 1.7×10^3 μGy/h. Limited data to draw conclusions.	Dose rate dependent effect on worm survival above 1.7×10^3 μGy/h. Too few data to draw conclusions.	Too few data to draw conclusions. Out of five references, only one listed two LOEDR* for dose rate >10^4 μGy/h, and an HNEDR# of 190 μGy/h for *Neanthes arenaceodentata*.	Too few data to draw conclusions.
Aquatic plants	Too few data to draw conclusions.	Too few data to draw conclusions.	No data available.	No data available.
Bacteria	Too few data to draw conclusions.	No data available.	No data available.	No data available.
Birds	No data available.	No data available.	Only six references were recorded, with data on a wide range of dose rates. Conclusive dose effects relationships could be drawn for chicken for dose rates >10^4 μGy/h.	Too few data to draw conclusions.
Crustaceans	No data for low chronic exposures. Only three references were recorded, with all dose rates >10^4 μGy/h.	No data on low chronic exposures. Only three references were recorded, with all dose rates >10^4 μGy/h.	No data for low chronic exposures. Only three references were recorded, with all dose rates >10^4 μGy/h.	No data available.

TABLE 2. OVERALL SUMMARY FOR CHRONIC EFFECTS DATA FOR THE WILDLIFE GROUPS, BASED ON THE FASSET RADIATION EFFECTS DATABASE (FRED) [8] (cont.)

Wildlife group	Morbidity	Mortality	Reproductive capacity	Mutation
Fish	One experiment, but not another, indicates effects on immune system at <8.3 μGy/h	Too few data to draw conclusions.	One study showing effects on gametogenesis at 230 μGy/h. Otherwise effects at $>10^3$ μGy/h.	Radiation exposure increases the mutation rate.
Fungi	Too few data to draw conclusions.	No data available.	No data available.	No data available.
Insects	Only seven references were reported with no experiments below 500 μGy/h. Only two described effects under gamma exposures for wide ranging dose rates, all above $\sim10^3$ μGy/h	No data on low chronic exposures. Only one reference was reported, with all dose rates $>10^4$ μGy/h.	Too few data to draw conclusions.	Too few data to draw conclusions. Only two papers for dose rates $>10^4$ μGy/h.
Mammals	Rat growth not affected at 16 μGy/h but affected at $>3 \times 10^3$ μGy/h. Some blood parameters affected at 180-850 μGy/h. No effect on thyroid function at 9×10^3 μGy/h	No effect on mouse lifespan at 460 μGy/h, but significant reductions above $\sim10^3$ μGy/h in the mouse, goat and dog.	Threshold for effects at ~100 μGy/h, with clear effects at $>10^3$ μGy/h.	Too few data to draw conclusions. One of nine references gives an LOEDR of 420 μGy/h for mice.
Molluscs	Too few data to draw conclusions. One of the two reported references gives an LOEDR of $>10^4$ μGy/h for *Physa heterostrophaone*.	Too few data to draw conclusions. Two references reported, both with LOEDR of $> 10^4$ μGy/h for *Mercenaria mercenaria*, and *Physa heterostrophaone*.	Too few data to draw conclusions. One of the two references gives an HNEDR of 10^4 μGy/h and an LOEDR $>10^4$ μGy/h for *Physa heterostrophaone*.	No data available.

TABLE 2. OVERALL SUMMARY FOR CHRONIC EFFECTS DATA FOR THE WILDLIFE GROUPS, BASED ON THE FASSET RADIATION EFFECTS DATABASE (FRED) [8] (cont.)

Wildlife group	Morbidity	Mortality	Reproductive capacity	Mutation
Moss/lichens	Too few data to draw conclusions.	No data available.	No data available.	No data available.
Plants	Plant growth begins to be affected at >100 μGy/h. Continued exposure at 21 μGy/h for 8 years increases the sensitivity in pines.	50% mortality at 8 years at ~10^3 μGy/h in pines.	A field study indicated a decrease in seed weight of a herb at 5.5 μGy/h.	The mutation rate in micro-satellite DNA increased at ~40 μGy/h.
Reptiles	No data available.	No data available.	No data available.	Too few data to draw conclusions.
Soil fauna	Too few data to draw conclusions.	Too few data to draw conclusions. One of nine references gives an LOEDR of >10^4 μGy/h for various species.	No data available.	Too few data to draw conclusions.
Zooplankton	Too few data to draw conclusions.	No data available.	Too few data to draw conclusions. The only reported reference gives an LOEDR of 440 μGy/h for *Tetrahymena pyriformis*.	No data available.

* LOEDR = Lowest observed effect dose rate.
# HNEDR = Highest no effect dose rate.

TABLE 3. EFFECTS OF DIFFERENT DOSE RATES OF CHRONIC IONIZING RADIATION ON SOIL FAUNA AND INSECTS (EXTRACTED FROM [6])

Dose Rate (μGy/h)	Species	Radiation	Description	End point	Reference
<100	Earthworm	Alpha	Reduced numbers compared with control plots Smaller, reproductive and histological changes	Mortality Reproduction Morbidity	[16]
	Insect larvae	Alpha	Reduced numbers compared with control plots	Morbidity	[16]
	Scorpion	Gamma	Increased chromosomal aberrations	Mutation	[2]
	Midge	Mixed	Increase in chromosome aberrations	Mutation	[17]
100–1000			No data available		
$(1–5) \times 10^3$	Earthworm	Mixed	Reduced population size	Mortality	[18]
$(5–10) \times 10^3$	Myriapods Spiders Earthworm	Beta	Reduced numbers compared with control plots	Mortality	[9]
$(10–50) \times 10^3$	Bark beetle	Gamma	Reduced pupal survival	Morbidity	[19]
	Soil invertebrates	Alpha	Reduced population sizes	Mortality	[16]
$>50 \times 10^3$	Ants	Gamma	Behavioural changes of colony	Morbidity	[20]

Earthworms showed reduced population size after exposure to <5000 μGy/h of gamma radiation, while myriapods and spiders also decreased in numbers following exposure to $(5–10) \times 10^3$ μGy/h of beta radiation ($^{90}Sr/^{90}Y$). Given their numbers and ubiquity, there are few reliable data for the effects of chronic radiation on insects.

Chromosomal aberrations were increased in midge larvae exposed to <100 μGy/h of mixed radiation, while a similar dose rate of alpha radiation reduced numbers of insect larvae. Bark beetles exposed to 21 × 10^3 μGy/h of gamma radiation had reduced pupal survival. An ant colony exposed to 100 × 10^3 μGy/h showed behavioural changes, although it was not clear whether this effect was due directly to radiation, or due indirectly to radiation induced changes in other aspects of the environment, e.g. plant cover.

5. IN SUMMARY

The primary initiating effect of ionizing radiation is damage to DNA in organisms, irrespective of species. Depending on the type and repair of the DNA damage within the organism, effects to the individual can be measured and aggregated under four umbrella end points: morbidity, mortality, reproductive capacity and mutation. The severity of the effects following a given radiation exposure will be dependent on the species of biota under investigation.

From research on non-human species, some very broad conclusions may, however, be drawn:

— the relatively large differences between the taxonomic groups that are seen in the responses to acute irradiation, particularly in terms of the LD_{50} values, become less pronounced for continuous, low dose rate radiation exposure, and particularly for end points other than mortality;
— although minor effects may be seen at lower dose rates in sensitive species and systems, e.g. haematological cell counts in mammals, immune response in fish, growth in pines, and chromosome aberrations in many organisms, the threshold for statistically significant effects in most studies is about 10^2 μGy/h; the responses then increase progressively with increasing dose rate and usually become very clear at dose rates >10^3 μGy/h given over a large fraction of the life-span;
— there are, however, some data that do not fit too comfortably within this broad generalization, e.g. the effects of tritium β radiation on the developing immune response in fish embryos (although the studies available [10–13] give somewhat contradictory results), on the developing goose barnacle embryo [14], and also, perhaps, on the developing oocytes in embryonic and neonatal mice [15]; and,
— the significance for the individual, or for the population more generally, of the minor responses, particularly in terms of morbidity and cytogenetic effects, seen at dose rates less than 10^2 μGy/h has yet to be determined.

The initial development of the radiation effects database has clearly shown that the great majority of the data relate to the responses of individuals. Furthermore, there are numerous gaps in the available information for certain combinations of umbrella end points and wildlife groups, and more generally, at the low dose rates of relevance for environmental protection. These findings indicate where future research effort should be concentrated. Although the present set of wildlife groups represents a means of summarizing data for many different species, it would be helpful for the further progress towards a system for the protection of the environment from ionizing radiation if a more restricted set of reference organisms could be identified. This new set of reference organisms would also provide an additional focus for research into the effects of radiation.

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THE EFFECTS OF EXPOSURE TO MULTIPLE STRESSORS
A regulatory perspective

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Abstract

In the environment, toxic effects are usually the result of exposure to a mixture of contaminants as opposed to a single contaminant. Concentrations of contaminants, which singularly may have no effect, may be toxic when present in mixtures. In an environmental risk assessment, the most common approach of predicting the toxicity of contaminant mixtures is the additivity model. There is currently insufficient information to determine the applicability of the additivity model to mixtures of radionuclides and non-radioactive contaminants. Assessment of site specific issues can be done using more complex observational methods such as toxicity tests on whole effluent or contaminated environmental media, TIE methods, SQT approaches and biological effects monitoring. The strengths and weaknesses of various models and approaches are discussed. Current knowledge on the effects of multiple stressors and assessment practices used in various industry sectors can form the basis of environmental protection safety standards for the nuclear industry.

1. INTRODUCTION

Nuclear facilities, like other large industrial complexes, discharge complex effluents to the environment. These complex effluents may consist of a mixture of radionuclides, metals and other stressors such as pH, chlorides, sulfates and heat. Consequently, in the natural environment, several contaminants are almost always found together forming a large variety of different toxic mixtures. Concentrations of contaminants, which singularly may have no effect, may be toxic when present in mixtures [1]. Chemical mixtures can be categorized as: related substances with similar physical and chemical properties; contaminants released at the same time and place in essentially a constant composition, but not necessarily related; unrelated contaminants having different physical and chemical properties occurring together by coincidence (e.g., landfill leachate), and manufactured formulations composed of unrelated substances (e.g., surfactants, co-solvent carriers, stabilizers) [2]. Contaminant mixtures released by nuclear facilities primarily belong to the first two categories.

The importance of identifying and evaluating the potential adverse effects of multiple stressors on both human health and the environment (i.e. non-human biota) has long been recognized and has lead to extensive research into the effects of chemical mixtures for a variety of organisms and end points (e.g. Refs [3–5]). For environmental protection purposes, the results of research (field and laboratory) on effects of chemical mixtures and complex effluents have lead to the development of risk assessment and management approaches that are either relatively simple or very complex (e.g. Refs [2, 6]). Pathway analysis, assessment and measurement end points for mixtures are essentially the same as for single contaminants. Likewise, bioassays for mixtures are the same as those for single contaminants (e.g. acute and chronic toxicity tests with fish, invertebrates and plants/algae). Field evaluations to assess the ecological effects of contaminant mixtures include biological surveys of fish and benthic invertebrates together with the monitoring of water and sediment quality and statistical analysis of the data. For the latter multivariate statistical techniques such as ANOVA, MANOVA, and PCA (principle components analysis) are best to determine the effect of the various stressors on the biota [7]. In many regulated industries requirements for biological effects monitoring have been implemented to assess direct environmental effects downstream of an effluent release point. These programs require before/after studies such as the Before-After-Control-Impact (BACI) [8] (for new facilities), preferably with replicated control stations [9] or an exposure/control study design (facilities with an operational history). Ecological models can also be used to assess the potential effects of contaminant mixtures on populations and the role that the individual constituents play in exerting the toxic effect [10, 11].

The following sections will provide an overview of scientific knowledge on the effects of multiple stressors and briefly describe some of the available risk estimation approaches and their relative strengths and weaknesses.

2. EFFECTS OF MULTIPLE STRESSORS

Effects of chemical mixtures, particularly, of metal mixtures and mixtures of chlorinated dioxins and furans have been studied in the laboratory for several decades. The interaction of contaminants in mixtures may be additive, synergistic or antagonistic. When the interaction is additive the total toxicity of a mixture is equal to the sum of the toxicity of its individual constituents. An interaction is synergistic if the toxicity in the mixture is greater than the sum of the proportional toxicity of the individual chemicals. Finally, toxicity interaction in a mixture is antagonistic if the toxicity in the mixture is less than the sum of the toxicity of the individual chemical constituents. The interaction of mixtures may vary with the test organism and the end point measured [5, 12].

In the case of chlorinated organics, effects of exposure to mixtures have been shown to be additive. Toxic equivalent factors (TEF) were developed to estimate the risk of complex substances containing chlorinated dioxins and furans. The method makes use of the dose addition concept where chemicals concentrations in mixtures are simply added to each other because they have similar modes of action. TEFs are used to assess the toxicity of complex substances when effects data for some of the constituents are not available [2].

A literature review of more than 68 publications dealing with metal mixtures was recently conducted to determine the frequency of occurrence of less than additive (i.e. antagonistic), strictly additive, and more than additive (synergistic) responses. These publications reported the results of 210 toxicity tests on 77 different species representing groups such as algae, bacteria, planktonic crustaceans, benthic crustaceans, aquatic insects, fish, protozoans and aquatic macrophytes. Mixtures were comprised of 2 to 11 different metals. The results indicate that the interaction was less than additive in 43% of the tests, strictly additive in 27% of the cases, and more than additive in 30% of the tests [13].

To our knowledge few studies have looked at the effects of contaminant interactions involving radionuclides. A study of the toxicity of strontium-90 and lead (stable) for Daphnia magna, a freshwater cladoceran, indicated that exposure to radioactivity had an ameliorating effect on the toxicity of this heavy metal at the lower radiation dose (less than additive) while the highest radiation dose enhanced its toxicity (more than additive) [14].

Other studies have looked at the effect of temperature and salinity on radiation effects [15]. Radiation effects generally increase with higher temperature and higher salinity. The effect of temperature, salinity and food supply on the toxicity of metals and pesticides has been reviewed by Heugens et al. [16].

Traditional impact assessment approaches characterize effects of multiple stressors on a one by one basis. Taking into consideration the available information on the effects of contaminant mixtures, when combined effects are estimated, they are typically treated as additive. Although the additivity model is generally considered to be conservative, the review of metal mixture toxicity discussed above [13] suggests that strictly additive and more than additive effects account for 57% of the metal mixtures tested. From the very limited data available on the interaction of radiation and non-radioactive substances, it would appear that the additivity model may also be useful for estimating effects of contaminant mixtures containing radionuclides.

3. ASSESSING THE EFFECTS OF MULTIPLE STRESSORS WITH ADDITIVITY MODELS

Additivity models can be broadly classified into two basic types: concentration addition models and response (effects) addition models [13]. In the concentration addition models, the concentration of all the toxic constituents of a mixture are added together to predict the toxicity of the mixture. Because each constituent may have a different potency, it is necessary to convert the concentrations to an equitoxic dose. The most commonly used concentration addition model is the Toxic Unit (TU) approach.

The response addition method is the other principal additivity model. For this model the different potencies of each of the mixture constituents is not important since the effect of the concentration of each constituent in the mixture is combined to predict mixture toxicity.

3.1. Toxic Unit approach

A common additivity approach to assess the toxicity of a mixture of contaminants is the TU approach. In this method, the concentration of each contaminant is normalized by dividing the specific contaminant concentration by a standard toxicity end point, usually the LC_{50}, and the resultant values are summed to give the TU. Other end points can be used as denominators for the TU, including both lethal and non-lethal end points. Ideally, the denominator should be based on the same bioassay and be the same for all the contaminants. In practice, LC_{50} values from the literature are commonly used to assess the TU, but other end points including estimated-no-effect-values (ENEVs) [5] and water or sediment quality guidelines [17] have been used. Using this approach no effects would be expected at TU <1. When a LC_{50} is used as the denominator, a TU of one predicts mortality of half of the population.

A variation of the TU method has been developed to predict the effects of sediment quality on benthic invertebrate communities. The mean sediment quality quotients (SQGQs), representing chemical mixtures in sediments, are calculated by normalizing each contaminant found in a sediment sample to its respective sediment quality guideline (SQG) value and then averaging the normalized values for a given suite of contaminants. A mean SQGQ value greater than one indicates that one or more contaminant exceeded its respective SQG. This method has recently been used to determine the predictive reliability of individual SQGs (chemical by chemical approach) for metals and radionuclides released from uranium mining/milling facilities relative to the additivity approach (i.e. mean SQGQs) [18].

The toxic unit approach is suitable for assessing the potential effect of multiple chemical and radionuclide interactions on the environment. It can easily be used in traditional ecological risk assessment (ERA) frameworks. The TU approach may be applicable for assessing the effects from certain physical stressors, such as changes in water temperature. However, this approach will not account for changes in biological stressors such as predation effects.

3.2. Effects addition approach

A number of studies have predicted the toxicity of metal mixtures using the effects addition method. The effect of the mixture is predicted to be the sum of the effects of the concentrations of the individual constituents. One of the advantages of this method is that it can use partial effect data (e.g. from dose response curves for mortality rate or growth rate) over a wide range of concentrations by allowing data from longer exposures at lower concentrations to be combined with shorter exposures at higher concentrations [13].

The additivity of toxic effects approach is used in POPMOD, a computerized population model used to assess potential population effects from exposure to contaminant mixtures. POPMOD can be used to assess the potential toxicity of mixtures of metals and radionuclides (radiation dose) on fish and benthic invertebrate populations [10].

3.3. Strengths and weaknesses of the additivity approach

The models described in this section provide a method of assessing the potential effects of complex effluents, or contaminated soils and sediments by allowing an integration of the toxicity of the various mixture constituents. The use of additivity models in ecological risk assessments may provide more robust predictions of potential ecological effects of complex effluents than a substance by substance assessment. However, experience has shown that assessments tend to focus on constituents for which toxicity information is readily available and may overlook potentially important constituents or exposure pathways.

Experimentation with population models suggests that the stressor by stressor approach leads to significant predictive errors, with interactions between concurrently acting stressors often leading to more significant consequences for the environmental attribute being assessed than stressors acting alone. However, the additivity model may lead to both over-prediction and under-prediction of observed effects [11].

4. ASSESSING THE EFFECTS OF MULTIPLE STRESSORS WITH MORE COMPLEX OBSERVATIONAL METHODS

More complex observational methods range from toxicity testing of contaminant mixtures (e.g. industrial effluent, contaminated soil and sediment samples) to field investigations to assess the ecological effects of contaminant mixtures. The latter may include biological surveys of fish and benthic invertebrates together with the monitoring of water and sediment quality and statistical analysis of the data.

The ability to predict ecological effects from toxicity test results and Toxicity Identification and Evaluation (TIE) methods is hindered by the need to extrapolate the results of tests conducted on laboratory organisms under well-controlled conditions to effects on populations and communities of organisms in the field exposed to a wide range of stressors (temperature, light, food availability, predation, etc.). On the other hand biological effects monitoring programmes (i.e. biological surveys together with the monitoring of water and sediment quality and statistical analysis of the data) are resource intensive and their value is strongly influenced by the robustness of the programme design. Well designed programmes are able to characterize effluent related effects on populations and communities. Identification of the causal factor or factors, however, can be challenging. The methods described in the next two sections can assist in identifying the toxic constituent(s).

4.1. Characterizing toxicity of contaminant mixtures using laboratory approaches

Constituents of the contaminant mixture (e.g. effluent, contaminated sediment) should first be characterized in terms of their chemical and physical properties. Standardized toxicity tests have been developed by many national jurisdictions and international organizations. Toxicity tests for contaminant mixtures are the same as those for single contaminants (e.g. acute and chronic toxicity tests with fish, invertebrates, plants/algae, earth worm). When a contaminant mixture results in a toxic response the constituents of the mixture and the parameters responsible for the toxicity can be determined using fractionation techniques such as in the Toxicity Identification and Evaluation (TIE) approach.

In the TIE method, samples are fractionated and toxicity tests are performed on each fraction to determine which fractions contribute to the toxicity of the mixture. Identification of the toxic constituent provides the information needed to move forward to the investigation of options to reduce or eliminate toxicity from the effluent. This method was used successfully at a Canadian uranium mine/mill where it allowed identification and then elimination of a toxic process chemical.

Although very useful as a diagnostic tool, these approaches do not provide any information on the biological availability of contaminants in the receiving environment. The following section describes methods that provide information on the toxicity of contaminant mixtures present in various environmental compartments.

4.2. Characterizing toxicity contaminant mixtures using field or combined field-laboratory approaches

The effect of sediment associated contaminants on biota can be assessed using the sediment quality triad approach [19]. This structured, integrative framework consists of the integration of: (1) sediment chemistry to document presence and concentration of contaminants in the sediment; (2) sediment toxicity bioassays to assess whether the contaminants are biologically available and toxic under controlled laboratory conditions; and (3) benthic macro-invertebrate community surveys to assess whether there is evidence of in situ toxicity (acute or chronic) leading to the alteration of the benthic community composition and structure. The SQT approach has been used downstream of uranium mines and mills and have helped advance our understanding of mining related impacts on sediment fauna.

Toxicity tests can also be conducted in situ in surface waters receiving complex industrial effluents. Because of the large number of variables that can cause an adverse response in the test organism effects data is best analyzed using the support of multivariate statistical techniques. For example when the results of toxicity tests conducted downstream of an uranium mine using caged fathead minnows were analyzed statistically (stepwise multiple regression following a principal component analysis) against a large suite of water quality parameters, dietary selenium uptake was proposed to account for the differential fathead minnow mortality observed among study sites. This was an unexpected result because arsenic, nickel and molybdenum were believed to be the main contaminants of concern [20].

4.3. Biological effect monitoring programs

Biological effects monitoring programs consist of biological surveys together with the monitoring of water and sediment quality and statistical analysis of the data. Biological effects monitoring is the most comprehensive approach to the determination of impacts of effluents at higher levels of biological organization (i.e. populations and communities).

In Canada, such programs have been regulatory requirements for the pulp and paper industry since the early 1990s, of uranium mines and mills since 1999–2000 and are a requirement in the base metal mining industry since 2002. However, some form of biological effect monitoring has been conducted by the uranium mining industry for about 15 years. Recent programs, however, have benefited from the experienced gained in the pulp and paper sector, and are now better designed.

Experience has shown that few of the field measured biological effects were predicted using traditional risk assessment methods based on predictions of water quality.

4.4. Strengths and weaknesses of the more complex observational approaches

The chemical composition of a mixture, and hence its toxicity, changes with time and distance from the point of release [2]. This is because of the various properties of the individual constituents such as partitioning to particulates, degradation rates, biological uptake, etc., which affect their fate in the environment. This is one of the reasons that results of toxicity tests conducted on whole effluent are not always representative of toxicity in the receiving environment. In situ toxicity tests alleviate these problems somewhat and also take into account the biological availability of various constituents. Toxicity tests in combination with the TIE methods are useful in identifying toxic constituents.

Biological effects monitoring is the most comprehensive approach to the determination of impacts of effluents at higher levels of biological organization. To be most effective, however, it requires a robust study design.

5. CONCLUSIONS AND RECOMMENDATIONS

A significant body of literature exists on the effects of exposure to mixtures of synthetic chlorinated organic substances and metals. These studies indicate that the effects of substances with similar modes of action are generally additive (e.g. chlorinated dioxins and furans). In the case of metal mixtures, about 43% of the test results indicate that the interaction was less than additive and 57% of the test resulted in strictly additive (27%) and more than additive (30%) effect. Consequently, when estimating the environmental consequence of releases of complex effluents, using an additivity model appears reasonable.

Several additivity approaches exist and have been used both for research and site assessment purposes. These approaches used in an ecological risk assessment framework are likely more appropriate than the substance by substance approaches used traditionally. There is currently insufficient information to determine the applicability of the additivity model to predict the combined effects of exposure to radionuclides and other toxic substances. This is an important data gap because nuclear facilities often discharge complex effluents.

The more complex observational methods discussed in section 4 are particularly useful at the operational stage of a facility or for contaminated site assessments. They are not predictive tools but provide information needed to assess the effectiveness of controls on emissions. These methods are recommended for facilities posing higher risks to the environment [21].

From a regulatory perspective, environmental protection safety standards for nuclear facilities should be based on existing approaches and methods. Most methods described in previous sections have been in use in many other industries as well as in segments of the nuclear industry (e.g. uranium mines and mills, sites contaminated because of historical practices or accidents) and are, therefore, well tested. Future developments such as those discussed in [6] will benefit all industry sectors, including the nuclear sector and will address important issues such as the interaction of contaminants with other stressors (e.g. predation, loss of habitat).

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CAN CONTINUOUS LOW LEVEL IRRADIATION AFFECT POPULATIONS?

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Abstract

The protection of the animate environment is variously taken to require the protection of either the individual organism, or populations of organisms. There exist reasonable data concerning both the radiation exposure of some individual organisms in contaminated environments, and, for a small number of species, their responses to incremental low level chronic irradiation. Taken together, these could be used as a basis for the development of criteria for the protection of individual organisms; the same is not true, however, for their populations. Although it is reasonable to suppose that any impacts at the population level will be a consequence of responses to irradiation that occur in the constituent individuals, there has, as yet, been little analysis of the links between these two end points. Thus, it is not possible to say with any confidence that measures to protect individual organisms would also, necessarily, protect the population. This paper uses a population modelling approach to demonstrate that the linkage between radiation effects in the individuals and in the population is very complex, and dependent on factors other than the radiation doses and the dose-response relationships. Future efforts to develop measures to protect the animate environment from the incremental radiation exposures arising from human activities will need to consider both the individual and the population to ensure that the intended objective is achieved.

1. INTRODUCTION

The rather trivial answer to the question posed in the title to this presentation is, of course, an affirmative. There is, however, a number of factors that need to be considered in order to provide a soundly based response when the question is examined in the particular context of the protection of the environment from the possible effects of the incremental exposures to ionizing radiation that result from human activities (i.e., above those from the internal and external natural background radiation fields). These include, but are not limited to:

— What is the degree of the radiation exposure of the flora and fauna?
— How is the requirement to protect the environment from such exposure to be interpreted?
— What types of damage are to be expected?
— How is the radiation damage to the population mediated; is it direct or indirect?
— How, ultimately, can the damage to individuals and/or populations be assessed and the information used to institute controls?

2. THE RADIATION EXPOSURE

It is inevitable that the regulated release of low levels of radionuclides to the environment in the course of waste management procedures will not only lead to the risk of human radiation exposure, but also to the concomitant probability of the exposure of wild organisms. Previous assessments of the degree of the radiation exposures of the flora and fauna in such contaminated environments have indicated that these will generally be (and are often much) less than 100 μGy/h, and always less than 10^3 μGy/h ([1] and references therein).

For example, in the period 1967–1970, when the releases of many of the most significant β/γ-emitting radionuclides to the northeast Irish Sea from the Windscale nuclear fuel reprocessing plant were near to their maximum historical rates [2], the estimated absorbed dose rates to a benthic fish, the plaice (*Pleuronectes platessa*), ranged up to 86 μGy/h, mainly from the contaminated seabed. These estimates were effectively confirmed by in situ measurements with LiF thermoluminescent dosimeters that were attached to the fish (2488 marked fish released in June 1967, and an additional 1092 in April 1968) and recovered over a period of 2½ years in the course of commercial fishing operations. The maximum time-averaged dose rate measured was 25 μGy/h (over a period of 1½ years) and the arithmetic mean dose rate across this population was estimated to be 3.5 μGy/h; the overall distribution of dose rates was, however, log-normal and did not vary significantly with the time at liberty [3]. In this particular instance, the exposure from external sources, mainly the contaminated seabed, was much greater than for the internal sources acquired through bioaccumulation. It must be stressed that, although many, if not most, dosimetric methodologies initially assume uniform distributions of bioaccumulated radionuclides in the whole body, the influence on the radiation exposure of specific target organs, e.g., the gonads, of differential uptake of radionuclides in these, or neighbouring, organs should be assessed, insofar as this is possible. This is particularly the case for α-emitting radionuclides due to the short ranges of the α-particles and their known greater effectiveness, per unit of absorbed dose, in producing effects. Methods are available to achieve this end (e.g., [4]) and estimate the impact on the radiation exposure [5].

In other situations, and, for example, for more sedentary organisms, the distribution of dose rates across the population would very likely be different. Such estimated, or measured, distributions of absorbed dose rate values across the population do, however, provide the only currently available, and secure, basis upon which the possible impacts of the radiation exposure of the flora and fauna, over their lifetime, can be assessed.

3. PROTECTION OF THE ENVIRONMENT

The protection of the (animate) environment is frequently, but often rather vaguely, expressed in terms of the aim of protecting populations of plants and animals, and, hence, it may be inferred, of conserving or maintaining healthy populations at their natural level within their natural geographic range. In recent legislative practice, however, protective action has also often been directed at individual plants and animals, and this applies more widely than those species that would be commonly recognized as either rare or endangered (e.g., [6]).

In general terms, protecting the individual could be taken to mean that its health should not be significantly compromised by the incremental radiation exposure; e.g., measures related to its growth, behaviour, reproductive performance, lifespan, etc. should be within the range (or close to the mean) for the species as a whole. In contrast, the aim of protecting the population would appear to require the adoption of a different viewpoint. A population is a collection of individuals that is defined by a set of demographic quantities (together with their ranges), e.g., number, density, birth rate, death rate and sex ratio, all of which are very likely to be age dependent. It also has the capacity to maintain itself, through reproduction, within the normal ranges of variability in the quantities defining the population, in the face of the natural variability in environmental conditions, without significant immigration from, emigration to, or inter-breeding with, other populations of the species [1, 7, 8]. It is important, however, to note two related points: first, that it is not immediately apparent that the attributes defining the population can be directly impacted by radiation exposure without the mediating influence of effects in individuals; and, second, that the quantities defining the population are aggregations (but not necessarily simple linear sums), across the population, of processes that are operating in individuals. Thus, slight negative effects of chronic low-level irradiation on the individual attributes noted above could (but might not) aggregate to produce significantly greater negative changes in the indicator quantities relating to the population. The identification of a linkage between effects in individuals and effects in the populations of which they are constituent members is hardly surprising, but it clearly indicates the area upon which attention should be focussed in any attempt to develop appropriate criteria for the protection of the environment from incremental radiation exposure.

4. THE EFFECTS OF RADIATION

Given the numerous reviews that have been made of the literature concerning the effects of radiation on non-human organisms (e.g. Refs [1, 9–15], it is not intended to repeat the exercise here. Rather, the relevant major findings and conclusions will be noted:

- There is more information available for acute, high dose irradiation than for the low-level chronic exposures that are relevant to the majority of sites contaminated as a consequence of regulated (authorized) waste disposals (i.e. < ~100 μGy/h);
- The great majority of the information relates to the responses of individual organisms to irradiation; there is an acute shortage of data relating to what could be genuinely regarded as population responses, i.e., relationships between measures of the absorbed dose (rate) to the individuals making up the population and the response in terms of the population statistics noted in the previous section;
- As a broad generalization, the processes of gametogenesis and embryonic development (collectively, reproductive capacity) appear to be more sensitive to chronic irradiation than the survival of post-larval, weaned, juvenile or adult individuals;
- On the basis of the evidence available at the times of the reviews, it has most often been suggested (e.g., [1, 12]) that:

  a. "... chronic dose rates less than 400 μGy/h would have effects, although slight, in sensitive plants but would be unlikely to have significant deleterious effects in the wider range of plants present in natural plant communities."
  b. "For the most sensitive animal species, mammals, there is little indication that dose rates of ... 40–100 μGy/h ... to the most exposed individuals would seriously affect reproduction in the population."

c. "For aquatic organisms, the general conclusion was that maximum dose rates of 400 μGy/h to a small proportion of the individuals and, therefore, a lower average dose rate to the remaining organisms, would not have any detrimental effects at the population level."

It must be stressed that these findings were **not** intended as recommendations for limits to provide for environmental protection, but as an indication of the general point of transition, for each of the groups of organisms, between insignificant and significant deleterious responses.

— Notwithstanding the two previous points, there is evidence that there are additional effects that can become apparent at lower dose rates, e.g., reduced immune response and, particularly, the induction of cytogenetic effects in somatic tissues. It should also be noted, however, that in experimental studies spanning the lifetime of the organism, the consequences of such effects would be captured by other measured end points.

The commonly observed effects of irradiation in individual organisms may be pooled into four "umbrella" categories that are relevant to the possible impacts on the quantities that are taken to define the population, i.e.:

— Morbidity (e.g., damage to the immune system, radiation cataracts, reduced brain size from embryonic exposure, etc.);
— Mortality (e.g., cancer induction, non-specific life-shortening, etc.);
— reproductive capacity (including fertility — gamete production, and fecundity — reduced Rembryonic survival, changes in behaviour or morphology affecting fertilization rates, etc.);
— Mutation rate (could lead to reduced fitness and influence all three preceding attributes in succeeding generations).

It must be emphasized that these four categories are, obviously, not mutually exclusive. This is the approach to generating summaries of data that has been adopted in the FASSET project of the EU 5th Framework Programme [15–17].

A closer examination of the data available for chronic radiation exposures allows some additional, and relevant, conclusions to be drawn. Leaving on one side changes in the heritable mutation rate, and apart from the possibility, at least in some types of organism, of cancer induction, the responses of the umbrella end points to chronic irradiation tend to be deterministic in nature, i.e., they show a sigmoid response with increasing radiation exposure. Even if cancer is a significant outcome of chronic radiation exposure, and is accepted to be a stochastic risk for the individual organism, the overall response in a group of organisms is likely to be a slight shift to earlier ages of the usual sigmoid mortality curve. One important experimental study of the effects of lifetime chronic irradiation on populations of *Daphnia pulex* have shown that the population birth and death rates respond in a quasi-sigmoid manner with increasing dose rate [18]. If, as appears to be fairly reasonable, a sigmoid response relationship is assumed between radiation effect and dose rate, this has two implications: first, there is likely to be some threshold incremental dose rate (in addition to the natural background) below which any effect of exposure would not be discernable within the natural variability; and, second, above this threshold, the response is likely to increase rapidly to unsustainable (and unacceptable) levels [19].

In respect of protecting the animate environment, however, the deficiencies in the available radiation effects information (related as it is, primarily, to responses in individuals) generate a significant problem. There is not a sufficient basis in empirical data for the development of criteria to provide for the protection of the population, if that is, indeed, the objective. It is likely, however, that criteria for the protection of individual plants and animals could be developed, i.e., for a series of representative organisms, and for each of the four umbrella end points, it would be possible to establish dose rates at which it would be reasonably unlikely that there would be any significant impacts of the cumulative absorbed dose on the general health of the great majority of individuals. This immediately begs the question: would such controls provide a sufficient degree of protection for the population and any higher level in the biological hierarchy? At the present time it would not be possible to provide assurance, with convincing supporting evidence, that the aggregated "insignificant" radiation effects, across the four end points for any given population, would not have significant effects at the population level. This problem is not, of course, unique to radionuclides as contaminants — it arises with equal relevance in the regulation of releases of non-radioactive contaminants to the environment.

5. THE POSSIBLE RESPONSES OF A POPULATION TO RADIATION

In view of the rather few empirical data that are currently available on the responses of populations of organisms to irradiation, an alternative approach is to develop appropriate population models and investigate how these respond to changes in the input values for the demographic parameters that might be affected by irradiation.

There are a number of points to be considered in the approach to the development of the population model [15]:

- It is known that the different life stages of many organisms show differential radiosensitivity and this must be taken into account;
- The most radiosensitive life stage of an individual organism might not necessarily be the most significant in determining the radiosensitivity of the population;
- Differences in life cycle, and particularly, the reproductive strategy, between species are likely to have a significant impact on the population response [20]; and,
- The influence of density-dependence in regulating the potential growth of natural populations.

An initial review of the models that have been used to assess the possible responses of populations to contaminant exposure has concluded that the Leslie matrix model approach shows the greatest promise for application to the particular problem of radiation impacts [21]. The apparent advantages of the matrix model approach are: first, the major parameters required to implement the model relate to precisely those individual attributes that are known to be affected by radiation exposure, i.e., morbidity, mortality and reproductive capacity; second, relevant demographic data are available for the development of the model structure for some natural populations of interest, e.g., fish; and, third, it appears to be relatively simple to use the model in an experimental mode, i.e. to investigate its behaviour by altering the model parameters in an informed manner.

The full details of the development of the matrix population model for the plaice are given in [21], and also for the thornback ray (*Raja clavata*, with a reproductive strategy different from that of the plaice so that comparisons may be made) in [22], and will not be repeated here. Briefly, the matrix model allows the age structure of the population, under the particular demographic parameters applied, to be projected into the future so that its evolution and behaviour may be investigated. It may be noted that, in addition to the four points outlined above, an attempt was made to include the influence of environmental stochasticity in the models. For the purpose of the present discussion, the starting populations of the plaice and thornback rays were assumed to aggregate 260 and 130 tonnes, respectively, with defined initial age/size distributions, and the other demographic parameters employed to implement the Leslie matrix projection models as given in Ref. [22] in Tables 1 and 2.

The time-dependent evolution of the un-irradiated model plaice and ray populations, both with and without the impact of an imposed fishing stress, is indicated in Figure 1 in terms of the spawning biomass and the number of recruits to the spawning biomass from the spawning that occurred 2 (plaice) and 6 (rays) years previously. With no adult mortality due to fishing, the number of Gp-II plaice recruits increases by a factor of ~3.5, and the spawning biomass increases to about 1100 te; correspondingly, there is an ~1.5-fold increase in the number of Gp-VI ray recruits and the spawning biomass increases to ~500 te. The addition of the fishing stress reduces the population growth potential with the result that there is now a doubling of the number of Gp-II plaice recruits and a marginal increase in the spawning biomass to ~350 te; for the rays, there is a very small increase in recruitment but the spawning biomass also increases to ~350 te. The initial sharp increase and decline in the ray population is most probably due to a mis-match between the assumed age distribution of the founder population and the combined effects of the demographic parameters used to run the model, together with the 6 year maturation period; i.e., it takes several generations for the population to achieve a quasi-equilibrium. This particular result demonstrates the crucial importance of correct model parameterization if the results are to be applied in detail; nevertheless, the overall trends are probably valid.

Although there are some data on the radiation exposure of the developing plaice embryo from the radionuclides on and in the egg, and in the surrounding water [23] and for the adult fish (see above), it is not possible to give a fully coherent picture of the radiation exposure, at each stage of development, across the plaice population in the northeast Irish Sea. Still less is it possible to say what effects these likely, but varying, degrees of low-level chronic exposure might have on the natural age-dependent survival and reproductive capacity of the fish in the population. There are, at present, no relevant dosimetric data for the thornback ray. The approach adopted, therefore, has been to investigate the influence that small reductions — of 0.5, 1, 2, 5, and 10% — in survival and reproductive capacity might have on the evolution of the exploited populations.

Before considering the results of the model experiments, a note of caution is appropriate. The validity of the results is contingent upon the degree to which the models of the two populations provide an accurate description of the natural situation; it must be emphasized that, although some of the values for the demographic parameters have been developed from literature sources (see Refs [21, 22]), others have been set more or less arbitrarily (for lack of data) to allow the models to behave in what appears, intuitively, to be a reasonably realistic way.

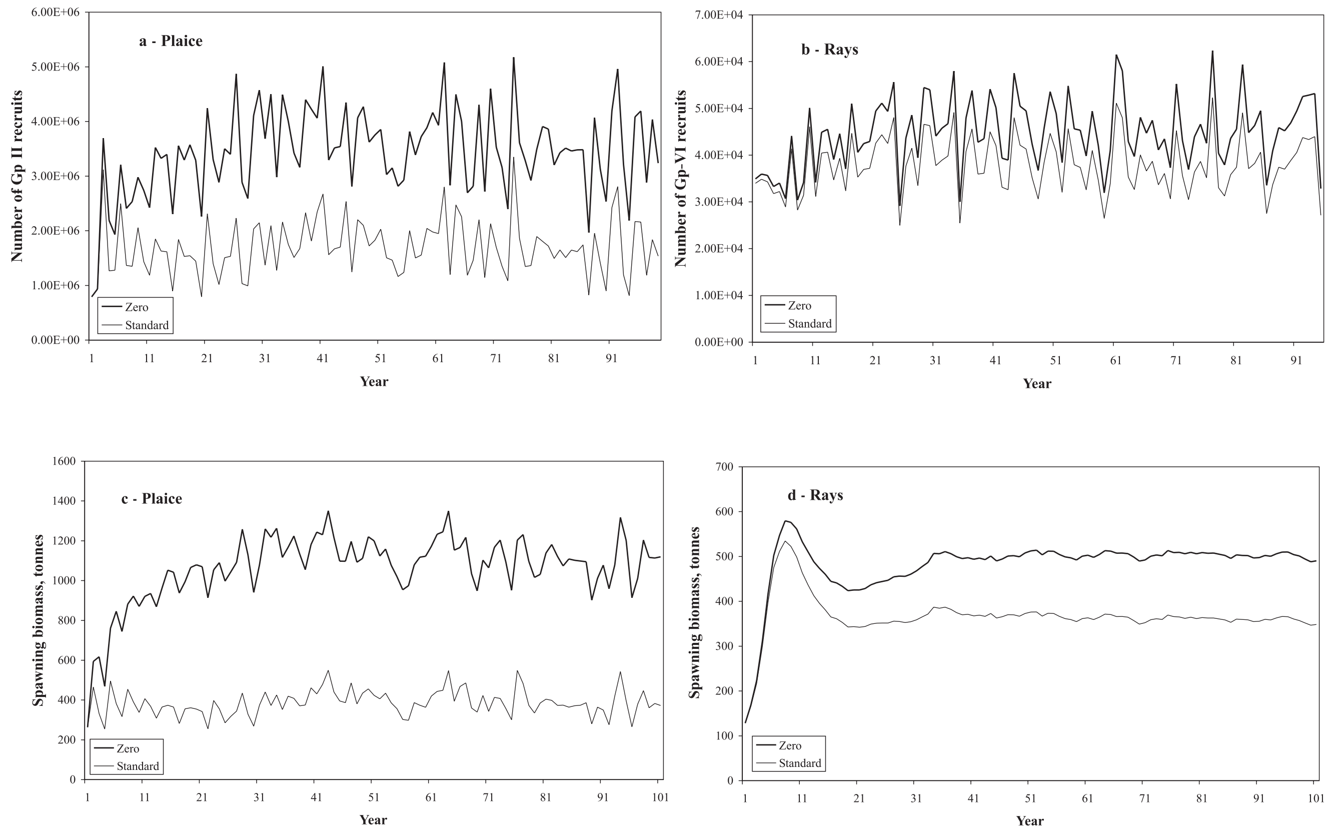

FIG. 1. The evolution of the plaice and thornback ray populations with zero and standard fishing pressure. Graphs 'a' and 'c' illustrate the recruitment of Gp-II plaice and Gp-VII thornback rays; graphs 'b' and 'd' illustrate the spawning biomass of plaice and thornback rays.

5.1. Fertility

Here, fertility is taken to be egg production per female, i.e., the production of ova that can be fertilized to generate viable developing embryos (although it is known that the production of sperm is also affected by irradiation, it is assumed for the present, that there are sufficient viable sperm for complete fertilization). The influence of the defined reductions in egg production on the projected evolution of the spawning biomass in the exploited plaice and ray populations, relative to the unirradiated baseline, is given in the 'a' graphs of Fig. 2. It may be seen that the impact on the population of reduced egg production appears to be greater for the plaice than for the ray. This response is the reverse of what might have been expected and implies that, in these particular model implementations (i.e. with the specific values employed for the demographic parameters), the aggregate influence of factors acting after spawning is more significant in affecting the outcome.

An alternative way to examine the behaviour of the populations is in terms of the mean annual potential rate of growth (Table 1). This indicates that, for a 10% reduction in egg production, the ray population appears to be in terminal decline (a mean annual potential growth rate < 1) whereas the plaice population retains growth potential at all levels of reduced fertility. A closer examination of the data in Table 1 shows that, for both species, the reduction in

TABLE 1. MEAN ANNUAL STOCHASTIC RATE OF SPAWNING BIOMASS GROWTH OVER THE PERIOD 30–100 YEARS, WITH THE INDICATED % CHANGES IN THE POPULATION ATTRIBUTES

Plaice					
Baseline1.00165	0.5%	1%	2%	5%	10%
Reduced egg production	1.00163	1.00161	1.00157	1.00144	1.00114
Increased coefficient of egg mortality	1.00162	1.00158	1.00150	1.00119	1.00036
Increased final age-dependent mortality	1.00164	1.00163	1.00161	1.00155	1.00143
Combined effects	1.00159	1.00152	1.00134	1.00053	0.99729
Thornback ray					
Baseline1.00020					
Reduced egg production	1.00019	1.00017	1.00014	1.00004	0.99983
Increased coefficient of egg mortality	1.00018	1.00016	1.00011	0.99994	0.99961
Increased final age-dependent mortality	1.00013	1.00005	0.99990	0.99944	0.99868
Combined effects	1.00009	0.99996	0.99971	0.99881	0.99660

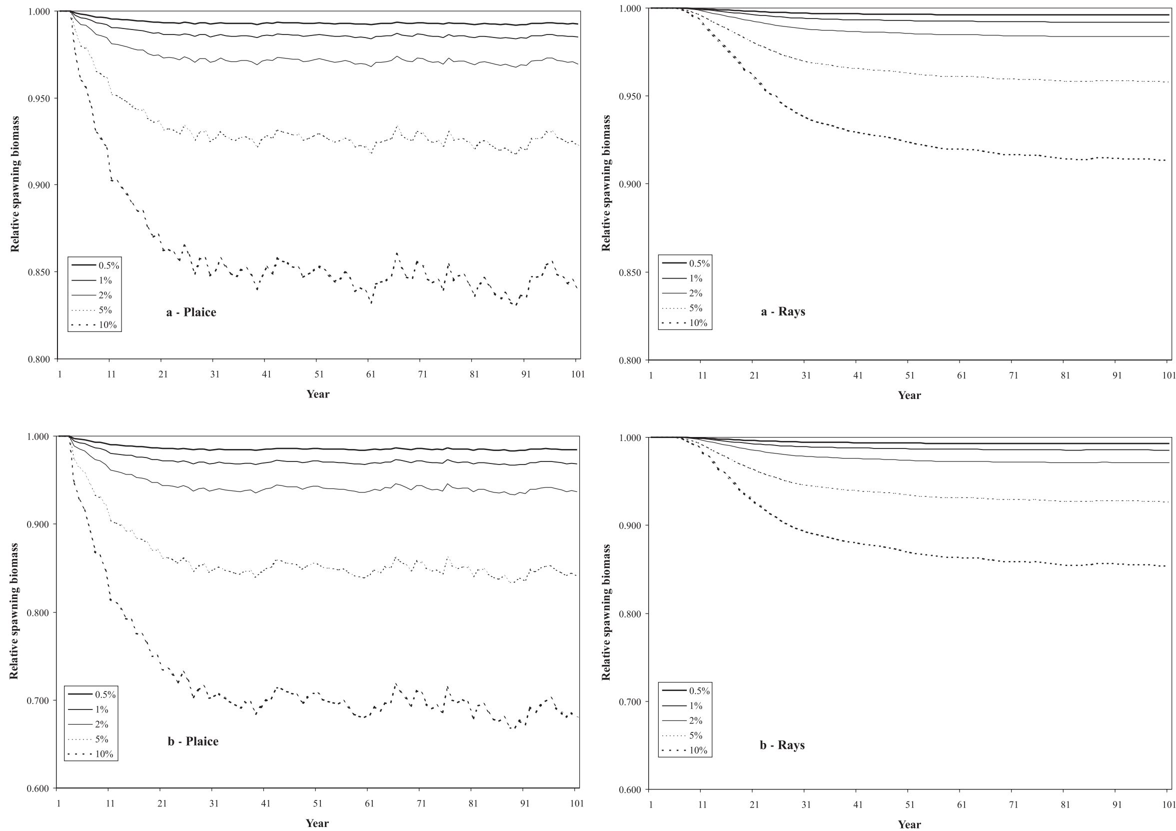

FIG. 2. Graphs which show the evolution of the plaice and thornback ray populations with varying reductions. In the 'a' sets: egg production per female; in the 'b' sets: embryo survival to hatching.

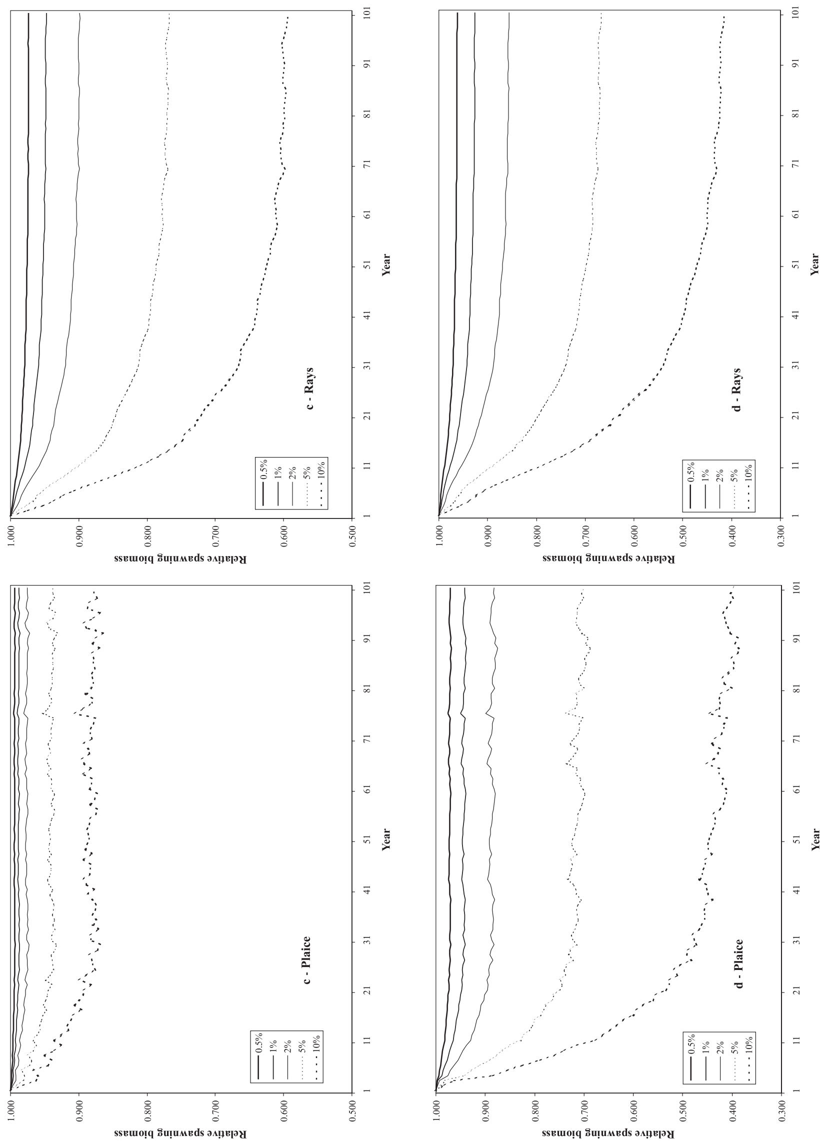

FIG. 3. Graphs which show the evolution of the plaice and thornback ray populations with varying reductions. In the 'c' sets: final age dependent survival and in the 'd' sets: the combined stresses.

growth potential is greater than in simple proportion to the reduction in fertility, i.e., the response is non-linear. (It should be noted that, although the mean annual potential growth rate may be > 1, the populations do not grow indefinitely due to the influence of non-linear interactions between the various density-dependent and density-independent factors.)

5.2. Fecundity

The effects of the reduced embryonic survival to egg hatch are shown in the ‘b’ graphs of Fig. 2. Relative to the unirradiated baseline, the projected evolution of the spawning biomass appears to be impacted to a greater degree (reduced) for the plaice population than for the thornback ray. The data for potential population growth in Table 1 indicate that given reductions in fecundity have a greater effect on the growth potential of both populations than corresponding reductions in fertility. Although the plaice population retains a potential for growth at all levels of reduction in embryo survival, the ray population is in apparent decline at the 5 and 10% levels of reduction. As was the case for reduced fertility, the response to increasing reductions in embryo survival is non-linear.

5.3. Survival

It has been assumed that continuous chronic irradiation over the lifetime of the fish would progressively reduce their likely survival. This effect has been implemented by increasing the age-dependent coefficients of natural mortality progressively over their lifetime to give the required final percentage increases for Gp-VII plaice and Gp-XXX rays. The effects of the increase in final age-dependent mortality attribute has the least impact on the plaice population as compared with reductions in fertility and fecundity, whilst the opposite is the case for the thornback ray. The ray population appears to be in decline at final age-dependent increases in the coefficient of natural mortality ≥ 2%. As was the case for the previous two attributes, the response to progressive increases in the age-dependent mortality coefficient is non-linear.

5.4. Combined effects

Naturally, the incremental radiation exposures will affect all three of these population attributes, although not to the same degree either for each attribute or for each species. In the absence of sufficiently detailed information on the probable relative degrees of effect arising from the (probably) differing incremental exposures at each life stage, the aggregate outcomes for the populations of equal degrees of effect on each attribute have been assessed. The results are given in the 'd' graphs of Figure 3 and Table 1. For the evolution of the spawning biomass, the aggregate reductions are similar for the two species; there is some indication, however, that the plaice population is slightly less sensitive at the low degrees of impact whilst the reverse is true for the combined effect of 10% reductions in the attributes. In terms of the population growth potential, the thornback ray is more sensitive to the cumulative effects of the radiation stress than is the plaice; the two populations are seen to be in decline at combined reductions in the three attributes greater than 2% and 10%, respectively.

6. CONCLUSIONS

It is worth repeating the earlier caveat: the utility of the results that have been obtained thus far with the Leslie matrix population model is very dependent on the degree to which the present model structure, and its parameterization, reflects the natural situation. Overall, however, it may be concluded that this modelling approach does give a reasonably robust basis for investigating the possible effects of incremental radiation exposure on populations of wild organisms. While the details of the results may be open to question, it may be reasonably concluded that:

— Small, and individually insignificant, impacts of continuous irradiation on the fertility, fecundity and risk of early mortality in individual organisms may aggregate, in a non-linear fashion, to produce significant damaging outcomes at the population level, i.e., it appears not to be the case that measures to provide an acceptable degree of protection to the individual organism would necessarily protect the population;

— The results appear to indicate that the most radiosensitive of the individual attributes would not necessarily be the most significant in contributing to the population response, i.e., measures to limit radiation impacts on this specific attribute would not necessarily provide for the protection of the population;

— The studies have confirmed that the relative importance of each of the population attributes, in determining the response of the population, varies with the life cycle characteristics and the reproductive strategy of the species under investigation; and,

— In terms of population growth, the expected lesser sensitivity of the plaice population relative to the thornback ray population to the damaging effects of irradiation appears to have been confirmed; more unexpectedly, however, it was the possible impacts on the long term survival, and, therefore, the aggregate future reproductive capacity of the population, rather than on the low natural breeding capacity of the individual thornback rays that appeared to be the most sensitive attribute.

From these initial explorations of the possible relationships between radiation effects in individual organisms and the resultant consequences for the population, it is clear that the situation is extremely complex, and, given the simplistic nature of the present population model, the available results are likely to have a large degree of uncertainty in the detail; nevertheless, it is possible to draw some reasonably robust general conclusions. It appears not to be possible, a priori, to say that a given measure to limit effects, at some non-zero level, in individual organisms will also provide for an acceptable level of protection for the population, nor vice versa. Both the individual organisms, and the populations of which they are constituent parts, must be considered as interacting entities when assessing impacts and developing protection criteria. This comprehensive assessment would require information relating to the level of chronic irradiation throughout the life cycle, and across the population, the consequent effects of these radiation exposures on the relevant attributes of individual organisms, and, some means of combining this information to provide an estimate of the impact on the population. At the present time, not all of the required information is available to make such an assessment for a species that might be regarded as sufficiently representative, or typical, to be designated as an example of a reference organism.

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EFFECTS OF RADIATION IN CONTAMINATED AREAS

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Abstract

Results are considered from radioecological studies on the evaluation of ionizing radiation effects on biota in the regions affected by radioactive contamination in the former Soviet Union (regions of the river Techa, the East Urals radioactive trail following the 1957 accident and the area that was affected by the accident at the nuclear power plant at Chernobyl in 1986). Exposure doses to plants and animals in these contaminated zones are presented. With the Chernobyl accident as an example, the correctness of the thesis "if radiation standards protect man, then biota are also adequately protected" is assessed.

1. INTRODUCTION

The development of the nuclear power industry and nuclear engineering, especially in the early stages, resulted in releases (sometimes uncontrollable) of radioactive material into the environment. This caused the formation of zones of enhanced anthropogenic radioactive contamination in different regions of the world. The origin of the contamination varies, and so do the characteristics of the areas affected, contamination density, nuclide composition of the radioactive substances in the environment, and time and mode of their introduction into the environment (single, chronic, etc.). In different countries, the

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areas that were affected by the releases of radionuclides into the environment had been subjected to a variety of nuclear activities. These included nuclear weapons testing, radiological accidents in the nuclear power industry and in nuclear engineering, the mining of radioactive ores with dissipation of activity to the surroundings, the disposal of radioactive waste and other releases owing to the failure to adhere to technical requirements for the storage of radioactive material.

The disposal of radionuclides into the environment and their subsequent dispersion and inclusion into the trophic chains resulted in the irradiation of non-human biota. In some contaminated zones, the density of radionuclide deposition, and accordingly the dose rates on biota, varied widely, with the maximum levels reaching high absolute values. The resulting impact on biota therefore covers a wide spectrum of responses — from molecular and cytogenetic changes in plants and animals to degradation and a complete destruction of natural and cultivated ecosystems.

Radioecological investigations in contaminated areas have made it possible to collect unique information and description of the characteristics of in the development of processes of radiation induced alterations in natural and cultivated ecosystems. The observation of these kinds of radiation effects provides a number of advantages, the most important of which are:

- Observation of the radiation effects in the natural habitat of living organisms (including the influence of combined effects of different natural factors and ionizing radiation, and an opportunity to monitor effects over extended time periods, etc.);
- Analysis of the irradiation impact on biota in the natural environment for different radioecological scenarios characterizing typical situations where the removal of radioactivity into the environment is likely (e.g., for different steps of a full nuclear fuel cycle, at sites where radioactive waste was buried, etc.);
- Study of the responses of biota to irradiation at the population and ecosystem levels over extended time periods;
- The opportunity to carry out a series of field observations of biota within a single landscape where the only variable factor is the contamination density (dose rate to biota), i.e. a possibility to establish a dose-effect relationship at the population and ecosystem levels;
- Methodological advantages of estimating radionuclide concentrations in biota due to the high absolute values of radionuclides observed in these zones.

Along with the advantages of studying radiation effects in biota on the territories with increased content of anthropogenic radionuclides some difficulties in the analysis of results are apparent. The most significant are:

— Difficulties in the estimation of absorbed doses in plants and animals in natural conditions, particularly when considering biota responses as a function of dose (poor development and difficulties of ecological dosimetry);
— Considerable variation in dose rate and absorbed dose to biota in time and space in ecosystems which complicate the interpretation of the experimental results;
— Assessment of the role of radiation in the observed changes in plants and animals in the context of the complex actions of other natural and anthropogenic factors also influencing biota in zones with the elevated content of man-made radionuclides.

Within the former USSR, the results of long term radioecological investigations in the following areas affected by radiation [1] are of the greatest interest in terms of assessing effects of ionizing radiation on biota:

— Region of the river Techa;
— Region of the East Urals radioactive trail ((EURT) the accident occurred in 1957);
— Region that was affected by the Chernobyl nuclear power plant accident (1986).

In all the above cases large areas were subject to radioactive contamination with a high content of radionuclides per unit area and in the two latter cases the radiation damage to biota was observed at the population and ecosystem levels with a complete destruction of populations, communities and individual ecosystems.

2. RADIOACTIVE CONTAMINATION OF THE RIVER TECHA

Between 1949 and 1956, the operation of the USSR's first plutonium plant, called "Mayak", resulted in the disposal of radioactive wastes to the river Techa and the adjacent areas (including a cascade of reservoirs termed the Techa cascade). During this period, this region received about 100 PBq (2.8 MCi) of radioactive material (fission products and nuclides with induced activity) resulting in an area with high densities of radioactive contamination.

TABLE 1. ESTIMATED ABSORBED DOSE RATES TO AQUATIC AND CIRCUMAQUATIC ORGANISMS IN THE PERIOD WHEN DISPOSALS OF RADIOACTIVE SUBSTANCES WERE AT THEIR HIGHEST, Gy/day [2, 3]

Organisms	Sampling site and distance from disposal site		
	Village of Metlino, 7 km	Village of Muslyumovo, 78 km	Village of Zatechenskoe, 237 km
Phytoplankton	0.04	0.004	0.00003
Zooplankton	0.08	0.01	0.0008
Macrophytes	1.0	0.25	0.014
Mollusks	0.5	0.08	0.007
Fish	0.3	0.03	0.004

No data were collected on the effect of ionizing radiation on the river biota in the Techa in the 1950s. Of interest are reconstruction doses to aquatic biota in the upper reaches of the Techa in 1950–1951 (Table 1). Such high doses of exposure could have caused damaging effects. Currently, exposure doses to plants and animals in this region have changed significantly and arrange from 1 to 50 mGy/a. According to estimates, the absorbed dose to aquatic organisms in the Techa was higher than for humans by average factors of 100 to 300 [2, 3].

3. THE SOUTH URALS ACCIDENT IN 1957 (THE EAST URALS RADIOACTIVE TRAIL)

This radiation accident is a result of a chemical (thermal) explosion on 29 September 1957 in a concrete tank storing wastes of radiochemical production (according to the IAEA parameters, the accident would have been registered as a 6 or 7 event on the INES scale). The explosion sphere involved some 740 PBq (20 MCi) of beta emitting radionuclides, with 74 PBq (2MCi) depositing on the adjacent area forming the East Urals radioactive trail (EURT). The main dose forming radionuclides within the EURT were $^{90}Sr+^{90}Y$ (5.4%), $^{144}Ce+^{144}Pr$ (65.8%) and $^{95}Zr+^{95}Nb$ (24.8%). The trail area of 20 000 km^2 is bounded by the 3.7 kBq/m^2 (0.1 Ci/km^2) isoline for ^{90}Sr which for that period, corresponded to twice the background of ^{90}Sr from global fallout [1].

In this accident zone, within the EURT area, dose fields were formed with high dose rates which induced various radiation alterations in biota.

TABLE 2. MAXIMAL ABSORBED DOSES IN BIOTA IN THE EURT AREA DUING THE ACUTE PERIOD (AUTUMN 1957 – SPRING 1958), Gy

Biota species	Dose
Pine	20–800
Birch	10–800
Herbaceous plants	20–800
Soil invertebrata	2–200
Mammals	10–200
Birds	5–100
Benthos	20–80
Fish	10–40

Within the EURT, doses to different biota species caused lethal damage to plants and animals (Table 2).

The major radioecological phenomena reported in studies of radiation induced changes in plants and animals within the EURT area may be summarized as follows:

— When radionuclides enter the environment and are included into the trophic chains of migration, a complex and dynamic space-time infrastructure of radionuclide distribution is formed that predetermines the establishment of complex dose fields;

— In the infrastructure of dose fields, ecological niches can be identified which are characterized by increased (or decreased) accumulation of radioactive substances (i.e. increased or decreased exposure doses to biota). Of special interest in terms of the development of radiation changes at the ecosystem level are situations when the highest doses are formed in the ecological niches inhabited by biota species that are especially sensitive to radiation. Examples of such niches within the EURT area are in the wooded parts of forest ecosystems (especially coniferous forest ecosystems) and soil invertebrata;

— In a single release of radionuclides to the environment, two periods are identified in the development of responses to exposure in plants and animals — acute and long term (with the decay of radionuclides and respective decrease in the dose rate to biota). The first period is dominated by responses that show damage, the second one by responses that show repair and post-radiation injuries in biota;

— In the exposed ecosystems primary radiation effects were identified connected with the direct ionizing radiation effects on biota and secondary effects caused by changes in ecosystems as a result of direct primary effects;
— Radiation damage to natural communities is dependent on the season when radioactive contamination occurs. It is more pronounced if fallout of radionuclides occurs in the spring-early summer period compared to the fallout in the autumn-winter time (in other words radiation changes in biota are expressed to a greater extent during the course of active metabolic processes in exposed plants and animals);
— In the aerial fallout of radioactive substances external irradiation of biota in the early period is the leading factor in the radiation exposure;
— In the event of fallout of a radionuclide mixture that includes beta emitters, aerial contamination of the above-ground parts of plants can play a significant role in radiation induced damage to plants (contrary to irradiation of animals);
— Genetic studies have revealed that, in spite of the existence of genetic effects in natural populations within the EURT area and alterations in the genetic structure of the populations with time, the presence of heterogeneity of populations in radioresistance, repair systems and evolutionary selection reduces the role of radiation injuries, and ensures sustainable existence of living organisms populations under these radioactive contamination conditions.

4. THE ACCIDENT AT THE CHERNOBYL NUCLEAR POWER PLANT

The radiation accident at the fourth block of the Chernobyl NPP occurred on 26 April 1986. Due to an explosion in the RBMK 1000 reactor in the active core of which 10^{20} Bq were contained, a release of fission products occurred estimated to be equal to 1.85×10^{18} Bq (excluding noble radioactive gases) [1]. Radioactive releases were extended in time in a process that consisted of several stages (before 10 May 1986). In a long term perspective ^{137}Cs (release of 3.7×10^{16} Bq) was the radionuclide that gave the greatest contribution to dose while in the early period ^{131}I (release of 2.7×10^{17} Bq) was more important. The total area with ^{137}Cs contamination density above 37 kBq/m^2 (1 Ci/km^2) amounted to 150 000 km^2. Particularly high contamination levels were found within the 30 km zone (exclusion zone).

Unlike the South Urals accident in 1957 which occurred in the autumn period, the Chernobyl accident took place in the spring, in the period of active

TABLE 3. CRITICAL DOSES TO BIOTA IN THE REGION OF THE CHERNOBYL ACCIDENT, Gy/year

Biota species	Dose, Gy/a
Terrestrial ecosystems	
Pine forest (pine)	0.4
Herbaceous plants (meadow, cereals)	3.0
Agricultural plants (cereals)	3.0
Mouse-like rodents	0.4
Cattle (cows)	0.6
Soil invertebrata	0.9
Aquatic ecosystems	
Phytoplankton	3.0
Zooplankton	2.5
Zoobenthos	0.9
Fish	1.0

development of physiological processes in plants and animals, thereby resulting in a greater level of radiation damage to biota. Radioeclogical observations of the pattern of radiation induced changes in biota in the Chernobyl affected zone confirmed the results of similar investigations within the EURT area. Simultaneously, they made it possible to significantly expand and specify the nature of the radiation induced injury. This is explained by a number of specific features of the Chernobyl accident:

— Time of the accident (spring);
— Radionuclide composition of the deposition (the presence of short lived radionuclides);
— Modes and physico-chemical speciation of the fallout;
— Biogeochemical peculiarities of the environment in the accident-affected area that predetermined the pattern of distribution and redistribution of radionuclides in landscapes and ecosystems.

Considering the radioecological situation in the Chernobyl accidental zone, critical doses were established of irradiation of some most important representative types of biota (Table 3). These are minimal doses at which significant, ecological shifts were observed (criteria of these shifts in various biota species are different). These doses varied from 0.4 to 3 Gy/a.

TABLE 4. EXPOSURE DOSES TO BIOTA IN THE REGION OF THE CHERNOBYL ACCIDENT (VILLAGE OF BORSHCHOVKA), Gy/year

Biota species	Years	
	1986	1991
Terrestrial ecosystems		
Pine forest (pine)	3.1	0.02
Herbaceous plants (meadow, cereals)	10	0.02
Agricultural plants (cereals)	6	0.014
Mouse-like rodents	0.6	0.03
Cattle (cows)	1.6	0.03
Soil invertebrata	7.9	0.06
Aquatic ecosystems		
Phytoplankton	0.06	0.00034
Zooplankton	0.18	0.00063
Zoobenthos	0.8	0.08
Fish	0.4	0.05

In the first year after the accident, exposure doses to terrestrial biota were above the critical doses in the most contaminated zone. For a number of representative types, doses exceeded lethal levels (Table 4). The relative dose burdens of different biota representatives and man (taking the dose to man as 1) were arranged as follows (Tables 4 and 5), Man (1) < Phytoplankton (1.2) < Zooplankton (3.6) < Fish (8) < Mouse-like rodents (12) <Zoobenthos (16) < Cattle (cow) (32) < Pine trees (62) < Agricultural plants (cereals) (120) < Soil invertebrata (158) < Meadow grasses (cereals) (200).

Five years following the accident exposure doses to man and biota were reduced, and the order of relative dose between man and ecosystem components differed as follows: Phytoplankton (0.007) < Zooplankton (0.014) Agricultural plants (cereals) (0.3) < Pine trees (0.4) = Meadow grasses (cereals) (0.4) < Mouse-like rodents (0.7) = Cattle (cow) (0.7) < Man (1) < Fish (1.1) Soil invertebrata (1.3) < Zoobenthos (1.7).

While in the early period after the accident the highest doses were received by the ecosystem components exposed to the aerial fallout, in the later phase the most exposed were components connected with the sites of radionuclide deposition — the soil and bottom sediments (accordingly soil invertebrata and zoobenthos). Hence, critical ecosystem components (most exposed) in the

TABLE 5. EFFECTIVE DOSES TO THE POPULATION IN THE REGION OF THE CHERNOBYL ACCIDENT (VILLAGE OF BORSHCHOVKA), mSv

Dose	Before evacuation (10 May 1986)	From 26 April to 15 September 1986	1991
External irradiation	39	197	10.7
Internal irradiation	11	65.6	35.2
Total dose	50	263	45.9
Dose to the thyroid	2.01	2.81	–

environment may change, as the radionuclide distribution in ecosystems changes, after a single input of radionuclides.

A database on the content of radionuclides in biota, as well as on doses and irradiation effects in the zone of the Chernobyl nuclear power plant accident makes it possible to evaluate the correctness of the ICRP postulate "if radiation standards protect man then biota are also adequately protected". As the basis for a comparison of ionizing radiation effects it is suggested that a comparison of the ratio between the absorbed doses actually received by man and biota representatives are calculated from their measured radionuclide content (D_h and D_b) in the zone surrounding the Chernobyl nuclear power plant and the so-called critical doses, for humans and biota representatives (CDV_h and CDV_b). This ratio of real permissible (critical) absorbed doses to humans and biota may be termed Radiation Impact Factor (RIF):

$$RIF_{h,b} = \frac{D_{h,b}}{CDV_{h,b}}$$

If RIF > 1 for man and biota, they may be considered as inadequately protected from ionizing radiation, in the described framework, and protected if RIF ≤ 1.

The comparison of RIF for humans and biota enables an assessment of the correctness of the ICRP postulate. It is correct if at $RIF_h \leq 1$ $RIF_h > RIF_b$ and the thesis is incorrect (i.e. man is protected and biota are unprotected) if $RIF_h \leq 1 < RIF_b$.

It is seen from Table 6 that RIF_b for 1986 is above 1 for all terrestrial components of ecosystems (i.e. these are not protected from ionizing radiation effects), whereas all aquatic biota in 1986 are protected from exposure. Five years after the accident all the biota representatives studied are protected from

TABLE 6. RADIATION IMPACT FACTORS FOR MAN AND BIOTA IN THE REGION OF THE CHERNOBYL ACCIDENT (VILLAGE OF BORSHCOVKA)

Biota species	Years		
	1986		1991
Terrestrial ecosystems			
Pine forest (pine)	7.85		0.05
Herbaceous plants (meadow, cereals)	3.33		0.007
Agricultural plants (cereals)	2.00		0.005
Mouse-like rodents	1.50		0.08
Cattle (cows)	2.7		0.05
Soil invertebrata	8.78		0.07
Aquatic ecosystems			
Phytoplankton	0.02		0.0001
Zooplankton	0.07		0.0002
Zoobenthos	0.89		0.09
Fish	0.40		0.05
Man	Years		
	1986		
Critical dose	Before evacuation (10 May)	26 April to 15 September	1991
1 mSv/year	50	263	45.9
5 mSv/year	10	52.2	9.2
50 mSv/year	1	5.3	0.9
100 mSv/year	0.5	2.6	0.46

Note: The population of Borshchovka was evacuated before 10 May 1986. Doses for the periods 26 April–15 September 1986 and 1991 were calculated on the assumption that the people were not evacuated.

ionizing radiation. At the same time, if we use for 1991 a permissible dose to the public of 1 mSv/year, the ICRP thesis remains correct. For the first post-accident year, if the accidental exposure doses to man (50 and 100 mSv/a) are taken, for a hypothetical case of non-evacuation of the population, the ICRP thesis for some (most exposed) biota representatives (at least pine trees and soil invertebrata) may be contradicted (i.e. man will be protected and biota unprotected from ionizing radiation).

In 1986, the RIF to man and the biota species studied could be observed as follows: Phytoplankton (0.02) < Zooplankton (0.07) < Fish (0.40) < Zoobenthos (0.89) < Man (1) <Mouse-like rodents (1.5) < Agricultural plants (cereals) (2.0) < Cattle (cows) (2.6) < Meadow grasses (cereals) (3.3) < Pine forest (7.9) < Soil invertebrata (8.8). By 1991, five years after the accident, the RIF in biota dropped drastically (from 3 to 400 times), which shows that the acute period of radiation stress for non-human species was relatively short.

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CONCEPT AND USE OF REFERENCE ANIMALS AND PLANTS

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Abstract

In order to manage the exposure of human beings to ionizing radiation, a device was needed that enabled exposures to be related to dose received, and hence for relating doses to effects. The result was an entity called Reference Man. It has therefore been argued that a similar approach could prove useful in attempting to manage radionuclides in the environment by having a framework with which to relate exposures to dose, and doses to effects, for other types of living things, by way of a set of entities called reference animals and plants. This set would necessarily be limited in scope, because it is clearly not possible even to try to encompass the vast array of living things that might need to be considered in various forms of environmental management practices. Nevertheless, a relatively small set could still be useful in drawing out many of the basic questions, and to serve as a reference against which other forms of animals and plants could be compared. This paper outlines some of the issues involved and makes some suggestions as to how they might be addressed.

1. INTRODUCTION

Over fifty years ago it was evident that a clear basis was needed to enable estimates of absorbed dose to be made, from inhaled or ingested radionuclides, in order to protect human beings from the harmful effects of ionizing radiation. It was a requirement that particularly related to situations of occupational exposure. Thus, in 1949, the first data on what was then known as '*Standard Man*' were formulated [1]. The data related to organ mass, some physiological characteristics such as water balance and respiration, plus the concentrations of some 15 elements in various organs and tissues. Further additions were then made such that, a decade later, there were models of the digestive tract, 'elimination' half-times for some elements, and concentration values for 44 naturally-occurring elements in 36 tissues [2]. These data proved to be so useful that, in 1963, a more comprehensive study was initiated by the ICRP in order to establish a *Reference Man* (the change in title being deliberate), with the carefully specified characteristics of a *typical*, occupationally exposed, individual.

This study resulted in the landmark publication, some twelve years later, of ICRP No. 23 [3]. Reference Man (*Homo sapiens*) was then defined as being between 20 and 30 years of age, the male being 170 cm tall and weighing 70 kg, the 160 cm tall female weighing 58 kg, both living in a climate with an average temperature of 10 to 20ºC. They were assumed to be Caucasian, with the customs and habits of Western Europeans or North Americans. In creating this hypothetical pair, the ICRP did *not* attempt to define what one might have regarded as *average* or *median* individuals of a specified population group; instead, it attempted to select *typical* values in order to specify particular attributes, which may or may not have been derived from such average or median values. The prime reason for — and most important aspect of — this concept, however, was that the relevant numerical characteristics were precisely defined; so that when variations were subsequently to be made and used for dose estimations, there was a known basis for their derivation, and thus for any subsequent adjustment factors that were to be applied to any other specified *type* of individual.

Since then, more detailed studies have been made in relation to particular anatomical and physiological features of the human body, such as the respiratory tract (in 1994 [4]) and the skeleton (in 1995 [5]) as well as in relation to a variety of age-dependent factors and aspects of radionuclide metabolism, as listed in [6]. Indeed, revisions and updates are still in progress; but it is useful to note that the creation of Reference Man became *the* scientific cornerstone of human radiation protection, and remains so today. It provides a foundation for the management of human exposures to radiation with respect to medical care, occupational exposure, and the protection of the general public, by providing a basis, or device, for relating exposure to dose received and thus the ability to relate dose to effect, or to risk of an effect.

The needs for the management of radioactive materials in the environment, and hence for the active protection of the environment itself, are different in detail from those relating to the management of human radiation exposure in medical, occupational, and environmental circumstances, but are nevertheless similar in their overall pattern of requirements. Radiation, at sufficiently high doses and dose rates, is known to have deleterious effects on animals and plants. These effects, it has been suggested, could usefully be grouped in terms of those causing early mortality, reduced reproductive success, some form of observable cytogenetic damage (the consequences of which are not known) [7–9], or just some form of morbidity, such as reduced growth rate. Because of this incipient risk, such information on the effects of radiation on different types of animals and plants needs to be formulated in such a way that it is useful to those who are directly involved in various, but different, environmental management practices — such as pollution control, or wildlife management, or environmental exploitation [10, 11]. All of which, of course, requires the sort of device that exists for human radiation protection: a basis for relating exposure to dose, and dose to effect. Hence the suggestion for a set of entities in the shape of Reference fauna and flora or, in plain English, reference animals and plants, to 'parallel' Reference Man [8, 9].

2. SELECTING REFERENCE TYPES

Creating a 'reference' *Homo sapiens* has not been an easy task; and this species shares the planet with well over 1 million other species of animals that have so far been described, plus at least half that number of plants. (Estimates of the actual totals vary considerably. New species have been described at the rate of about 10 000 per year in recent decades, and about half of these are insects. Indeed, about 80% of all described animals are insects!) The selection of potential *types* of animals and plants therefore has to be done on a very pragmatic basis. A number of selection criteria have been suggested [12], of which the most important are probably the fact that we already have a reasonable amount of relevant information on them and that, where data are lacking, there is a reasonable prospect that such information gaps could be filled. Some types of animals and plants therefore effectively select themselves as an initial basis for relating exposure to dose, and dose to effect — bearing in mind that these types need not necessarily be the only or prime objects for environmental protection, anymore than the original Reference Man is the prime target for human radiation protection in terms of race or age, or body shape and size.

So where to start? We have a reasonable amount of information on small mammals, as a result of numerous laboratory studies, particularly rodents, as well as on some birds (mainly chickens), certain types of fish, and on some of the 'higher' plants, as has been recently investigated by the FASSET programme [13]. But if a small set of reference animals and plants is to be developed and progressed to form a primary base for further comparisons, as intended by the ICRP [14], then it would also be sensible to try and encompass some of the range of life histories and life styles of animals and plants that are 'typical' of major habitats worldwide.

Of course vertebrate animals usually dominate both public and legislative concerns, but even here there is a bewildering variety from which to choose. Thus, although low in species diversity (about 4500), the mammals probably have the greatest morphological diversity, with adult weights ranging from a few grammes to over 100 tonnes. Reference Man is itself a medium sized mammal; so a small mammal would certainly be warranted as part of the set, and rodents are the best studied from a radiobiological point of view. Birds, too, are clearly important. Fortunately they have a small range of, essentially similar, anatomical features. They are also the most ecologically widespread vertebrate animals on Earth. Reptiles and amphibians are much more restricted in their geographical range, but the latter are of interest because of their 'dual-habitat' existence, in water and on land, their markedly different anatomy and physiology, and the process of metamorphosis from juvenile to adult. And finally, one cannot overlook the fact that over half of the known vertebrates are fish.

Invertebrate animals present a greater challenge because of their immense diversity. Some sort of easily studied insect is clearly essential, in view of their prevalence, and preferably one with a four-stage (egg, larva, pupa, adult) life cycle. But the selection of other invertebrate animals as Reference types might just as well reflect their 'universality' and hence likelihood of exposure to radiation — such as earthworms in the soil — as to be selected on any other basis, providing that they are amenable to future study.

Plants are different from animals in a number of interesting ways with respect to the relationships between exposures and dose, and dose and effects. Thus, in trees, the layers sensitive to radiation, such as the cambium, occupy only a very limited but critical part of the plant. In some types, such as the pines, there are interesting issues that relate to the time scales over which dose rates should be sensibly integrated (as in seed formation), as well as the 'volume-elements' within which the dose should be calculated. Thus the formation of conifer embryos can involve a process that takes 18 months to complete; and *all* of the next season's growth is pre-packaged into very small volumes — the terminal buds. And in marked contrast to the 'higher' plants, others, such as the seaweeds, can have very complicated life cycles in which the 'adult' plant can be either haploid or diploid.

Indeed, if a broader but basic understanding of the effects of radiation is to be forthcoming, it is also useful to consider what we do know (or do not know!) of effects at the molecular level. Virtually all of our information arises from studies on mammals, and is directed at an interpretation of the consequences for *Homo sapiens*, with his (2n) 46 chromosomes. Animals generally have between 12 and 60 (2n) pairs of chromosomes, but there is considerable variation, even in similar 'types'. Thus *Diptera* (flies) have from 4 to 20, *Lepidoptera* (butterflies and moths) from 14 to 446! Even such basic factors as the chromosomes that determine sex are somewhat variable. In mammals we have the familiar uneven pairing of XX (female) XY (male) pattern. But in birds the system is reversed, with ZZ (male) and ZY (female), a feature also found (but in relation to different chromosomes) in snakes. This form is also found in some insects, but in others only the female has double chromosomes, the males having one. (But there are, of course, many other variations, just within the vertebrates. In some reptiles the sex of the embryo depends on the temperature of incubation: high incubation temperatures of the eggs of alligators create males, whereas in some turtles they create females. Some fish species even change sex during life.)

The molecular biology of plants is much more variable than that of animals, with more frequent recombination and re-assortment of genes during meiosis. Nuclei, mitochondria, and plastids within plant cells all have their distinct DNA systems that play a part in phenotypic expression. Polyploidy is also common (50% of all flowering plants), usually because a diploid (2n) plant, by irregular division, gives rise to a tetraploid (4n) plant. Then, as a result of pollination, triploid (3n) plants are formed. These are unable to produce gametes compatible with either 2n or 4n 'parent', and thus such forms often diverge because of the resultant genetic isolation [15].

Collectively, therefore, even a small set of reference animals and plants would provide an interesting framework for the purposes of deriving suitable dose models, to consider the usefulness and relevance of different 'categories' of radiation effect, and how these relate to consequences that are expressed at the individual and population level. So how might such 'reference' creatures be described, and to what level of generality?

3. DESCRIBING A REFERENCE ANIMAL OR PLANT

It has previously been argued that a description at about the taxonomic level of Family would be about right, both for providing an initial generalized 'type' description, and for selecting species upon which further experimental work could usefully be made [10, 12]. An example might help: such as the selection and description of a 'reference' bird.

In view of the limited range of birds upon which further experimental material could be obtained, and the need for an obvious interface with different approaches to environmental management, then a reasonable choice would be a duck. Ducks are found in rural and urban areas, and a number of species have been 'domesticated' in various parts of the world and hence bred in captivity and used as a human food source. Wild ducks are also taken for food in some countries, but many species are increasingly protected and 'wildfowl' generally are regarded as vital components of 'wetland' ecosystems; and 'wetlands' are, in turn, variously protected to provide habitats for wildfowl, either in relation to breeding or in relation to feeding and resting areas for migratory species.

And although most radiobiological information seems to have been obtained on chickens, there are some basic data on ducks [13].

Ducks are members of the Family the Anatidae (ducks, geese, and swans), containing some 164 species. The small number of swans (7 species) are rather restricted in their global distribution, geese (29 species) less so. But the various types of ducks, of which there are about 128 species (78% of the total), classified into 35 Genera, collectively occur virtually all over the world, from the Arctic to New Zealand.

Ducks are indeterminate egg layers. Clutch sizes vary amongst species, usually with a lower range of 4 to 7, and an upper range of 10 to 15 although, exceptionally, over 30 can be laid in a season. Fledged young generally remain with adults until the next season. Most dabbling and diving ducks can breed at one year old, but 'sea' ducks do not do so until they are two years old [16].

Thus a *typical* dabbling duck *might* be described as follows. It would have a weight of 1 kg and a length of 55 cm from tip of beak to end of tail. (This, for the purposes of whole-body dosimetry, could be converted to a solid ellipsoid with the dimensions of 35 cm by 15 cm, assuming that the bird's head was held in a 'withdrawn' position.) It would be assumed to spend 50% of its time on fresh water, and 50% of its time standing on a mud bank such that the centre of its body was then 15 cm above the ground. It would feed on a diet that was a 50:50 mixture of aquatic plants and aquatic invertebrates. The female would lay 10 elliptical eggs each season, each egg being 6×4 cm and weighing 50 g. The eggs would be laid at one-day intervals and maintained at a temperature of 38ºC. Incubation would take 30 days. The nestlings would spend their time equally divided between being on the ground and on the water. They would be fledged at 60 days, the birds then remaining as juveniles for 1 year, at which age they would breed for the first time. They would then breed annually for 10 years, thus having a total life span of 11 years, during which the female would have laid 100 eggs. To simplify lifetime calculations, it could be assumed that the birds would be non-migratory. None of this would be taken as describing any particular species, but would be a reasonable description of a typical dabbling-type duck.

Using such a biological template, one could then calculate dose rates from background and from other sources as required, at different stages in the life cycle, and integrate doses over different periods of time. One could then evaluate relationships between radiation dose and different types of biological effect that were of relevance to the individual or groups of individuals.

For the sake of contrast, what about another vertebrate, such as a benthic teleost fish? These types of fish have been well studied in relation to their radiobiology. *Typical* of such fish would be members of the Family *Pleuronectidae*, examples of which are widely distributed in cool temperate waters of the Atlantic, Pacific, and Indian Oceans. The majority are shallow-water, bottom-living fish; although some, such as the Greenland halibut, live part of the time in, and actively hunt in, mid-water. Many species also penetrate estuaries and brackish waters. Some species attain a very large size (over 300 kg) and live to a great age (50 years). But more *typical* members of the Pleuronectidae are smaller and have shorter average life spans [17]. Thus a typical example might be described as being a shallow-water, bottom feeding fish that attains an 'adult' size of 40 cm in length and an average adult weight of 1.25 kg. It would spawn in the spring at a water depth of about 30 m and produce an average of 300 000 eggs each year. The eggs would be about 1.5 mm diameter and require a salinity of at least 12 parts per thousand in order to float. The eggs would hatch in 15 days and the larvae, about 5 mm in length, would swim in the water column until they were fully metamorphosed into their adult form at the age of 50 days. They would then settle on the bottom and grow continuously throughout life, maturing at four years of age and, with a life expectancy (if lucky!) of 10 years, would produce about 2 000 000 eggs in a lifetime.

Thus just in comparing these two hypothetical but 'typical' vertebrates, it is interesting to note similarities and differences pertinent to assessing exposure to dose, and dose to effect. Both adults are similar in size, life span, and their 'larval' development periods are similar. Both have lifestyles that involve the aquatic environment. But their exposures to radionuclides are very different, and their reproductive capacities and strategies are completely different. Thus, their responses to radiation would probably have quite different consequences, both for individuals and populations of such individuals, even if all the members of such populations were equally exposed.

By way of complete contrast, plants would need to be very differently described. Important characteristics might include such features as the size of the seeds, their containers (such as a pine cone), the type and size of the buds, the depth of the growing area (the cambium) from the external surface in relation to age, the size, growth rate, longevity, and so on of the adult plant. But again it would not be too difficult to describe, say, a *typical* pine tree, or any other type of plant, in such terms.

4. THE USE OF REFERENCE ANIMALS AND PLANTS

There are clearly a number of related aspects of the management of radiation in the environment that could be addressed by adopting such a reference animal and plant approach. One would be to use them to explore the relevance, or extrapolation, of some of the basic concepts of radiation protection, and hence some of the terminology, all of which has been derived in a purely human context. Hence one could explore such issues as the following. In what generalized contexts do the terms chronic and acute dose rates have meaning, or require further definition, for animals with life cycles of only days or weeks, or for plants that can live for centuries? What is the significance or use of differences in RBE amongst animals and plants, and is the concept of a radiation weighting factor of value for different types of animals and plants? Is the concept of deterministic and stochastic effects relevant to other animals (or plants) — what generalizations can be made? To what extent are different biological 'end points' and their consequences (such as early mortality, reduced reproductive success and so on) of value in different environmental management circumstances?

But perhaps the most immediately useful application of the concept might be to use such entities as a framework for re-examining our existing information on exposure and dose, and the relationship between dose and effects, for different types of animals and plants. This information could also be set out in relation to what is already known about their likely background dose rates, or could be readily calculated with a fairly minimal amount of effort. A good range of dose models, plus many of the data needed to derive external and internal exposure to both natural and artificial radionuclides, has already been developed within the FASSET project [18]. Further studies may be necessary to assess the need and relevance for more detailed models, particularly with respect to internal organ and tissue dosimetry for low LET radiation.

In terms of a possible management tool, assessments of the dose rates required to produce different categories of biological effects, set out relative to their background dose rates along the line of the suggested Derived Consideration Levels [8, 9] could serve to interface such information with the different needs of different approaches to environmental management, as discussed elsewhere [11]. For local application, this would best be achieved by way of linkage via other (and often less complete) 'secondary' sets of data on animals and plants, as have been derived by way of both the FASSET and EPIC programmes. If the reference animal and plant approach proved to be sufficiently robust then it could also be used, together with Reference Man, to work towards the derivation of the equivalent of Environmental Quality Standards for radionuclides in the environment.

5. DISCUSSION

It is evident that, with regard to ionizing radiation, a sound scientific basis for relating exposure to dose and dose to effects on biota other than human beings is essential if policy and decision makers are to be convinced that the presence of radionuclides in the environment can be managed in an effective way. The need to manage such a presence could arise for many reasons: waste disposal practices (actual or hypothetical), accidents, 'dirty' bombs used in terrorist attacks, as well as from re-evaluations of existing contaminated sites. There is already a large amount of data available. Thus the time would seem to be appropriate to use this information to construct a firm basis for further evaluation and application. In the case of human radiation protection a key step was the action taken to create data bases and models that could be used as points of reference and departure. The same approach could be useful with regard to environmental protection. There is already much to build upon, including the compilation of reference data sets by the IAEA [19] for the marine environment, currently being revised, plus the data bases, new models, and new interpretations from the FASSET and EPIC programmes. The ICRP has taken on the task, supported by the IUR and others. Experience has shown that, as for man, it will take time to develop; but as experience with human radiation protection has also demonstrated, it will be difficult to proceed without it.

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Topical Session 4

DISCUSSION

S. MIHOK (Canada): There are very serious problems with some of the radioecology literature — especially some of that from the former Soviet Union. That being so, how are we to use data such as those from the EPIC project when considering, in particular, radiation effect thresholds? We cannot be sure that the data have been subjected to proper quality assurance and peer review.

P. STRAND (IUR): In my presentation I did not focus explicitly on data from the former Soviet Union. I believe that good quality assurance is very important whatever data we are talking about; we should not focus on data from a particular country.

Now that we are concentrating on plants and animals, there is a lot to be done with the literature. For example, when dose rate is reported in the literature, we need to examine the dosimetry and try to reconstruct the dose. That has been done partially for the existing databases, but we are struggling or are using reference organisms, reference geometries and so on. All that will have an influence on the quality assurance or the possibility of comparing data and dose effect results between different studies.

I.A. GOUSSEV (Russian Federation): We always consider the radiation protection of humans in relation to specific health effects, for which the relative biological effectiveness (RBE) has been established, but what RBE does one consider in the case of the radiation protection of non-human species?

C.-M. LARSSON (Sweden): In the database which we built up for the FASSET project, we have indicated whether there are data which can be used in the evaluation of RBE. Very few of the 1050 references examined by us in order to obtain the approximately 25 000 data entries which we listed actually dealt with RBE, and only some of those contained reliable RBE estimates.

As far as I can see from the data, there is no single end point used in the estimation of RBE, which is possibly why there is such a wide range of values in the literature.

If I may expand on that, I would like to raise the question of how much the RBE (or rather the radiation weighting factor) matters when one is making an assessment. In my view, the answer will vary from one assessment situation to another. In many cases, the radiation weighting factor does not play a big role, but it does play a big role when one is considering high background data — which is, of course, important in many natural situations.

When applying the radiation weighting factor, you have to exercise some degree of expert judgement depending both on the scientific data available and on the assessment situation or the specific case you are dealing with.

S.R. JONES (United Kingdom): With regard to the fate of radionuclides in the environment and their effects on biota, are we striving for a state of knowledge roughly equivalent to what we know in the case of chemicals or for more?

C.-M. LARSSON (Sweden): In some areas, we know more about radionuclides than about chemicals and in some areas less.

In my view, the most important thing is that we follow a similar assessment approach both for radionuclides and for chemicals. When considering radionuclides, we can learn what was done in the case of chemicals, and for stakeholders — and for us — it is less confusing if the same system is applied for radioactive contaminants as for other contaminants.

R.M. ALEXAKHIN (Russian Federation): In his presentation, Mr. Strand spoke of the “radiological risk” to the environment. Was he referring to the risk of environmental contamination, of environmental damage or of both?

P. STRAND (IUR): In my presentation, I tried to make the point that there is an overall framework when it comes to environmental protection. What we are endeavouring to do is to facilitate the assessment process by identifying which risks the environment faces because of ionizing radiation, so that the consequences for sustainability, conservation and so on can be determined.

I did not intend to introduce a new concept. The issue is more one of developing a tool whereby comparisons can be made between radioactive and other contaminants. For that purpose, efforts have been made — through the use of, for example, reference organisms — to determine which end points are important.

D.B. CHAMBERS (Canada): What experimental studies — either laboratory or field — are under way or being planned with a view to filling the data gaps which have been identified?

C.-M. LARSSON (Sweden): There are fewer such studies than we wanted. The EC 6th Framework Programme is oriented more towards the policy and management areas and less towards the basic science.

Originally, there was a much stronger focus on experimental studies in the forthcoming ERICA project, in order to address — inter alia — the issue of extrapolating from individuals to populations.

P. STRAND (IUR): I would add that the available resources are very limited and it was not easy to have experimental work included in the EC 6th Framework Programme.

However, experimental work is being done worldwide, and the International Union of Radioecology is establishing a network for communication among the various research communities within and outside Europe, with the focus on — for example — the harmonization of experimental approaches and the validation of models.

B.J. HOWARD (United Kingdom): In this connection, I think it is important that we do not end up with a lot of numbers that many scientists have very little confidence in.

We need to do a better job of critically evaluating our efforts, with a view to providing a really good justification that will lead to the provision of more funding for those efforts.

D.B. CHAMBERS (Canada): If, as Mr. Strand just said, the available resources are very limited, what should be the main experimental programme priorities?

B.J. HOWARD (United Kingdom): As an animal ecologist, I would like to see the main emphasis placed on the transfer radionuclides to birds and amphibians.

C.-M. LARSSON (Sweden): In most cases, the greatest uncertainties are those associated with transfer assessments. In that connection, perhaps the main emphasis could be placed on forest ecosystems, where really only caesium and strontium are involved.

Then I would like to see close attention paid to biological effects on wildlife groups that have not yet been considered and to the efficiency of radiation in causing such effects.

S.W. FOWLER (IAEA): I would add that, in my view, refining the transfer factors for the models being used is very important. The IAEA Marine Environment Laboratory is using experimental techniques in an effort to refine — inter alia — biological half-lives, assimilation efficiencies and transfer rates from water. Also, we are using nuclear techniques to obtain similar data for heavy metals.

In this connection, I would mention that in developing countries there is much more interest in using nuclear techniques to gain a better understanding of non-radioactive contaminant fluxes than in radioactivity per se.

A. JOUVE (France): Which is more sensitive from the point of view of environmental protection, sediment or plankton?

S.W. FOWLER (IAEA): It depends on the end point being considered.

Obviously, you can perform measurements much more easily in sediment than in plankton. Moreover, plankton composition changes seasonally and different species yield different values, so that you get fluctuating results, whereas you get fairly constant results with sediment. So it may be more profitable to monitor sediment than zooplankton.

However, if you are dealing with food chains, particularly ones leading to fish and then humans, you have to know what is at the base of the food chain, which means monitoring radionuclide levels in zooplankton — as difficult as that may be.

J.C. BARESCUT (France – Chairperson): I would add that sediment consists of a part that is biologically available and a part that is not biologically available. Obviously, what is important for us is the biologically available part, which complicates interpretation of the measurement data.

H. VANMARCKE (Belgium): The nuclear industry seems to have its radioactive discharges well under control, whereas there is as yet not much effective control in the case of technologically enhanced naturally occurring radioactive material (TENORM). Within the European Union it is left to individual States to do something about TENORM, and the phosphate industry, the oil and gas industry and other industries are discharging enormous amounts of low level natural radioactivity into all environmental compartments.

In that context, I would be interested in hearing views about man-made radiation versus natural radiation.

P. STRAND (IUR): The TENORM issue is attracting more and more attention, and — unlike natural background radiation — you can do something about TENORM.

From my work in Norway I know that the oil and gas industry in many European countries is introducing much stricter regulations about TENORM, but there is a need for more harmonization between countries.

In my view, there will in future be a strong emphasis on harmonization with regard to the regulation of TENORM generally.

B.J. HOWARD (United Kingdom): I would mention that in the forthcoming ERICA project we have a work package on case studies and that two of the case studies relate to exposures to natural radionuclides. One case study deals with offshore drilling platforms used in the oil and gas industry and the other with the Komi Republic (in Russia), where there are also high exposures to natural radionuclides.

S. SMITH (WWF): Given the gaps in our knowledge about interactions between radioactive substances and biota, can one say with confidence that the protection of human health and safety results in adequate protection of biota?

B.J. HOWARD (United Kingdom): I do not think that one can. In my view, further work needs to be done before that statement can be made with confidence.

We currently have difficulties in quantifying transfers of radionuclides to biota, and I think some pathways could lead to higher internal exposures.

P. STRAND (IUR): I agree with what Ms. Howard just said.

D.S. WOODHEAD (United Kingdom): In a retrospective sense we can probably show reasonably well how different situations may or may not fit into the ICRP paradigm, but I believe that in a prospective sense the knowledge gaps which have been identified militate against our accepting that paradigm.

F. BRECHIGNAC (France): In filling data gaps on the basis of allometric relationships, is it possible to work just with existing data or does one need new data?

B.J. HOWARD (United Kingdom): One needs both existing data and new data, for different nuclides and different species.

I.A. GOUSSEV (Russian Federation): Perhaps the title of this conference should have been “Protection of the Environment from the Effects of Internal Exposure to Ionizing Radiation”. So far, nobody has mentioned the importance of external radiation exposure.

C.A. ROBINSON (IAEA): Perhaps the question of external radiation exposure will be raised when we come to talk about dosimetry.

S.R. JONES (United Kingdom): In my view, this is an important question, as one can argue that for very small animals and for gamma-emitters the transfer factor is unimportant because external radiation exposure will predominate. One must consider both radioecology and dosimetry.

L.-E. HOLM (Sweden): Ms. Salomaa said in her presentation that in preventing deterministic effects we also prevent stochastic effects to a large extent. I do not follow her reasoning — in humans, stochastic effects are observed after exposures to doses that are orders of magnitude lower than the doses necessary to cause deterministic effects.

S.I. SALOMAA (Finland): In my view, when we protect non-human biota from deterministic effects we are protecting the most sensitive organism in the population or ecosystem from such effects. There will be other — less sensitive — organisms, but the protection should be based on the dose rates for practical purposes.

R.M. ALEXAKHIN (Russian Federation): I would like to ask Ms. Salomaa whether she compared the situation where non-human biota is irradiated by alpha-emitters with the situation where humans consume alpha-emitting food products. Does the ICRP paradigm hold?

S.I. SALOMAA (Finland): I was considering radiosensitivity vis-à-vis radionuclides that have already been incorporated. In other circumstances there may be — or probably are — species that are more radiosensitive than humans.

DISCUSSION FOLLOWING THE PRESENTATIONS OF MENZEL AND CHAMBERS

L.-E. HOLM (Sweden): In his presentation, Mr. Chambers proposed an RBE value of 10 — a sort of average. The question is “for what?” There seems to be a lack of clarity about what RBEs are for. We seem to use them for everything, and when we talk about the weighting factors for humans we say that they relate specifically to stochastic effects — and, if I remember correctly, in 1990 the recommendations of ICRP indicated that the RBE for deterministic effects was rarely more than a factor of 2, so there may be an argument for using a value of 1 for deterministic effects in non-human biota.

If the evidence in the ICRP report was based on all of the available animal data, why should we differ so much in evaluating weighting factors for deterministic effects in other populations — other species?

D.B. CHAMBERS (Canada): There are a couple of reasons for the recommendations made by Canada’s Advisory Committee on Radiological Protection in this regard.

We thought about the implications of using different numbers for humans and non-human biota. There is a very nice review paper by Professor Barendsen on the subject. The appropriate alpha radiation weighting factor for non-human biota might well be less than 10, but there are uncertainties. From the review of data I feel that a notional number of about 10 would allow for the uncertainties and would be appropriate for a wide range of deterministic effects.

I acknowledge that this is uncertain, and if somebody was doing a sensitivity analysis/an uncertainty analysis he would use a range. I proposed 5–20, but it might be 2–40. However, we could have a number like 20 for alpha particles and humans, and we can change our minds later if we get more data, but I feel that we must have some practical way of moving ahead.

L.-E. HOLM (Sweden): Since we say that the basic molecular effects are so similar in all species, why are there such big differences? Do you think that we need to change the value for deterministic effects in humans to higher values as well?

D.B. CHAMBERS (Canada): Probably not. My recommendation of 10 reflects my misgivings about the large uncertainty in the data. The value may well be lower; in the light of an assessment made by Mr. Gentner in collaboration with Akhilesh Trivedi, I think a value of 5 might be better.

Having heard concerns about uncertainty, however, I would propose 10 as a provisional, interim number.

M. BALONOV (IAEA): Given my radiobiological background, I believe that the key point here is not so much the effect itself as the duration of the exposure — the opportunity for the DNA to repair the damage.

In this case we are considering the annual exposure, so the number should not be very far from 20 for stochastic effects in humans despite the fact that we are considering deterministic effects. However, the time for repair is very long, and in the low-LET case the cell has an opportunity to repair the damage. So it should not be very far from the human case for stochastic effects.

H.-G. MENZEL (ICRU): I doubt whether you can account for all situations through a simple weighting of absorbed dose. Alpha particle exposure is very particular in that with low doses the vast majority of cells do not receive any dose at all. So you have to be very clear what you mean by "absorbed dose". In the case of an organ (of anything macroscopic), the averaging, which is in effect what you are doing, may not be very meaningful. Is the use of a weighting factor then good enough to account for that? In the case of the use of effective dose for radon and radon daughters, we have realized that things cannot be right, and at the moment ICRP's lung model is not being used for lung exposures to alpha particles. I think that this has to do with the fact that there are limits to the concept of averaging over large volumes where there is energy deposition in only a few cells and those cells receive a high dose.

All in all, it is an empirical approach, but as with all empirical approaches we should at least consider where the limits are.

D.B. CHAMBERS (Canada): I agree. There are a number of uncertainties involved in dosimetric calculations, one being the uncertainty associated with averaging over an entire organ or tissue. One needs to consider the dose calculation procedure, which unfortunately is not well described in some reports, so that it is not clear how the dose calculations were performed.

Perhaps we should adopt, for alpha particles, a dose calculation procedure whereby we calculate the absorbed dose for low-LET and alpha particles with a slightly different procedure for alpha particles.

Within the current dose calculation ability, we are limited in practice to something like what I suggested — absorbed dose and some weighting factor.

K.A. HIGLEY (United States of America): With regard to external exposures to alpha particles, I would note that — as frequently stated — the range of alpha particles is very short relative to the entities of concern. However, there are cases where — as with, for example, fish eggs and root hairs — the range of alpha particles is not so relatively short and cells of concern may be hit.

I have been asked in the past whether I have taken account of the potential effects in the case of root hairs buried in the soil with surface alpha particles. When one starts performing the calculations, one encounters the question of the absorbed dose in the range of a cell. We know from radiobiological studies that a single hit to a cell nucleus can kill the cell, whereas the cell can survive millions of hits to the cytoplasm. One therefore finds oneself considering how many interactions or decay events are going to occur during the life cycle or the sensitive life stage of the entity of concern.

In my view, for the sake of scientific rigour — or simply because it is an interesting issue — we should focus more on external exposures to alpha particles.

H.-G. MENZEL (ICRU): There must be situations where external exposures to other emitters also have to be considered — situations where entities of the size of a cell or a few cells are concerned. Whether such situations are significant from the point of view of environmental radiation protection, I cannot say.

N. GENTNER (UNSCEAR): In response to the point raised by Mr. Holm just now, I would recall that RBE varies according to — inter alia — the particular stochastic end point, the dose and the dose rate. It may be lower for the types of deterministic effects relevant in human radiation protection (for example, lens opacification), but not for other types of deterministic effects.

As with stochastic effects, we may expect a range of RBEs for deterministic effects. Those important for environmental radiation protection — reproductive success — may well have a different value. So we should not fall into the trap of again expecting one value.

D.B. CHAMBERS (Canada): I agree, and I feel comfortable with a notional number and a range.

I.A. GOUSSEV (Russian Federation): Does the existing dosimetric system for non-human species ensure sufficient risk assessment accuracy to satisfy the present regulatory requirements?

D.B. CHAMBERS (Canada): There are large uncertainties, but that is only a part of the puzzle. In my view, the main issue is whether we force biota to be at a specific point or let it move over its natural range. These uncertainties compound.

I personally think that there are large uncertainties in dosimetry, especially in situations where alpha particles are irradiating only nearby cells.

The art (it is not a science) is to suggest workable guidelines. If you have a guideline of 100 μGy/h that is never to be exceeded, that is a problem. On the other hand, you could have a guideline of 100 μGy/h to be used as a guideline to indicate when you may have to look more closely at the situation. However, I think we should also be very careful about what we suggest as guidelines, since there are large uncertainties at every step of the process.

H.-G. MENZEL (ICRU): What is intended ultimately is some sort of protection. That means, as with the radiation protection of humans, that you want to keep the risks below a certain limit — and you may want to optimize.

You cannot specify the risk as precisely as you can in the case of human radiation protection, where you say that the stochastic effect is carcinogenesis. So it has to be something else. However, once you have this concept, it should be related to some dose.

If you go back, there have been frequent references to a “knowledge gap”, and I often ask myself how one knows where there is a knowledge gap and what the knowledge is for. I conclude that it is for the evaluation of the dose or some dose quantity related to the risk — and I think you can work your way backwards only if you know that. Then you will have to find out what else you need to know in order to evaluate that dose.

It is my impression (but I may be wrong, as I am not a specialist in this field) that the knowledge gaps which are perceived are the knowledge gaps which scientists working in the field perceive. It is as if the efforts to identify knowledge gaps are driven by curiosity.

In my view, if you want to have a targeted approach, you must have the dose in mind, and it must be the dose which provides the basis for whatever you want to do in the way of risk limitation.

D.B. CHAMBERS (Canada): I agree. In my view, if we are to talk about a limiting value of 100 μGy/h it should be expressed as an absorbed dose.

When performing dose calculations, we must all have the same model in mind. I think there is a consistency issue all the way through that we should give some thought to notwithstanding the scientific uncertainties.

L.-E. HOLM (Sweden): Has the importance of genetic effects been discussed against the background of UNSCEAR’s recent statement that the genetic effects in humans seem to be much lower than was previously believed?

D.S. WOODHEAD (United Kingdom): Essentially, it has been decided that genetic effects will affect the population because they persist into subsequent generations and that many genetic responses (dominant lethals and so on) will appear as higher mortality or reduced fitness and will be indirectly included among some of the other end points.

The one thing we have difficulty in dealing with is changes in allele frequencies and their significance for the fitness of a population. It is amenable to study, but I think it is something for the longer term.

I. ZINGER (United Kingdom): I would add that, it is still possible that you need to look at the results recently reported by UNSCEAR to see how they might or might not affect the results for non-human biota.

M.R. QUASTEL (Israel): Has the question of hormesis — a bone of contention in human radiobiology — ever arisen in connection with radiobiological studies of non-human species?

P.A. THOMPSON (Canada): There have been some studies relating to the ameliorating effects of chemicals and radiation at low doses. I do not think there is any doubt that such effects occur, but they vary from short term to long term (relative to the life span of the organism of interest) so that it is difficult to use information about them in making risk assessments or predicting effects on populations.

Work has shown that in many cases the hormetic response is an adaptive response to low exposures. As exposures increase and when we have mixtures of stressors in the environment, hormesis may not be very relevant to environmental protection.

N. GENTNER (UNSCEAR): In all species, most genetic and hereditary changes are selectively neutral. Most systems for looking at the process of mutation are chosen to give high yields of the end point in question. Consequently, linking the mutation level to a possible adverse effect on the population is difficult. Not only are most mutations selectively neutral, but many systems — for example, minisatellite mutations — occur in areas of the genome that the cell could not care less whether or not they were removed.

Regarding mixtures of radionuclides and other agents, there is not a paucity of data on ionizing radiation or radionuclides and other agents. Annex H to UNSCEAR's 2000 report contains many hundreds of references dealing with the combined action of ionizing radiation and other agents.

A similar conclusion was reached: except for agents that act on steps of similar rate or rate limitingness in a given pathway, isoadditivity seems to be the way to go. I think that conclusion is fairly well substantiated, but on the basis of plentiful data — not a paucity of data.

P.A. THOMPSON (Canada): I have another perspective. I do not think there is a very good correlation between the number of mutations in cells and possible effects on individuals. However, there have been some studies carried out for conservation biology purposes where changes in the gene pool have been important for determining whether a population will be able to recover if conservation efforts are made. Also, there have been some studies carried out downstream from pulp and paper mills and other facilities where changes in the gene pool have reduced the fitness of populations by limiting gene pool variability and making fish and other organisms more sensitive to stressors that come later than those which were there in the first place.

So, I do not think that we can discount those types of effects and the significance of genetic effects. In my view, the difficulty lies in trying to draw conclusions about the significance of mutations from their number. This is an area where a lot of conservation biology and other research is being done, but at present it is difficult to extrapolate from numbers of mutations to higher level effects.

D.B. CHAMBERS (Canada): Would Ms. Zinger care to comment on the usefulness of biomarkers in environmental monitoring and on the relationship between biomarkers and potential effects?

I. ZINGER (United Kingdom): At the Environment Agency we have looked at biomarkers, and techniques do exist. The main problem is that a biomarker technique may work in the laboratory, but in the environment there may be a combination of contaminants and you may be unable to determine which contaminant is the cause of the effects that you see. There is still some research to be done so as to be able to use biomarkers for environmental monitoring for regulatory purposes, where it is necessary to identify the cause.

I personally think that, when you have environments with many contaminants present, the use of biomarkers is a good starting point in determining whether you have a problem.

J.A. STEEVENS (United States of America): In her presentation, Ms. Thompson talked about the use of bioassays. There has been some success in assessing, with the help of bioassays, complex mixtures of conventional chemicals, but can one use bioassays for radionuclides — and, if so, what bioassay method or toxicity test would Ms. Thompson recommend?

P.A. THOMPSON (Canada): In many cases, a number of bioassay methods — essentially the traditional ones — are appropriate. There is no reason why those methods should not be used for sites contaminated both radioactively and non-radioactively. The usefulness of the test — it will give you an idea of the type of biological response you may expect from exposure to the mixture of radioactive and non-radioactive agents.

We have found that in many instances the response is dominated by chemical toxicity. That in itself is useful information, because it allows you to decide where to focus your efforts.

H. VANMARCKE (Belgium): Within the framework of the FASSET project there was a survey of studies on the effects of ionizing radiation on ecosystems. What proportion of the studies was carried out in the field and what proportion in the laboratory?

I. ZINGER (United Kingdom): The majority were carried out in the laboratory.

M. BALONOV (IAEA): In her presentation, Ms. Zinger referred to an assessment of 16 wildlife groups and many biological end points which led to the conclusion that there is a more or less universal threshold of 0.1 mGy/h. Does the conclusion apply to all 16 wildlife groups and all the end points?

D.S. WOODHEAD (United Kingdom): It is a generic conclusion applying to all 16 wildlife groups, but for certain wildlife groups the threshold would be much higher. However, I do not think that we really want to have different thresholds for different wildlife groups. In the same way as earlier "guideline" dose rates were worked out, it is based on the most sensitive species, which are likely to be the mammals and some of the other vertebrates.

A. JOUVE (France): Is there a way of integrating as a stressor the thermal discharges from nuclear power plants into rivers during hot spells like the one which affected so much of Europe this past summer?

P.A. THOMPSON (Canada): In carrying out environmental assessments, we have looked at temperature effects in relation to the effects of various agents.

For certain fish populations, we have information on the effects of water temperature increases at critical life stages — for example, the effects on egg survival and the survival of the young. That information can — because it is often generated in a manner that looks like dose-response relationships, for example, or threshold chemical values — be integrated into an assessment. The population model I described included data for arsenic, nickel, uranium and radiation, but that model can be used for assessing temperature effects in combination with the effects of chemicals.

The difficulty lies in obtaining the critical information on the fish species of interest. However, the US Environmental Protection Agency has compiled and will provide information on many fish species.

J. SUTCLIFFE (United Kingdom): I would mention that the laboratory of David Brenner in New York can, using a kind of biomarker method, now show what the changes in DNA and cells are. He hopes that in about five years' time this will be useful in the human health area, and I believe that it could be useful in the environmental protection area.

DISCUSSION FOLLOWING THE PRESENTATIONS OF WOODHEAD, ALEXAKHIN AND PENTREATH

A.J. GONZÁLEZ (IAEA): Mr. Woodhead said that the fitness of a species is reduced by an increase in the mutation rate. In an environment that is changing as a result of factors such as industrial pollution, however, might an increase in the mutation rate not be beneficial in that it increases the possibility of adaptation?

D.S. WOODHEAD (United Kingdom): I think there may have been a slight misunderstanding. Dominant lethal mutations would appear as reductions in fertility. Some mutations reduce fitness, and that would affect mortality. So the effects of some mutations will to some extent be captured by other end points.

I was careful to say that I could imagine situations where mutations — particularly when they continue into subsequent generations and have perhaps adaptive advantages or change fitness in ways we do not yet recognize — might be important. However, I do not have either the information or the tools necessary for considering such situations, so I left them to one side. Not that the problem is unimportant, and if other people have the necessary information and tools they should tackle it. I know that that particular population-type model has been used in looking at genetic effects, so it can be done.

A.J. GONZÁLEZ (IAEA): The thesis "if radiation safety standards protect humans, then biota is also adequately protected" presupposes that one is complying with the radiation safety standards. In my view, therefore, the Chernobyl accident and the Techa river situation are not helpful examples for testing the applicability of current international standards, since the radiation safety standards were not complied with.

That having been said, I recognize the value of the data presented by Mr. Alexakhin on radiation impacts on humans and various other species.

R.M. ALEXAKHIN (Russian Federation): I agree with Mr. González; it impossible to use this information for checking the correctness of the ICRP paradigm if we consider the situation during the period immediately following an accident. These data are useful for studying long term effects in the field rather than under laboratory conditions.

R.J. PENTREATH (United Kingdom): The issue here is a difficult one. In a situation where there is serious radioactive contamination of the environment, you can protect humans by evacuating them, but what do you do with everything else in the environment?

A problem for policy-makers is that there is no single number which protects people; ICRP has not a single number but a set of numbers for managing many different situations. It is not a question of regulation but of managing situations. What, then, can we use in the case of the environment? How can the environment be made safe if we do not have criteria for judging whether it is safe?

L. KOBLINGER (Hungary): In the Techa river region, have there during the past 50 years been any significant changes in the fauna — for example, any extinction of species or creation of new species?

R.M. ALEXAKHIN (Russian Federation): As I mentioned in my presentation, the doses incurred decades ago in the Techa river region were not measured directly; they have been reconstructed on the basis of the concentrations of radionuclides in components of aquatic systems — water, sediments, aquatic organisms and so on. The calculations were performed by Mr. Kryshev, who is attending this conference.

We have not seen any subsequent changes in the flora and fauna of the Techa river region.

In the Urals there have been very important marginal effects — the intrusion of flora and fauna species from surrounding areas which has resulted in small changes near the Techa river. The near-shore area along the Techa river is very narrow, so that the influence of marginal movements of species is extremely important.

I have observed the same situation in the East Urals. Given the very high doses, we expected drastic effects, but the influence of marginal movements of species (animals and plants) overcame the effects.

A. JOHNSTON (Australia): We all understand why protection has been pursued at the population level, but it is difficult to translate effects on the individual into effects on the population. Given that in general we all expect that radiation protection of the environment is not really going to be a significant problem, could a pragmatic outcome be a protection regime that is based on protection of the individual rather than of the population?

D.S. WOODHEAD (United Kingdom): Yes, provided that you can show that whatever criteria you apply at the individual level have the effect of protecting the population. Use simple models if you wish, but whatever happens you will be forced back into protecting — or preventing effects — at the individual level and will apply dose rates to individuals. We are not going to have collective doses for populations.

We must have dose rates at the individual level, although, for compliance purposes, they will undoubtedly be converted (back) to environmental concentrations.

S. MIHOK (Canada): In the 1960s and 1970s — and earlier — there were in the former Soviet Union many highly respected ecologists doing long term population studies on small mammals — just the people to generate the data which we need in order to interpret dose effects on populations and on. The

Chernobyl accident provided these ecologists with a good opportunity for obtaining funds and other support for their work, but I have not found in the literature any reports on population studies carried out in the Chernobyl area — and I am wondering why.

R.M. ALEXAKHIN (Russian Federation): The reason is probably that in many countries of the former Soviet Union we publish the reports on work done by us mainly in Russian.

In recent years, we have published at least 50 reports on population studies, more than half of which were carried out in the Urals and in the Chernobyl area.

We recently published (as a very thick book) a comprehensive report on the medical and ecological consequences of the Chernobyl accident and other serious nuclear accidents that occurred in the former Soviet Union. The report has already been translated into Japanese, and it is expected that an English translation will be published next year.

R.J. PENTREATH (United Kingdom): Mr. Mihok's intervention touches on a broader issue — the science base for environmental radiation protection is largely outdated; many of the data sets in the FASSET database are 20–30 years old. That is not to say that they were not good (some of the best work was done over 30 years ago), but they do need to be updated.

Environmental science has advanced considerably during the past 30 years, but in the field of environmental radiation protection we have not been asking the right questions properly, and the necessary research work has therefore not been done. All too often, we have simply been looking at areas where there are high radiation levels in order to see what we can find; that is exploration — not science.

S. SAINT-PIERRE (France): As someone from the nuclear industry, I should like to be sure that I have an accurate picture of the situation, while recognizing that not everything can be clear.

Firstly, on the assumption that the modelling is reasonable, a number of about 1 Gy/a seems to be a kind of lowest guidance value for the protection of populations. I have not seen any evidence to the contrary.

Secondly, situations in which that figure is approached are exceptional situations like the one which existed after the Chernobyl accident, and even then the dose rates declined fairly quickly over time.

Thirdly, biota seems to be able to recover quickly as well — and in that context I would think developing and applying a simple system is quite feasible.

R.J. PENTREATH (United Kingdom): In my view, from the limited number of population studies that have been carried out one can draw some conclusions if those are the questions one is asking. The trouble is increasingly populations of animal and plant types other than those which have been studied because they are easy to study at the population level.

Experiments have been carried out at the population level and other questions have arisen — the most common ones nowadays probably relating to the practicality of maintaining biological diversity in all its forms (which includes genetic diversity within species). For obvious reasons, these are difficult questions.

In the case of fish, you can irradiate populations instead of building models based on your knowledge of individuals. The numbers seem to converge, but they are answers to only a very limited number of questions. Probably the questions asked 20 years ago are not the questions being asked nowadays.

Round Table 3

DISCUSSION

K.A. HIGLEY (United States of America): There is something to be learned from the old joke about the drunkard searching one night for his house keys by a street lamp-post — when asked whether he had dropped his keys there, he replied “No, but this is the only place where there is enough light to search for them.” At this conference, I have participated in discussions that have been very useful in suggesting where one should search. For example, Mr. Beresford’s views on “does size matter?” may help to move the lamppost to where it is needed.

However, we shall have to exercise caution when moving the lamp-post; we must not let our preconceptions limit the scope of our search. For example, we have excellent modelling tools that we can apply uncertainty and sensitivity analysis to, and the results obtained are being used to indicate where we should focus our research efforts. However, these tools are valid only insofar as the underlying models are accurate representations of the processes which they model.

Earlier this week, we were told by Mr. Strand about an analysis which suggested that the uncertainty in dosimetry accounted only slightly for our lack of knowledge about radiation effects. However, the conclusion in question was based on the assumption that external alpha radiation is inconsequential and the assumption that mean dosimetric quantities such as absorbed dose are the appropriate measurement units for short range high LET radiation such as alpha radiation.

Then there is the simplifying assumption — again for alpha radiation, which I refer to because it constitutes a convenient example — of homogeneity in tissue distribution or conversely point source approximations in or around the organism of concern. However, the environment is not nearly so simple in its distribution.

Moreover, we tend to discount the external alpha doses to cells. What, however, if a fish egg or a pine root hair is the organism of concern? What about the protracted sporadic low-level irradiation of that organism as it develops?

One more thought — regarding the role which we, as scientists, play in the broader context of the development of environmental protection policy. Mr. Larsson described the role of the FASSET and EPIC projects in this connection; Ms. Clark spoke about our role in her presentation on searching for coherence and consistency; and Ms. Oughton spoke about values, ethics and perceptions.

At this conference, the question has been repeatedly asked whether we know with certainty that if we protect humans we are also protecting the environment, and by and large the answer has been "No". An intrinsic contradiction in science, however, is the fact that the more we learn about something the less we feel we really know about it, and we need to be careful about how what is a valid expression of scientific uncertainty is perceived by our non-technical counterparts. We need to have a healthy debate with them, but we must make it clear to them that non-human biota is not dying in vast numbers because of the current practices involving ionizing radiation. My gut feeling (a bad thing to mention when one is talking about science) is that the radiation effects on non-human biota at the present level of human radiation protection are small, subtle and scarce or non-existent, but we need rigorous research in order to determine what exactly the situation is.

J. GARNIER-LAPLACE (France): There are undoubtedly data gaps, and in my view the main challenge for us now is to establish a priority list for filling them. In establishing that list, we should be pragmatic and focus on those data gaps which significantly reduce our ability to apply an ecological risk assessment methodology.

I think we all agree that the domain of interest is limited to chronic low level exposure — "chronic" meaning significant relative to the duration of the life cycle. We must consider a range of timescales because of the different life cycles of different organisms — from one day for phytoplankton to many years for mammals. By "low level" exposure I mean environmentally relevant dose rates. That having been said, it should be recognized that bioaccumulation, of alpha emitters in particular, may result in relatively high dose levels in cellular or sub-cellular structures, even at low ambient dose rate levels.

To be pragmatic, let us consider the basic requirements of an ecological risk assessment for radionuclides. The first stage is exposure analysis. The approach proposed by Ms. Howard in Topical Session 4 for the application of biological scaling based on size and the allometric approach to filling transfer factor data gaps will obviously need to be validated through field or laboratory experiments in order to gain in credibility.

Attention should be paid to radionuclide bioavailability, knowledge of which is essential for an accurate assessment both of exposures and of effects. I think it is now well established that knowledge of the distribution of a given chemical element (radioactive or non-radioactive) among its various physico-chemical forms is necessary in order to understand both its mobility (that is to say, its transport from one compartment to another) and its biological reactivity (that is to say, its transfer within living organisms and the potential induced effects). In that sense, bioavailability is also a factor responsible for ecotoxological effects of radionuclides emitting alpha and beta particles, which are the most radiotoxic in cases of internal contamination.

We also need to know about the geochemical behaviour of radionuclides in order to accurately calculate the external radiation dose or dose rate and thus to predict the effects on the life style of the living organisms being considered.

We need in addition to do research into radionuclide behaviour within what one might call the “reservoir compartments” of ecosystems — that is to say, sediments and soils acting as secondary sources of radionuclides.

The second stage in ecological risk assessment is effects analysis. There, I think we have to focus on the chronicity of exposures — the chronicity of exposure to a pollutant leads to different biokinetics, although most of our present knowledge relates to acute exposures at high level doses. The specifics of the exposure conditions are important; the pathways (direct through trophic transfer), the radionuclide concentrations and the exposure duration strongly modify the internal radionuclide distribution at various biological stages, which obviously modifies the delivered dose, the dose rate and the potential induced effects.

It is also important to consider the different timescales of biological effects (from early effects to delayed effects) at different organizational levels, from the sub-cellular level to higher organizational levels. As regards extrapolating from individuals to populations, I believe that, as Mr. Woodhead said, one way of gaining greater credibility would be to use demographic modelling and other demographic techniques. The extrapolation issue should be an important aspect of the ERICA project.

The last stage of any ecological risk assessment — the risk characterization — combines information about exposures and effects. As part of this process, there is a need to develop an appropriate methodology for deriving environmental quality standards for particular radionuclides.

J.M. GODOY (Brazil): I shall try to answer the question “What are the most significant data gaps from the nuclear regulator’s point of view?” Could we carry out an environmental radiological risk assessment for a given nuclear facility in Brazil? The answer is “yes and no” — yes if we want to perform an exposure analysis in order to compare the numbers we obtain with certain proposed dose limits; no if we want to perform an effects analysis, since we do not have biological effects data for site specific receptors.

The use of reference fauna and flora has been proposed. In that connection, I suggest that for Europe an appropriate reference fruit tree would be an apple tree (a small tree with many leaves and with homogeneously distributed fruits that lives for many years) and for Brazil a banana tree (a tree that has few — but large — leaves and an inhomogeneous distribution of fruits and that is felled after harvesting).

The two types of tree are very different, so you may think that I have taken an extreme example. Therefore, let me give you another example. On page 252 of the Book of Contributed Papers (S.R. Jones et al., paper No. 75) you will find the following sentence: “The uptake of natural radionuclides by marine organisms has been quite extensively studied, and the range of natural doses experienced by most marine organisms can be quite easily established.” If you look at Table 1 on that page, you will see a median value of 37 Bq/kg wet weight for polonium-210 in molluscs. However, there is a kind of mussel found all along the Brazilian coast in which we have measured polonium-210 concentrations ranging from 200 to 2000 Bq/kg wet weight.

How can one solve the problem of defining appropriately specific organisms for consideration given the scarcity of funds? My suggestion is that one revisit areas of high natural radioactivity. There are some studies, carried out a long time ago but very well. For example, Drew and Eisenbud (see Health Physics 12, 1966) took mice and rats at Moro do Ferro (Iron Hill) in Brazil; they found 300 Sv; they did a dose calculation (the models are described in the paper) — a 300 Sv/y lung tissue dose — and no pathology. On the other hand, there is the paper of Gopal (1972) in the proceedings of the First International Symposium on High Natural Radioactivity; he found sterility and cytogenetic abnormalities in plants growing in Kerala.

There is strong social and ethical pressure for an integrated environmental risk assessment, but I would remind you that there is the concept of the “critical group”. I agree with Mr. Oliveira — I am not sure if the concept is being applied correctly; a critical group is a theoretical group which can be located anywhere — in the Kara Sea or at the perimeter fence of a uranium mining and milling facility.

I have another concern. We are talking about deterministic effects, so we have to take account of the background and how to apply any future protection approach to a high natural background environment like the ones existing at several uranium mining and milling facilities.

The pressure for an integrated environmental risk assessment does not come just from the nuclear industry; the same happens in other industries. There is an interesting paper recently published by Munns et al. (see Human and Ecological risk Assessment, Volume 9, 2003) with a proposal for an integrated environmental risk assessment including a human and ecological risk assessment for conventional industries, which are facing the same problems as us.

In conclusion, I would remind you of what Socrates said over 2000 year ago: “I know nothing except the fact of my ignorance.”

R. AVILA (Sweden): The more we learn, the more we realize how much we still do not know — so there will always be data gaps. The best we can do is to identify the more important ones and try to fill them. There are techniques for doing that, but they are context-dependent.

In recent years we have developed a framework, and I think we should now try to apply this framework to sites and scenarios which are relevant for our daily work and determine where the gaps are and which ones we can fill, and then maybe interpret the results in a more general context of risk. There are many sources of uncertainty, but they are often not significant within the framework as a whole.

Everyone here will have his/her own list of "favourite" gaps, depending on the field in which he/she is working. As I am working in the field of radio-ecology, I am very conscious of the gap relating to transfer factors. In my view, the easiest solution to this problem would be to drop the use of such factors, as they are so variable and so much uncertainty is associated with them. Perhaps we should try to identify some parameters that are more amenable to scientific estimation because they have some physical meaning. At present, transfer factors aggregate many processes into a simple factor that is uncertain. That having been said, I would add that I am trying to be a little provocative.

What should we do about uncertainties? The first thing we must do is accept the fact that they exist. There will always be uncertainties, and we should therefore develop methods for taking decisions and performing risk estimates in the presence of uncertainties. That means that we should stop looking for a magic number and settle for a range of values. There are techniques for performing assessments with a range of values as easily as with a single number.

A similar question may be applied to standards — why should the standards be defined in terms of a single number? A range of values, such as that emerging for human protection, would provide more flexibility and allow for uncertainty.

One way we have of reducing uncertainties is to integrate the protection of humans and environmental protection, for if we protect the environment it will be safe both for humans and for non-human biota. Often, we base our standards for the protection of humans on our knowledge about non-human biota. Perhaps we should now reverse the process. Why do we not integrate everything into a single system that protects both humans and non-human biota? It would then be a matter of choosing the appropriate standard for pragmatic radiation protection. My favourite would be concentration in different media; the concentration could be derived from the knowledge we have about the effects on both humans and non-human biota. We would also then have a basis to compare with other contaminants and with other risks.

M. BALONOV (IAEA): For me, the biggest gap is the one between individual effects and population effects. Ms. Salomaa has stated that, if the individual is protected, the population is protected. Mr. Woodhead has stated the opposite. I tend to agree with Ms. Salomaa. As regards Mr. Woodhead's position, the problem for me is that he has considered mainly deterministic effects in fish populations; if the effects are deterministic, "safe" means "below the threshold". If all the effects considered are "below the threshold" for individuals, how can they harm the population?

K.A. HIGLEY (United States of America): I understood Mr. Woodhead to be sounding a cautionary note, saying that everything depends on what level of protection you specify for the individual before you see effects in the population — so you really have to be careful.

J. GARNIER-LAPLACE: With regard to the issue of extrapolation from individuals to populations, I do not think there is a generic answer for all species effects. It depends on the resultant effects on the life cycle of the species being considered and on the most sensitive life stages, as demonstrated by the modelling approach using demographic parameters outlined by Mr. Woodhead.

J.M. GODOY (Brazil): In my view, it is also quite important to recognize that environmental parameters generally have a log normal distribution, so that high values are normal occurrences and where you set the limit is a difficult question.

R. AVILA (Sweden): One problem of extrapolating from individuals to populations is that populations are — in real life, as opposed to models — regulated by a combination of stressors and other factors. Everything is context-dependent.

J. GARNIER-LAPLACE (France): You can use the sort of approach outlined by Mr. Woodhead as a tool for sensitivity analysis in order to see which effects and which parameters are important. It would then be possible to combine the influences of other stressors, such as heavy metals, on which we have quite a lot of data.

D.S. WOODHEAD (United Kingdom): Regarding the comment made by Mr. Balonov a few minutes ago, in my Topical Session 4 presentation I was not claiming that, if you protect individuals, you will not protect the population. As Mr. Avila just said, everything is context-dependent; the life cycle influences what the outcome is going to be at the population level. You cannot assume that a given level of protection based on any of the parameters which influence a population will necessarily protect the population. You have to look at both the individual and the population end points — to go through simple modelling approaches and to consider other stressors, as Mr. Avila was just saying.

Included in the model which I outlined is a carrying capacity for the environment; there is stochasticity in some of the parameters, which is why, particularly in the plaice population, the results are so variable.

At the moment, a normal distribution is assumed. However, I agree with Mr. Godoy that in fact some of those parameters have log normal distributions.

All these things are easy to investigate once you have set up the model; you change your parameter and press a button, and you can see the response. In most cases, however, this response will be different from what you expected.

K.A. HIGLEY (United States of America): It is indeed easy — and also enjoyable — to carry out such intellectual exercises in a library, but we must convince the people controlling the financial resources that we need also to do the practical laboratory and field work.

D.S. WOODHEAD (United Kingdom): I agree. The validation of these models is going to be extremely difficult.

Fisheries biologists have been trying to manage fish populations for the past century, and we all know where that has got us. The sort of work I described today must be embarked upon with great caution. It has only just started, and we are only scratching the surface, but it does indicate that there are things we must bear in mind when we are going through the process of setting up a system for protection of the environment. We must understand what the objective is and try to focus on it.

D.B. CHAMBERS (Canada): A system for protection of the environment must be capable of being explained to the people who are going to pass the legislation necessary for its establishment. Such a system will not reflect all the variability that exists in the environment. We should therefore do the necessary scientific work and propose something which takes account of as many uncertainties as possible while being comprehensible for our legislators.

K.A. HIGLEY (United States of America): We have standards for the protection of humans, with regulatory bodies determining what those standards mean. In the case of radionuclides, we have concentration limits which must not be exceeded. They are very easy to explain, and I expect that we shall ultimately have something similar for environmental radiation protection.

J.M. GODOY (Brazil): The standards that we have today are based on the natural background. If you wish to establish standards for fauna and flora, you will have to adopt the same approach.

R.J. PENTREATH (United Kingdom): In my view, we are moving towards the establishment of a common framework. In that connection, there has been a lot of discussion of human radiation protection. However, although the natural background radiation levels encountered by humans vary by almost two orders of magnitude (from about 2 mSv to well over 100 mSv), one does not see radiation effects in people living in areas with high natural background levels. Moreover, in most cases the doses incurred by people through occupational exposures are well below the limits, so perhaps we do not need any numbers for management purposes and could abandon the complexities of regulatory management (that would permit a reduction in the number of ICRP committees).

The purpose of discussions like the present one is to arrive at some sort of balance. In my view, the broader framework that we are trying to explore will allow for all the various effects of ionizing radiation.

It is widely believed that only humans suffer stochastic effects due to ionizing radiation, but other animals — and also plants — suffer such effects. For example, cancer occurs in other vertebrate animals — and even in invertebrate ones. However, our focus has been too narrow. We need to broaden it, engaging in discussion with all those who are trying to manage the environment in their different ways — particularly the sorts of discussion that have been taking place within the ICRP setting in the past couple of years. I believe that human radiation protection stands to gain a lot from work being done on the radiation protection of non-human biota.

Y. ZHU (IUR – Chairperson): As an environmental biologist, I would like to comment on an ecotoxicological aspect of the issue.

A lot of work has been done on heavy metals, the ecological impact of which depends on their bioavailability. A question that arises in this connection is which biological receptors should be considered — the most sensitive species, the most important species or what? Again in this connection, it is difficult to determine which species is the most important one as biodiversity generally leads to stability of the ecosystem.

B.E. CEDERVALL (Sweden): Under the pressure of an increased radiation dose rate, the E. coli Rect gene induces about 20 other genes. That affects the ability to evolve; it induces repair enzymes, but it also induces misrepair. Why does it do that? In my view, probably because of a need to be able to evolve under unusual conditions.

Turning to something that is a little more like a human being, I recall an experiment performed about four years ago with two fruit fly populations. One population was given a low radiation dose periodically, and after some time was found to be much healthier than the other population. The price it paid was probably the premature death of more individuals in its case than in that of the other population. If so, what was bad for individuals was good for the population.

C.G. LINDVALL (Sweden): We have been carrying out environmental measurements around nuclear power plants and other nuclear facilities in Sweden for several decades, and we have not detected any changes in flora and fauna attributable to radioactive releases from those facilities. Can we assume that the radioactivity levels of the releases are below what would be harmful to the environment?

K.A. HIGLEY (United States of America): Biota may not be seen to be suffering radiation effects, but I think that, rather than making assumptions, you should analyse all the available data carefully in order to be able to make a rigorously supportable statement of fact.

J.M. GODOY (Brazil): When some millibecquerels of cobalt-60 were detected in sediments, there was such an outcry in the Brazilian media that we discontinued the release of liquid effluent from Brazilian nuclear facilities. The only radionuclides now released from those facilities are tritium and noble gases, but they have not been detected in the environment.

P.A. THOMPSON (Canada): There are data gaps relating to — for example — the bioavailability of radionuclides and the extrapolation of radiation effects on the individual to radiation effects on populations. I suspect that there are similar data gaps in areas of environmental science besides environmental radiation protection, and I was wondering what the significance of data gaps might be from the point of view of environmental policy.

Y. ZHU (IUR – Chairperson): In my view, bioavailability is a key issue in the study of both radioactive and non-radioactive contamination. So far, however, we do not have a clear definition of "bioavailability" and we cannot measure the bioavailability of some contaminants — for example, heavy metals.

As regards radioactive contamination, another key issue is the early effects of radiation on biological receptors. We have the single cell electrophoresis method for looking at DNA damage, but we need an early-warning system for chronic low-dose radiation effects on particular biological species in the environment.

L.-E. HOLM (Sweden): Regarding the comments just made by Mr. Lindvall and Ms. Higley, we have analysed the available data in relation to uptake in various organisms, but not in relation to end points of those organisms. The data have been used only in calculating doses to critical groups.

D.S. WOODHEAD (United Kingdom): Further to what Mr. Lindvall said, I would note that we have radioactive discharge monitoring data that go back for about 50 years. If the models that we already have were applied to those data, we would learn a lot about the sensitivity of the parameters and be able to determine where the critical points in the chain are and calculate what the dose rates are.

For the Irish Sea, I calculated the dose rates on the basis of environmental values, but I could have gone through a modelling exercise asking what dose rates to expect and comparing them with what was actually measured. The result might have gone either way, but would it have mattered?

There are about 50 years of experience waiting to be “mined”.

H.G. MENZEL (ICRU): I have a feeling that for many scientists working in the field of environmental radiation protection the main task is to accumulate more and more data on more and more species. In my view, at present it would be more useful to take the existing data and — maybe through the reference species approach or other approaches — try to develop a concept which could be used as a management tool.

J.M. GODOY (Brazil): As a regulator, in using the reference organism approach I would need to explain to people in Brazil how a pine tree can be used as a reference for a banana tree, but in what ways are they are similar?

M.A. BOYD (United States of America): Given the fact that UNSCEAR and IAEA reports suggest a factor-of-ten difference in levels of protectiveness for aquatic versus terrestrial organisms and plants versus animals, I wonder whether there is still support for the broad species based differences in radiosensitivity that we have heard about this week.

D.S. WOODHEAD (United Kingdom): Regarding what Mr. Godoy just said, I would emphasize that the pine tree is not meant to represent the banana tree; it is just a reference organism — something for which you can make an assessment. If you want to make an assessment for a Brazilian banana tree, you can make a site specific one, but you should do the same thing for a Brazilian pine tree growing at the same site, so that you can compare across sites — so that there is a common point of reference.

J.M. GODOY (Brazil): The problem is that we regulators have to deal with people. During the licensing procedure for a nuclear facility, I have to explain to an auditorium full of people how I made my assessment, and nobody would trust my results if I said that in calculating the radiation doses to the local trees I used a pine tree as a reference.

D.S. WOODHEAD (United Kingdom): If the people in the auditorium want to know everything about everything, the situation is impossible.

J.M. GODOY (Brazil): Some things can be avoided and some cannot.

L.-E. HOLM (Sweden): The situation described by Mr. Godoy may be one where the local regulators should define their own reference organisms. ICRP is proposing to define only a very limited set of reference organisms, in order to make the “reference organism” concept known. You can define as reference organisms whatever organisms you consider appropriate for explaining how you have calculated the doses or made the risk assessments. However, you may wish to be able to relate your reference organisms to an international set of reference organisms.

K.A. HIGLEY (United States of America): Regarding Mr. Boyd’s intervention, I have not heard anything in the presentations made here to suggest that we should abandon the present positions on dose rate responses — but things could change.

As to the reference organism issue, we are searching for a grand unified theory of biota, of which we are a part, and reference organisms can serve as a tool in that search. However, it may be that cell cycle times — not reference organisms — are the important parameter in determining dose effects.

We have a variety of modelling and other tools which can help us to focus our thoughts, and I hope that ultimately we shall arrive at a simple recipe for protecting biota. However, the process is a messy one.

R.J. PENTREATH (United Kingdom): Regarding pine trees and banana trees, what we are trying to do is arrive at a situation where we can say something sensible about a defined type of tree. It does not matter what type of tree it is provided that it lends itself to the answering of an internally consistent set of questions about a tree. Once you have answered those questions, you can look into how other types of tree differ in their basic biology from the defined type, what parts of their life cycle are likely to be most important with regard to radiation effects and how that would relate to their exposure in different circumstances — and then you can make a reasonable response to a question which may or may not have been reasonably asked. That is all we are trying to do.

G.M. GODOY (Brazil): I referred to the banana tree only in order to stimulate discussion.

I take this opportunity to point out a major difference between South America and Europe — South America has primarily a north-south orientation, whereas Europe has primarily an east-west orientation, so that the ecological differences are greater in South America than in Europe. The changes in flora and fauna as one traverses South America from north to south are dramatic, and that will have implications for the defining of reference organisms.

U. KAUTSKY (Sweden): During the past 20 years, a lot of work has been done by ecologists, ecotoxicologists and others on extrapolating from individuals to populations, and I do not think that there is a knowledge gap in that area. However, radioecologists do not use the information that is available, even though it is as applicable to radionuclides as to non-radioactive contaminants.

S.I. SALOMAA (Finland): There is a great deal of data available on genetic effects on mice, drosophila and various other organisms, and with these data you can extrapolate from acute to protracted exposures — at least you can extrapolate from high doses to low doses.

However, I do not know how much data there is on genetic effects on plants.

J.M. GODOY (Brazil): Some work has been done on genetic effects on plants — mainly plants growing in areas with high natural radioactivity levels. For example, Gopal has done such work in Kerala.

With plants there are indications of declining fertility.

B.E. CEDERVALL (Sweden): In the botanical field, a great deal of genetic data was collected 50 or more years ago; one of the key names is Browm (see Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 1964). In the early 1960s, Lars Ehrenberg (see Hereditas, 1966) published a number of papers on mutation rates in barley and pollen grains; the data collected by him and others are of very high quality.

S. SAINT-PIERRE (France): Around most facilities there is so far no evidence of harm due to ionizing radiation. In my opinion, therefore, it would be a misallocation of resources to develop numerous systems with numerous reference organisms. I am not opposed to the reference organism approach, but I think a simple system would suffice for dealing with what does not appear to be a big problem.

A. JOUVE (France): In my opinion, an important consideration when selecting organisms to serve as reference organisms should be how widely spread the organisms are.

K.A. HIGLEY (United States of America): You might then find yourself selecting the cockroach as a reference organism, which might not be the best choice.

C.-M. LARSSON (Sweden): Regarding what Mr. Saint-Pierre just said, I would emphasize that what we are trying to do now is systematically examine all the available data with a view to determining whether there are really no harmful effects that we should be concerned about. However, there are so many data gaps that the final evaluations will have to be made and the resulting decisions taken under conditions of considerable uncertainty.

Given the uncertainty, how should risk characterization be performed?

J. GARNIER-LAPLACE (France): Perhaps that question will be answered by the ERICA project.

In any case, from the field of chemicals we have many examples of methods for communicating with stakeholders. It would also be helpful to use the risk characterization methodology used for chemical pollutants. This methodology, modified to take account of the specificities of radionuclides, might help us to establish a priority list of data gaps.

R. AVILA (Sweden): We talk about risk characterization, but we could say that we want to measure the risk somehow and to compare it with some reference values that will be applicable for a reasonable period of time.

It would also be valuable to establish standards that are applicable in practice — for example, concentrations in environmental media such as soil. To arrive at the concentrations, you could use the reference organism approach. You would get a concentration range in which you would not see any effects and in which it would be appropriate to look only at certain types of organism — instead of performing calculations for all organisms each time. Such an approach could be applied by different regulators to specific situations.

I think this way would be more flexible, and the availability of the standards would somehow reflect uncertainties.

K.A. HIGLEY (United States of America): Also regarding what Mr. Saint-Pierre just said, we do not see any problems at operating nuclear facilities. However, we have to think about site remediation after the decommissioning of nuclear facilities, and in that connection we must consider what is an acceptable level of risk for the environment. By seeking better guidance for the cleanup of sites we are not casting aspersions on the nuclear industry.

J.M. GODOY (Brazil): I am sure that the right way to go is to use the concepts used in the field of chemicals.

I have serious doubts about the use of reference fauna and flora and favour the use of concentrations in different media.

If you publish such a table of defined concentration values, it is necessary to take account of natural background in its derivation.

IMPLICATIONS OF ICRP PROPOSALS FOR INTERNATIONAL SAFETY STANDARDS

(Topical Session 5)

Chairperson

Z. Pan
China

ICRP DEVELOPMENTS ON PROTECTION OF NON-HUMAN SPECIES

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Abstract

The International Commission on Radiological Protection (ICRP) is currently revising its recommendations. Until now, the Commission has not published any recommendations as to how assessment or management of radiation effects in no-human species should be carried out. In 2000 the ICRP set up a Task Group to address this issue and recently adopted the Group's report. This report addresses the role that ICRP could play in this important and developing area, building on the approach that has been developed for human protection and on the specific area of expertise to the Commission, namely radiological protection. ICRP will develop a small set of reference animals and plants, plus their relevant databases to serve as a basis for the more fundamental understanding and interpretation of the relationships between exposure and dose, and between dose and certain categories of effect, for a few but clearly defined types of animals and plants. This concept is similar to that of the reference individual (Reference Man) used for human radiological protection, in that it is intended to act as a basis for calculations and decisions. The Commission has now established a new Task Group to continue the work with defining effects end points of interest, the types of reference organisms to be used by ICRP, and defining a set of reference dose models for assessing and managing radiation exposure in non-human species.

1. INTRODUCTION

ICRP's advice targets the regulators and implementers that have the responsibility for establishing radiological protection standards. Environmental protection has made considerable progress since ICRP's recommendations on radiological protection were published in 1991 [1]. The increasing public concern over environmental hazards has resulted in many international conventions, and the need to protect the environment in order to safeguard the future well-being of man is one of the cornerstones of the Rio Declaration [2]. Radiological protection of the environment has attracted increasing attention over the last decade, and there is currently a frequently held view that protection from harmful effects of ionizing radiation should also be provided for non-human species. In several countries, for example in Sweden, there are already legal requirements to do so [3].

ICRP has, until now, not explicitly dealt with protection of the environment, except in those situations where radionuclide levels in non-human organisms were of relevance for the protection of man. There are no ICRP recommendations on protection of the environment, and there is, therefore, little guidance as to how radiological protection of the environment should be carried out, or why.

The human habitat has indirectly been afforded protection as a result of the ICRP's system of protection of humans. However, it is difficult to convincingly demonstrate that the environment has been or will be adequately protected in different circumstances, since there are no explicit sets of assessment criteria, standards or guidelines with international authority. Different approaches have been used to address the many questions raised with respect to the application of ICRP's position on environmental protection, ranging from arguments that when man is protected, all other organisms are protected, to systematic frameworks to assess environmental impact of radiation in specific ecosystems [4]. The development of approaches to protect the environment is to a large extent driven by the needs of national regulators and by international organizations to safeguard a sustainable development.

In 2000, the ICRP set up a Task Group to advise it on the development of a policy for the protection of the environment, and to suggest a framework by which it could be achieved. The Task Group concluded that a systematic approach for radiological assessment of non-human species is needed in order to provide the scientific basis for managing radiation effects in the environment [5]. It has chosen an approach proposed by Pentreath [6] and that uses a reference set of *dosimetric models* and a reference set of *environmental geometries*, applied to *reference animals and plants.* This approach will allow judgements about the probability and severity of radiation effects, as well as an assessment of the likely consequences for either individuals, the population, or for the local environment. The Task Group further recommends that the radiation induced biological effects in non-human organisms be summarized into three broad categories: early mortality, reduced reproductive success, and scorable DNA damage. These categories comprise many different and overlapping effects and recognize the limitations of the current knowledge of such effects.

The Task Group has proposed objectives for a common approach to the radiological protection of humans and the environment [5]. This includes safeguarding the environment by preventing or reducing the frequency of effects likely to cause early mortality, reduced reproductive success, or scorable DNA damage effects in individual fauna and flora to a level where they would have a negligible impact on conservation of species, maintenance of biodiversity, or the health and status of natural habitats or communities.

The ICRP recently adopted the Task Group's Report, and has decided to develop a framework for the assessment of radiation effects in non-human species [7, 8]. This decision has not been driven by any particular concern over environmental radiation hazards. It has been developed to fill a conceptual gap in radiological protection and to clarify how the ICRP can contribute to the attainment of society's goals of environmental protection. ICRP does not intend that the proposed system will include regulatory standards. It is instead a framework that can be a practical tool to provide high level advice and guidance and help regulators and operators demonstrate compliance with existing legislation. The Commission has also established a new Task Group to continue the work on defining effects end points of interest for the effects of radiation, the types of reference organisms to be used by ICRP, and defining a set of reference dose models for assessing and managing radiation exposure in non-human species.

2. REFERENCE ANIMALS AND PLANTS

The purpose of developing a systematic reference animal and plant approach is to derive a reasonably complete set of related information for a few types of organisms that are typical of the main environment types [4, 5]. This approach cannot provide a general assessment of the effects of radiation on the environment as a whole, but it could provide the basis for judgements about the probability and severity of the likely radiation effects on such individuals. Using these and other environmental data, one should then be able to assess the likely consequences for either individuals or the relevant population, in order to make managerial decisions relevant to the circumstances.

In order to calculate radiation dose, a set of reference values is required to describe the anatomical and physiological characteristics of an exposed individual. Such reference values have long been used for dose assessments for humans [9, 10]. For the environment as a whole it will not be possible to provide a general assessment of the radiation effects. The concept of deriving such data sets for reference animal and plants is similar to that used for human radiological protection, in that it is intended to act as a basis for many calculations and decisions [5]. It is also similar to the concept of assessment and measurement end points used in the Environmental Risk Assessment frameworks [11]. Each reference organism would serve as a *primary* point of reference for assessing risks to organisms with similar life cycles and exposure characteristics. More locally relevant information could be compiled for any other fauna and flora; but each such data set would then have to be shown to be related in some way to the reference animals and plants.

For each reference animal and reference plant for environmental assessments, one should obtain a fairly internally consistent set of data on:

— Basic life cycle biology;
— Pathways of exposure to radiation that can be expressed in terms of dose per unit exposure;
— Dose model(s) to estimate doses received by the relevant organs;
— Radiation effects (early mortality, reduced reproductive success, and observable DNA damage) on individuals.

Such data sets, for a number of reference animals and plants, would also serve as 'default' values for use in various assessment scenarios. The reference animals and plants should also have some form of public or political resonance, so that both decision makers and the public are likely to know what these organisms actually are, in common language — such as a duck, or a crab.

The variety of dose models needed for reference organisms, in addition to the obvious considerations of target size and shape, will clearly depend upon how the consequences of radiation result in one of the above categories of biological effect. A short hierarchy of dose model complexity has been suggested by Pentreath and Woodhead [12]. Many of these models are providing the basis of the current studies being made within FASSET [13]. Another important consideration is that of the possible range of 'environmental' geometries within which these dose models could be set.

3. DOSE CONSIDERATION LEVELS

Another question regarding the reference animal and plant approach is how to interpret and apply data on the relationships between doses and biological effects. For the protection of humans, ICRP is proposing an approach based on *levels of concern* with explicit reference to background dose rates [14]. For animals and plants, data could be set out in similar scales of dose-effect levels — *derived consideration levels* — to aid in the consideration of different management options [5]. There are currently only two bases upon which to assess the potential consequences for fauna and flora: natural background dose rates and dose rates known to have specific biological effects on individuals.

TABLE 1. EXAMPLE OF DERIVED CONSIDERATION LEVELS

Derived Consideration Level	Relative Dose Rate (Incremental Annual Dose)	Level of Concern
1	< Background	Low concern. No action considered.
2	Background range	Low concern. Probably no action considered.
3+	Background and higher	Concern dependent upon the nature of effects, the numbers and types of individuals affected, the spatial and temporal aspects, etc.

Bands of derived consideration levels for reference animals and plants could be compiled by combining information on logarithmic bands of dose rates relative to normal natural background dose rates, plus information on dose rates that may have an adverse effect on such organisms. An example of how derived consideration levels might look is shown in Table 1. Additional of dose rates that are only a fraction of the background doses experienced by these organisms might be considered to be of low concern, and those that are orders of magnitude greater than background would be of increasingly serious concern because of their known adverse effects on individual organisms [5].

Restricting the advice on individual animals or plants does not imply that the individual is necessarily the object of protection. A large number of animals and plants are already afforded protection at the level of the individual in international or national law, and it would be inappropriate to provide advice that could not be used in such legal contexts. Effects upon ecosystems are usually observed at the population or higher levels of organization, whereas information on dose responses is usually obtained at the individual level. Radiation effects at the population level — or higher — are mediated via effects on individuals of that population, and it therefore seems appropriate to focus on the individual for the purpose of developing an assessment framework [5].

Presenting data in terms of dose rates that are known to have particular radiation effects on different types of animals and plants would appear to be an appropriate and transparent format in which to provide general advice. This could be used to support legal frameworks at a national level, or in terms of using dose rates as the basis of any form of guidance or stricter form of legislative control.

4. ICRP'S FUTURE WORK

The aims of the work of ICRP's new Task Group on Reference Animals and Plants are to:

— Define end points for assessing radiation effects in non-human species;
— Select and define reference animals and plants to be recommended by ICRP;
— Develop a reference set of dose models and derived consideration levels for reference animals and plants; and
— Agree upon a set of quantities and units that could be suggested for use for reference animals and plants.

The criteria used in the selection of relevant reference animals and plants include the:

— Extent to which they are typical of a particular ecosystem;
— Extent to which they are likely to be exposed to radiation;
— Stage(s) in their life cycle likely to be of most relevance for evaluating total dose or dose rate, and of producing different types of dose-effect responses;
— Extent to which their exposure to radiation can be modelled using simple geometries;
— Possibility to identify radiation effects in an individual organism;
— Amount of radiobiological information already available;
— Their amenability to future research; and,
— Extent to which both decision makers and the public are likely to know what these organisms actually are [5].

The Task Group has begun to consider eleven types of reference animals and plants, essentially as generalized to the taxonomic level of family, although such details have not yet been finalized. They are as follows: rodent, duck, frog, freshwater fish, marine flat fish, marine snail, bee, earthworm, pine tree, grass, and brown seaweed. These represent organisms of the terrestrial, freshwater and marine habitats (Table 2).

The objective of the reference animals and plants approach is to provide a common basis for the assessment of exposure, radiation dose and possible responses for individual organisms. This, in turn, would be the starting point from which assessments for other individual organisms (e.g., different exposure pathways, bioaccumulation, geometries, etc.), and populations, could be made. The reasons for selecting each organism are summarized below:

TABLE 2. REFERENCE ANIMALS AND PLANTS IN RELATION TO THEIR ECOLOGICAL SPREAD

Organism	Terrestrial	Freshwater	Marine
Rodent	X		
Duck	X	X	
Frog	X	X	
Freshwater fish		X	X
Marine flat fish			X
Marine snail	X	X	X
Bee	X		
Earthworm	X	X	X
Pine Tree	X		
Grass	X	X	
Brown Seaweed			X

- **Rodent** (Family **Muridae, rats and mice)**: A small mammal with a generic mammalian life cycle. There exists a good database for effects and bioaccumulation kinetics, and also for effects of other pollutants, including carcinogens. The rodent is amenable to experimental study, and data can be extrapolated to and from small mammals in general.
- **Duck** (Family **Anatidae**, ducks, geese and swans): A bird with a generic bird-type life cycle. There is a limited database for effects and bioaccumulation kinetics, and also for effects of other pollutants, including carcinogens. The duck is amenable to experimental study (both egg and adult) and it has public resonance and economic value. Data can be extrapolated to and from all birds in general.
- **Frog** (Family **Ranidae**): An amphibian, with a life cycle that contrasts with other vertebrate animals. It is amenable to study at all stages of its life cycle. A limited data base is already available. Frogs are farmed commercially in some countries. They have ecological and public resonance.
- **A freshwater fish** (Family **Salmonidae,** salmon and trout): Fish that live in the free water column. There is a good database for effects and bioaccumulation kinetics and data are available for other carcinogens. The salmonid is amenable to experimental study (all stages of life cycle), has public resonance and economic value. Data can be extrapolated to and from most fish living in the water column.

- **A marine flat fish** (Family **Pleuronectidae**, dabs, plaice and flounders): Fish that live on the sediment surface. There is a limited database for effects and bioaccumulation kinetics. The flat fish is amenable to experimental study (all stages of life cycle), and it has public resonance and economic value. Data can be extrapolated to and from other fish living on the sediment.
- **A marine snail** (A **neogastropod** mollusk): Has egg, larval and adult stages. There is a limited database for effects, with bioaccumulation kinetics available for marine species. The gastropod mollusc is amenable to experimental study (all stages of life cycle), and it has public resonance and economic value. Data can be extrapolated to and from gastropods, but not readily to and from other molluscs.
- **The Bee** (Family **Apidae**, bumblebees and honeybees): A social insect of key ecological relevance with an insect-type life cycle. There is a limited database for effects and bioaccumulation kinetics. The bee is amenable to experimental study (all stages of life cycle), and it has public resonance and economic value. Data can be extrapolated to and from essentially all insects.
- **Earthworm** (Family **Lumbricidae,** common earthworms): There is a very limited database for effects and bioaccumulation kinetics. The worm is amenable to experimental study (all stages of life cycle). It has public resonance, economic value, and ecological relevance.
- **Pine tree** (Family **Pinaceae**, pine trees): A radiosensitive gymnosperms. There is a reasonable database for effects, but limited for bioaccumulation kinetics, and data are available for other pollutants, particularly airborne. The pine is amenable to experimental study, and it has public resonance and economic value. Data can be extrapolated to and from other gymnosperms, but doubtful to angiosperm trees.
- **Grass** (Family **Graminaea**, the grasses): Limited database for effects and bioaccumulation kinetics. Grass is amenable to experimental study. It has public resonance and economic value, and is ecologically very important. Data can be extrapolated to and from other herbaceous angiosperms.
- **Brown seaweed** (A **Phaeophycean** seaweed, possibly such as a Fucoid): There is no database for effects, but a substantial one for bioaccumulation. Brown algae are amenable to experimental study (all stages of life cycle), have public resonance and economic value. Data can be extrapolated within the brown algae.

The Task Group will consider these types of animals and plants in more detail. Once finally selected, it will describe each reference organism in a consistent manner and provide a short database for modelling (size, weight, height, lifespan, world distribution etc.). The Task Group will also provide a matrix of dose geometries and environmental geometries for each organism and for various relevant stages of their lifecycles. Results from the FASSET project (see www.fasset.org) will provide reference radionuclides in the environment to enable the calculation of background dose rates, plus data for other radionuclides, as appropriate. Data will also be collated with respect to what is known about the various effects of radiation on these types of animals and plants, or the nearest available information.

5. DISCUSSION

A framework for radiological protection of the environment must be practical and, ideally, a set of ambient activity concentration levels would be the simplest tool. There is a need for international standards of discharges into the environment. The IAEA could play a valuable role in the consideration of the way in which effects manifested in individuals are expressed on higher levels of organization, and in the compilation of transfer factors from different sources. In order to transparently demonstrate the derivation of ambient activity concentration levels or standards, the reference animal and plant approach will be helpful. The IAEA is working towards the development of a Safety Standards publication on protection of the environment. At a Specialists Meetings in November 2001 [15], the participants agreed that: “the use of reference organisms is a reasonable approach to adopt in the development of a system to protect biota from the effects of radiation”.

ICRP’s framework will be designed so that it is harmonized with its proposed approach for the protection of humans. To achieve this, an agreed set of quantities and units, a set of reference dose models, reference doses per unit intake, and effects analysis will be developed. A limited number of reference animals and plants will be defined and developed to aid assessments, and others can then develop more area and situation specific approaches to assess and manage risks to non-human species.

The Commission’s system of protection has evolved over time as new evidence has become available and as our understanding of underlying mechanisms has increased. Consequently the Commission’s risk estimates have been revised regularly, and substantial revisions made at intervals of about 10 to 15 years. It is therefore likely that any system designed for the radiological protection of the environment would also take time to develop, and similarly be subject to revision as new information is obtained and experience gained in putting it into practice.

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BUILDING A SYSTEM FOR RADIOLOGICAL PROTECTION OF THE ENVIRONMENT
Contribution from the OECD/NEA Committee on Radiation Protection and Public Health

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1. INTRODUCTION

The primary aim of radiological protection has always been to provide an appropriate standard of protection for the public and workers without unduly limiting the beneficial practices giving rise to radiation exposure. Over the past few decades, many studies concerning the effects of ionizing radiation have been conducted, ranging from those that examine the effects of radiation on individual cells, to epidemiological studies that examine the effects on large populations exposed to different radiation sources. Using information gained from these studies to estimate the consequences of radiation exposure, together with the necessary social and economic judgements, the International Commission on Radiological Protection (ICRP) has put forward a series of recommendations to structure an appropriate system for radiological protection, and to ensure a high standard of protection for the public and for occupational exposed workers.

Recent debates on radiological protection have begun to raise the question of establishing a system for protecting the environment. Until now, the system of radiological protection has focused on the protection of humans, implicitly assuming that this would also appropriately protect the environment. However, an evolving civil society is increasingly unsatisfied with such an approach, and it is becoming imperative to demonstrate that the environment is sufficiently protected.

To advance solutions to these issues, the OECD Nuclear Energy Agency (NEA) has been working for some time to contribute to the evolution of a new radiological protection system, through its Committee on Radiation Protection and Public Health (CRPPH). Recently, this interest has included a very active CRPPH programme to develop ideas and suggestions that the ICRP can take into account in its work, and the CRPPH has become an active partner with the

ICRP to provide the views of regulators and experts from the NEA's 28 member countries.

Regarding the initiative to develop a system for radiological protection of the environment, the NEA has embarked on various activities. In early 2002, a first NEA/ICRP forum[1] assisted in defining the path forward to a new radiological protection policy[2]. Based on the Taormina policy discussions and after the publication of a draft ICRP document on radiological protection of non-human species[3], a CRPPH expert group analysed the draft ICRP material specifically looking at the implications that might arise should the ideas and concepts in the draft material be implemented in the form of a recommendation. In a third step, the NEA assisted to broaden the input to ICRP, and organized the second NEA/ICRP forum[4], in April 2003. This forum opened the discussion on implications to a broader group of stakeholders, such as the nuclear power industry, nuclear power labour organizations, academia, and environmental NGOs.

This article summarizes the main findings of the Taormina forum, assisting in developing a new system for protecting the environment, and possible implications of the draft ICRP framework on radiological protection of non-human species, as discussed by an NEA expert group, and further elaborated during the Lanzarote forum.

2. A NEW SYSTEM FOR PROTECTING THE ENVIRONMENT

Based on discussions at the Taormina forum, the system for protecting the environment will have to be built on solid scientific foundations, and lead to the formulation of clearly defined regulations so that situations can be properly assessed and monitored. This will help ensure successful implementation. While predicated on scientific considerations, it will have to be flexible enough

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[1] The first OECD/NEA–ICRP forum on "Radiological Protection of the Environment, The Path Forward to a New Policy?" was held on 12–14 February 2002 in Taormina, Italy.

[2] Radiological Protection of the Environment, Summary Report of the Issues, OECD 2003.

[3] Protection of Non-human Species from Ionising Radiation: Proposal for a Framework for the Assessment and Management of the Impact of Ionising Radiation in the Environment, ICRP draft document, July 2002.

[4] The second NEA-ICRP forum on "The Future Policy of Radiological Protection, a Stakeholder Dialogue on the Implications of ICRP Recommendations" was held on 2–4 April 2003 in Lanzarote, Canary Islands, Spain.

to include social, philosophical, ethical, political and economic considerations as well. It will also draw upon those aspects of the precautionary principle that are relevant to this application. In the end, the systems for protecting humans and protecting the environment should clearly take mutually coherent approaches. This will be important for societal acceptance, but it does not necessarily mean adopting strictly identical systems, which could be difficult to achieve. The current notions of justification and optimization will have to be redefined in order to integrate the environmental component into the broader system. Trends that go beyond the current anthropogenic definition of optimization are already emerging. Indeed, there is currently a notable shift in the ALARA (as low as reasonably achievable) principle as it applies to the management of discharges into the environment. With increasing pressure from society, regulators are beginning to consider ALARA in parallel with the notion of BAT (best available techniques). This clearly corresponds to the public's demands to discharge as little waste into the environment as possible — as a precaution, but also in response to a new notion of maintaining a 'clean environment'.

2.1. Defining the environment to be protected

If the environment is confined to the human habitat, the existing system of radiological protection, if applied correctly, is sufficient. By protecting people on an individual basis the environment is respected. Under the current anthropocentric approach, for example, the environment is monitored to ensure that the public is not overexposed. To this end, regulatory limits are imposed on what can be discharged into water or the atmosphere, and regulators already take these factors into account when licensing nuclear facilities. Such aspects are also considered when contaminated sites are rehabilitated and subsequently reoccupied by the public. The drawbacks of such a system are most evident in the cases of sparsely populated or uninhabited areas of the planet. In addition, the co-factors classically studied for humans, namely chemical, physical or bacteriological toxins, are more extensive in the case of the environment. If the definition of the environment is broader than just humans and their immediate surroundings, and extends to uninhabited areas, the tenet of "protection through protection of man" remains to be proven, and would, in fact, seem not to hold true under all circumstances. It would notably fail to address the issue of sites from which humans are absent, such as the Kara Sea, but which are nonetheless the subject of deep concern. Nor does it address the issue of environmental protection in connection with the management of deep geological disposal sites, even though as much as possible is being done to ensure that the current and future impacts on humans and their environment are negligible, or at least acceptable. Other ‘hybrid’ cases can also be imagined, such as releases which cause little exposure to humans or to parts of the human food chain, but which significantly expose other components of the environment. A biocentric approach in which certain species would be designated for protection runs the risk of being both subjective and incomplete.

An ecocentric approach, based on the preservation of ecosystems, seems best suited to protecting the environment as a whole. This is supported by the growing ability of scientists to demonstrate that an action at one level, however trivial, can have a delayed impact in both time and space. Actions leading to climate change and problems of the ozone layer are examples. However, once the target of protection has been identified, the problems of assessing effects and estimating risks remain to be resolved.

2.2. Setting protection levels

If the system is to be practicable, regulators will require clear definitions of the objectives and the methods for attaining them. The same principles of protection should also apply to all environmental pollutants, be they radiological, chemical or biological. The system will have to be pragmatic if it is to be credible, and if it is to be understood by users and by the public. Regulators need numbers in order to monitor the system’s application. Obviously, the simpler these numbers are, and the easier they are to check, the more likely the system will be implemented and understood. Given the global nature of environmental protection, it would seem necessary to devise a system that is coherent at the international level, and also provides guidance and boundaries that are sufficiently clear and specific to preclude differing local interpretations of environmental protection levels. However, coherency does not necessarily mean uniformity, and the environmental protection system will have to be flexible enough to allow for local initiatives, since public acceptance of an environmental policy requires consensus between stakeholders at different levels. In the case of ‘highly mobile pollutants’ that are able to cross borders easily, and that can be found anywhere on the planet, an international consensus is clearly desirable. This would cover pollution of the air as well as the oceans, seas and rivers. Such pollution could be brought on, for example, by atomic weapons testing and extremely serious accidents such as Chernobyl. In other situations, in which the impact of discharges is confined to a certain space, a regional consensus would be enough, bringing together a number of affected countries but not going beyond the limits of a given geographical area. This is the case with certain facility discharges that, because of their ecological behaviour or half-life, will affect limited geographical areas only. For pollutants with limited dispersion, such as radioactive waste that is to be stored deep underground, the consensus will have to be achieved at the national and even local level, because populations living tens of kilometres from a storage site may not perceive the site's hazards in the same way as those living nearby. This geographic definition alone may greatly help in resolving certain potential conflicts. For example, some populations in locally contaminated areas may prefer to run slightly higher risks rather than lose jobs or be forced to relocate. The figures adopted could convey dose rates (Gy/unit of time) to which targets (reference species for example) are subjected, and/or concentrations (Bq/unit of mass or volume) in which targets live. To define an internal dose, as for humans, would seem almost impossible and unnecessary, and could only complicate the system. A simple dose rate or concentration approach would allow better comparisons with other environmental pollutants. For this, studies to define 'sentinel species', representative of the 'health' of an ecosystem, will be necessary. With evolving technology, the system will have to be flexible, and designed to allow for advances. With the acceptability of some risks being subjectively judged at the local and/or national level, it is conceivable that the system will allow for a given country's level of development, with more being asked of the most technologically advanced countries while not being lax vis-à-vis others. Protecting the environment will clearly be a long term process, and the speed with which the system is applied will have to take societal context and national priorities into account. Such discussions, for example, are ongoing with regard to the atmospheric pollutants that threaten world climates, and consideration must be given to a similar approach to discussions between countries so as not to unduly penalize the developing world. These discussions reinforce the previously discussed need for flexibility.

2.3. Public consultation and societal aspects

Few would question the need for dialogue with all segments of society before such a system is instituted, but this will also be necessary when the system is put in place. Populations face a variety of different social constraints, and important among these is the need for employment. Stringent protection that would jeopardize such key considerations would most likely be rejected sooner or later, and it could trigger secondary effects in society that would be worse than the hazard being combated. Any international organization that proposes a new system, such as the ICRP, will have to dialogue with, listen and be responsive to users.

2.4. Possible implications of the draft ICRP framework on radiological protection of non-human species

An NEA expert group analysed the ICRP draft document on radiological protection of non-human species, specifically looking at the implications that might arise should the ideas and concepts in the draft material be implemented in the form of a recommendation. The results of this analysis has been published in a recent CRPPH report[5], which raises a number of issues and makes a number of suggestions to enhance the understanding and transparency of the ICRP recommendations. Based on these findings, the Lanzarote forum opened the discussion to a broader set of stakeholders, including the nuclear power industry, nuclear power labour organizations, academia, and environmental NGOs. The conclusions of the CRPPH report were broadly supported by participants, and were echoed in remarks from other presentations. The full conclusions of the Forum will be developed and published by the NEA.

2.5. Key findings

The development of an explicit system of radiological protection for the environment is not driven by concern over the current state of the environment, but rather by the need to fill a gap in the system of radiological protection, and by the need to demonstrate that the environment is sufficiently protected. The rationale for this explicit inclusion of the protection of the environment has to be made clear in any new recommendation.

Radiological protection of the environment has to be in line with general concepts of environmental protection — including the concept of sustainable development.

The ICRP document is a 'framework' document, providing discussions of the guiding principles and overall concepts that the ICRP is proposing to use as the bases for its recommendation. As the details that would be necessary to fully understand the implications and ramifications of the new recommendation are not yet presented, it is assumed that the ICRP will modify, based on the views and opinions it is currently collecting, its framework appropriately and use this to develop detailed recommendations. These details have to include various key issues, such as the basic principles Justification, Optimization, and Authorized Levels; and the concept of reference flora and fauna to establish radiological protection criteria. Other issues for further detailed discussions are, establishment of environmental assessment criteria, flexibility

[5] Possible implications of the draft ICRP recommendation, OECD 2003.

of the future recommendation with respect to national needs, the management of radioactive waste, and the costs involved in implementing the new recommendations.

Addressing the question of risk transfers, particularly within the optimization process, has been one of the more difficult aspects of the current system of radiological protection. The additional emphasis being placed on the radiological protection of the environment will complicate this even further. It will be essential for the Commission, in its new recommendations, to discuss the aspects that it would see as useful for the balancing of protection of humans and non-human species at the policy, regulatory and operational levels.

A key aspect of risk assessment and management is the addressing of uncertainties. Both assessment and management require the use of assumptions, biological models, environmental transport models, dose-effect models, etc. All of these assumptions and models include uncertainties, implying that the end result of such models also has a given level of uncertainty. At this point there is still very little knowledge, relatively speaking, of various ecosystems, implying that some margins of conservatism will be used. Although the ICRP has, in the past, provided some guidance as to how uncertainties should be addressed in regulation and practice, further guidance is certainly necessary. This should begin with general guidance with respect to the overall approach to uncertainty, and continue with more specific guidance as to how such uncertainties should be understood in practice (policy, regulation and application). The need for and use of margins of safety, in regulation and practice, should be part of this discussion for the protection of both humans and non-human species. Regulatory authorities and practitioners will also need to keep in mind the growing demand for trained experts.

The ICRP is generally seen as the appropriate body to develop recommendations based on scientific evidence regarding the impact of ionizing radiation on non-human species, as long as the development process allows for appropriate input from a broad set of relevant stakeholders. Depending on the pressure from society, national governments may wish to go beyond the protection of non-human species, and consider the protection of the non-living environment with a view to nature conservation, and the strive for a “clean environment”. But this is clearly a societal choice which governments have to make.

3. CONCLUSIONS

Protection of the environment with the current system of radiological protection is sufficient, as long as humans are part of the ecosystem. In situations where man is absent, the system cannot prove that the environment is adequately protected. The future system for the radiological protection of the environment will need to be pragmatic, and flexible enough to provide for regional solutions. The process for developing the system will need to involve a wide range of stakeholders so as to ensure its acceptance, which can greatly influence future implementation.

The series of NEA-ICRP fora are part of a positive process of dialogue that is being put in place. Cooperation among the scientific community and other interested parties should lead to the development of a widely beneficial and efficient system of protection.

The CRPPH appreciates the openness of and collaboration with the ICRP to advance radiation protection for the benefit of society.

STATUS OF IAEA WORK ON THE DEVELOPMENT OF STANDARDS ON ENVIRONMENTAL RADIATION PROTECTION, AND IDEAS FOR THE FUTURE

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Abstract

The International Atomic Energy Agency (IAEA) has established a programme of work to develop safety standards that address the protection of the environment from the effects of ionizing radiation, in cooperation with other relevant international organizations. This paper reports on the current status of this work and explores the challenges still to be faced and the possible form of related safety standards in the future.

1. INTRODUCTION

The IAEA has a long history of work on the assessment of the effects of ionizing radiation on species other than man. The initial focus for this work was to provide guidance on setting limits on the practice of dumping at sea, in the context of the London Convention, and for assessing doses to 'typical' marine species living at or near the sea floor. For example, in 1979, IAEA published Technical Reports Series No. 190, A methodology for assessing impacts of radioactivity on aquatic ecosystems [1]. In 1992, IAEA moved beyond the marine environment with the publication of a report that considered the impacts of radionuclide releases on terrestrial and freshwater environments, in its Technical Reports Series No. 332 [2].

During the last few years, there has been an increasing awareness of environmental issues, evidenced by the growing number of national and international legal instruments that relate to environmental protection. The Rio Declaration of 1992 [3] was a particularly significant step; it contains a total of 27 Principles, many of which relate explicitly to environmental protection. This change of attitude is reflected in the IAEA Safety Fundamentals for

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Radioactive Waste [4], published in 1995, which include the principle: "Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment". There is a need to provide supporting guidance on the practical interpretation and application of this principle and, as a consequence, the IAEA has recently been working towards the development of safety standards that explicitly address environmental protection.

The first stage in the process of standards development was the identification of the key issues that would need to be addressed. This activity culminated in the publication of a discussion document, IAEA-TECDOC-1090 in 1999 [5]. The next step was to elaborate the ethics and principles underlying environmental protection and to consider their implications for the development of an approach for radiation. An expert group was established to undertake this work, which was published as IAEA-TECDOC-1270, Ethical Considerations in Protecting the Environment from the Effects of Ionizing Radiation, in 2002 [6].

The principles of environmental protection, defined in IAEA-TECDOC-1270 [6] are outlined briefly in this paper, but the focus of this paper will be on subsequent work on the development of a practical approach to assess the impact of radioactive materials in the environment. This work takes account of these principles, approaches applied for the control of other environmental pollutants, and the most appropriate use of the scientific information on the effects on non-human biota of exposures to ionizing radiation.

2. ETHICS AND PRINCIPLES OF ENVIRONMENTAL PROTECTION

The IAEA is an inter-governmental body comprising over 130 Member States, from all parts of the world. IAEA Member States thus represent a wide variety of cultural backgrounds that affect the way in which nature is viewed and the way in which 'protection' is interpreted and implemented. In an effort to understand the possible impact of such differences, an IAEA expert group explored the range of environmental ethics and the 'norms' that define environmental protection in existing international legal instruments. The results of this work are discussed in detail in IAEA-TECDOC-1270 [6], but a number of the key features are outlined below.

The IAEA expert group identified three ethical viewpoints that could be considered as representative of the wide spectrum of views on the environment and human interactions with it. These are referred to in very simplistic terms below, a more detailed treatment is given in Ref. [6]:

— Anthropocentric – the interests of humans are paramount;

— Biocentric – individual human rights are extended to other living organisms, described as an ‘individualistic’ environmental ethic [7–9];
— Ecocentric – value is assigned to the diversity of species, ecosystems, rivers, mountains and landscapes. Referred to as an ‘holistic’ environmental ethic [7, 9].

The different viewpoints imply different protection interests. There is thus no single over-riding goal for protection of the environment from the effects of ionizing radiation or other pollutants. However, a number of core principles can be identified by a consideration of the environmental objectives included in international legal instruments. This is outlined in more detail in IAEA-TECDOC-1270 [6], but the key principles are paraphrased below for ease of reference:

— Any radiation exposure should not affect the capability of the environment to support present and future generations of humans and biota (principle of sustainability);
— Any radiation exposure should not have any deleterious effect on any species, habitat, or geographic feature that is endangered or is under ecological stress or is deemed to be of particular societal value (principle of conservation);
— Any radiation exposure should not affect the maintenance of diversity within each species, amongst different species, and amongst different types of habitats and ecosystems (principle of maintaining biodiversity);
— The management of any source of radiation exposure of the environment should aim to achieve an equitable distribution of the benefits from the source of the radiation exposure and any harm to the environment resulting from the radiation exposure, or to compensate for any inequitable damage (principle of environmental justice); and
— In decisions on the acceptability and appropriate management of any source of radiation exposure of the environment, the different ethical and cultural views held by those humans affected by decisions should be taken into account (principle of respect for human dignity).

The impact of ionizing radiation on the environment may be assessed in terms of the first of the three principles discussed above [6]; conservation, maintenance of biodiversity and sustainable development. Building an assessment methodology that provides a quantitative measure of the extent to which these principles are adhered to requires both an understanding of the effects of radiation on biota and on the potential impacts of such effects on biodiversity, sustainability and conservation. Conservation may imply protection of individuals, populations or habitats, while the maintenance of biodiversity and sustainability are inherently focused on the higher levels of ecological organization — populations and species. The relative weight given to each of these principles is likely to depend upon cultural and ethical values, and the particulars of the situation in question, as outlined in more detail in Ref. [6].

In making environmental management decisions, there is a need to balance various interests. The two other principles — those related to human dignity and to environmental justice — inform such judgements. Human dignity provides support for preference to be given to human interests, relative to those of biota, but it also acts to support the idea that those affected should be involved in the decision making process (informed consent) — stakeholder involvement. The principle of environmental justice allows both the distributions of benefit and impact to be taken into account and for potential compensation for environmental damage incurred.

Some societies may set additional goals, but the five principles above represent a baseline from which internationally agreed assessment end points and criteria for acceptability may be derived. The detailed interpretation of these principles, their relative weight, and the application of assessment methodologies may be expected to differ among Member States, depending upon underlying cultural values and the way in which these are implemented in law.

3. THE DEVELOPMENT OF AN INTERNATIONAL FRAMEWORK

From the foregoing, it is clear that there will be differences in the way in which different Member States interpret environmental principles, and the detailed application of environmental protection measures. However, an international systematic approach to assess the impact of radiation on biota would provide a valuable baseline for internationally relevant situations, for comparison purposes, or from which Member States could derive their own approaches.

3.1. Assessing the effects of ionizing radiation

It is known that detrimental effects on biota can be observed at radiation doses and dose rates considerably above those that occur naturally. Indeed, much of the current basic knowledge about the molecular and cellular mechanisms of radiation damage has come from studies with both animals and plants. Possible consequences of exposure are that the lifetime of some organisms will be shortened, reproductive ability may be reduced, and the genome may be adversely affected. Were sufficient numbers of organisms in a given species to be affected in these ways, changes in populations occur and the ecosystem could be perturbed as a result.

Reviews of environmental radiation levels and radionuclide concentrations, and of the effects of radiation on biota, exist, notably by the United Nations Scientific Committee on the Effects of Atomic Radiation [10, 11]. However, uncertainty remains about the actual radiation doses experienced by natural biota throughout their lifetimes, due partly to insufficiencies in the present dosimetric methods. As a result of recent debates, it has been recognized that there would be value in developing a more systematic and internationally agreed procedure for assessment that allows for a more detailed specification of the types of effects experienced at different dose rates and to different types of organisms. The principal biological impacts on biota may be defined as follows: radiation induced early mortality, increased morbidity, reduced reproductive success and possible deleterious hereditary effects [6, 12, 13].

3.2. Reference organism approach

In order to develop a practical framework for assessing the impact of ionizing radiation on non-human species, it is necessary to link the principles to measurable indicators of four effects or end point categories. To achieve this, the ‘reference flora and fauna’ approach has been proposed [12–16]. This approach is analogous to the Reference Man approach used for humans and would allow the systematic interpretation and application of existing information on exposures, doses and effects.

The ICRP accepted the reference flora and fauna approach in its Publication No. 91 [17] and has established a Task Group to develop a primary reference data set. The preliminary choice of flora and fauna that have been identified as candidates for further consideration, and the criteria that influenced their choice are described elsewhere in these proceedings [18, 19]. This work will be supported by the results of a number of recent work programmes. For example, a European project, called ‘Framework for Assessment of Environmental Impact’ (FASSET), which is nearing completion, has reviewed dosimetric methods and effects data that will inform the work of the ICRP Task Group [20].

In accepting such an approach, it is recognized that effects on higher levels of organization (e.g. populations) occur only if individual organisms are affected [6]. The need for further information on the extrapolation of individual effects to higher levels of organization is a continuing source of uncertainty. It is difficult at present to take account of the interdependence of species within an ecosystem and of the cumulative impact of multiple stressors. It would therefore be prudent to develop a flexible assessment and management approach that will allow such issues to be accounted for when and if the necessary information becomes available.

The ICRP Task Group is expected to provide information on the dose and exposure-relevant characteristics of a small number of reference animals and plants. It will also provide information on the likelihood of the specified radiation induced effects at various dose rates, which may be expressed in relation to the background rate to which the organism is exposed [18]. It does not intend to develop limits or to give detailed advice on the acceptability or otherwise of different levels of exposure. This will depend upon the societal factors that will vary between different exposure situations and between different countries.

4. PRACTICAL IMPLEMENTATION OF ICRP APPROACH

The IAEA is working in parallel with ICRP to provide guidance on the practical implementation of the developing ICRP approach. For example, the primary set of reference animals and plants cannot be expected to fully represent all protected or other organisms for which an impact assessment may be required. It is therefore likely that other typical or secondary reference organisms may need to be specified for particular purposes. The interpretation of impact will depend upon relating the characteristics of the secondary organism to one of the primary set. Guidance on such approaches will form part of the IAEA standards development work in this area.

The dose consideration levels, presented in ICRP Publication No. 91 [17], were presented within the context of *levels of concern* being proposed for human protection purposes. It is clear that safety standards on the control of radioactive discharges to the environment will need to be developed that take account of the protection of both human and non-human species. It is possible that benchmarks, expressed as activity concentrations in environmental materials, could be derived using Reference Man and animal and plant data, for discharge control purposes. The methodology used to derive such values and their inclusion in future safety standards, would be the subject of detailed consultation with IAEA Member States.

Additional assessment requirements may also be implied by nature conservation legislation. For example, this may involve an assessment of the cumulative impact of radiation and other environmental stressors on a particular area or species to be assessed. Thus, it is essential that an appropriate level is built into both the approach and supporting methodological guidance.

It should also allow for different exposure situations — prospective and retrospective situations. An IAEA expert group has developed preliminary guidance on a stepwise assessment approach that would provide for such flexibility and could be the basis for future practical guidance.

4.1. Stepwise environmental assessment and management procedure

An overall approach for assessment and management involves both technical and societal components, as illustrated in Figure 1. This approach is consistent with those used for both human radiological protection and environmental protection from non-radioactive pollutants. Each of the processes involved is briefly presented in Figure 1.

4.1.1. Planning

This is the stage at which the context and objectives for an assessment are established. The relevant legal background, and the possible role of

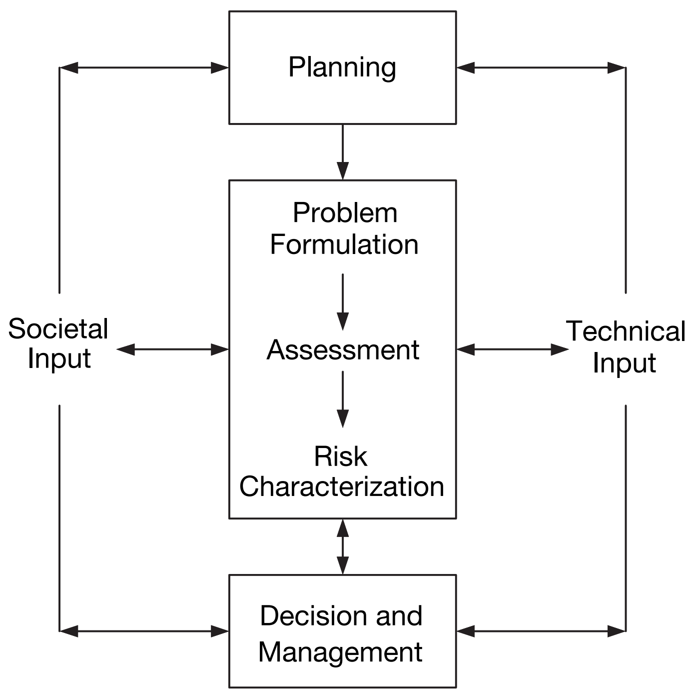

FIG. 1. A simplified illustration of an environmental protection approach, adapted from Ref. [21].

stakeholders in the process, will need to be established at this point. It is important to note that nature conservation requirements may place additional conditions that are not currently addressed in radiological protection.

4.1.2. Problem formulation

This step involves the specification of the detailed technical aspects of the assessment. These include: an evaluation of the practice or activity under consideration, and the form and characteristics of the release of radionuclides; the definition of assessment end points, the appropriate level of complexity of the assessment approach and the treatment of uncertainties.

4.1.3. Assessment

This is the main technical analysis stage. It includes characterizing the pathways leading to radiation exposure and estimating doses from those exposures (exposure analysis) and an analysis of the data on the effects of radiation on biota that are relevant to the end points (effects analysis). These activities are closely linked, and may be conducted concurrently if sufficient information is available.

4.1.4. Risk characterization

Here, the technical evaluation of the relationship between the probability of the effect and the magnitude of the exposure is made, and the nature and magnitude of the environmental risk as specified in the assessment context earlier in the process. The implications of the uncertainties in the exposure, doses and effects data are also summarized.

4.1.5. Decision and management

This final process in the overall approach entails the use of the results of the risk characterization to make decisions on the acceptability, or otherwise, of the assessed situation and on any subsequent actions that may be required. This would entail the identification and evaluation of alternative regulatory options and selection from them. Comparisons with relevant criteria are made and compliance with any relevant legislation is taken into account. An important consideration in decision making and management will be selecting an acceptable balance among conflicting values and priorities, entailing socioeconomic, and legal factors that are beyond the scope of radiological protection.

5. THE POSSIBLE FORM OF FUTURE SAFETY STANDARDS

In the long term, radiation protection of public and the environment will need to be considered together, at least for the purposes of discharge control. However, we are not currently in a position to combine these approaches, as it is dependent upon the further development of the approach for environmental radiation protection. Hence, it is possible to identify the likely features of future standards, as follows:

— Principles for protection of the public and non-human species;
— Criteria for protection;
— Basic assessment approach;
— Planned release situations;
— Existing residues in the environment;
— Monitoring for compliance.

This structure is consistent with traditional radiological protection approaches — source specific consideration of the impact radiation in isolation. However, it is likely that the need to consider the combined impact of environmental pollutants, for example as part of nature conservation considerations, may place additional requirements on the way in which future standards are formulated. Some of the main issues that remain to be resolved in completing this structure are outlined briefly below.

The principles relating to public protection are outlined elsewhere [22], while the contents of Reference [6] and its interpretation by ICRP [17] are expected to form the basis for the principles relating to the protection of non-human species. Criteria for the public exist, as outlined in [22] but it should be clear from the discussion above that a significant amount of work remains to be done to define criteria for non-human species. There are scientific and societal features of setting criteria that need to be considered further. The systematic collection of information on dose and effects information for reference animals and plants, being undertaken by ICRP, will promote transparent decision aiding, but the societal judgement of what level of effect is unacceptable is still to be resolved. Indeed, the extent to which generic international judgements are possible, given the wide range of environments and cultural considerations considered is still an open question. The IAEA would be the appropriate body to take this further. The IAEA's inter-governmental structure and its statutory mandate to establish international safety standards, and the complex mechanisms for consultation with Member States that support it, provide a suitable forum to take account of the technical and societal judgements required.

The basic assessment approach outlined above provides a template for an international approach that is flexible enough to be used in a variety of assessment contexts. The planned release situation will include a review and revision of existing practices and guidance on the control of radioactive discharges to the environment [23], to explicitly include consideration of non-human biota. This revised guidance may include environmental activity concentration benchmarks, if IAEA Member States consider this appropriate. Existing residues are likely to need case specific consideration and the relevant IAEA advice is likely to concentrate on the way in which secondary reference organisms may be related to the primary animals and plants, derived by ICRP. Finally, the implications of the consideration of non-human biota on monitoring for compliance will need to be considered in detail and the existing guidance modified appropriately.

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Topical Session 5

DISCUSSION

D.B. CHAMBERS (Canada): In her presentation, Ms. Robinson used the word "optimization". How would one perform an optimization on the natural environment?

C.A. ROBINSON (IAEA): I used the work "optimization" in a very general sense, in talking about the specification of discharge limits for routine situations; I was not thinking in terms of anything like a numerical cost-benefit analysis.

However, I certainly believe that in decision making we need to take into account both impacts on humans and impacts on other things. There may be difficult decisions to be taken, and I am not sure that the radiation protection community are necessarily the right people to take them.

L.-E. HOLM (Sweden): We perform optimization assessments when we take decisions regarding releases to the environment, and I think that will continue. What ICRP is proposing is "consideration levels" for non-human organisms. I am not sure that there is a need for an optimization method different from the one we employ today.

S. MUNDIGL (OECD/NEA): In my view, optimization is a very important process which will continue to be applied in all situations where there is ionizing radiation. It will necessarily involve stakeholders, since you may wish to optimize to different end points depending on what the stakeholders are asking for. People living in an area with high natural radiation levels or contaminated by past practices or by an accident will want to discuss with you how to optimize protection and there may be conflicting objectives.

D. CANCIO (Spain): The subject of environmental radiation protection was included in the EMRAS programme but work on it was then postponed. I was therefore wondering whether the IAEA intended to develop an action plan for environmental radiation protection.

L.-E. HOLM (Sweden): In my view, one of the purposes of this conference is to formulate guidance that will help the IAEA to develop such an action plan. In that connection, I would recall that last year the General Conference of the IAEA welcomed the steps taken by the IAEA Secretariat "to assist in developing an international framework for the protection of the environment from ionizing radiation".

I believe that another purpose of this conference is to clarify the roles to be played by UNSCEAR, ICRP, the IAEA, OECD/NEA and others in the field of environmental radiation protection. There is a great deal to be done, so I do not think that there will be much overlapping.

C.A. ROBINSON (IAEA): I think it would be very helpful if this conference clarified who is to be responsible for what.

Regarding the EMRAS programme, work in the field of environmental radiation protection was postponed to allow for broader participation in the project as more institutes develop capabilities in this area.

We are making plans to establish a group to consider assessments for non-human species, and we have been speaking with the coordinators of the ERICA programme about possible cooperation in the conduct of case studies and the intercomparison of models.

J. LOY (Australia): In her presentation, Ms. Robinson mentioned “environmental justice” and “respect for human dignity” and said that those principles were more relevant to the decision making stage than to the assessment stage. Perhaps she could say a little more about them.

C.A. ROBINSON (IAEA): I think that discussions during this conference have demonstrated the importance attached to the principle of “respect for human dignity”. A serious attitude towards stakeholder involvement and informed consent is one form in which respect for human dignity manifests itself.

Trying to achieve “environmental justice” means trying to avoid situations where benefits and drawbacks are distributed inequitably.

L.-E. HOLM (Sweden): The principle of “environmental justice” is reflected in international conventions that affect the legislation of many countries. We therefore have to take account of it when, for example, planning a radioactive waste repository — we have to consult with the countries that may be affected by the construction and operation of the repository.

C.R. WILLIAMS (United Kingdom): In the light of Mr. Holm’s presentation on “ICRP developments related to the protection of non-human species”, I was wondering whether ICRP as currently constituted has the range of expertise necessary in order that its pronouncements regarding environmental radiation protection be broadly accepted.

L.-E. HOLM (Sweden): The Task Group recently established by ICRP represents a high level of relevant expertise, but there is a lack of relevant expertise in ICRP’s committees and Main Commission. However, I am sure that, as a result of the elections for 2005 and beyond, the composition of these bodies will change in a manner which reflects the need for new types of experts.

By the way, ICRP is increasing its access to necessary expertise by putting draft material on the web for comment by international organizations, national organizations, the nuclear industry and private individuals. It did that with

Publication 91 and received over 40 responses, some consisting of 50–60 comments.

I should like to take this opportunity to say how pleased I have been with the interest taken by the United States federal agencies in the general review of ICRP's recommendations. The United States still has not adopted ICRP's 1990 recommendations, but I believe it will adopt the recommendations due to be made by ICRP in 2005.

R.M. ALEXAKHIN (Russian Federation): I would be interested to know why ICRP has not included any domestic animals (cows, pigs or whatever) among the reference animals it is defining.

L.-E. HOLM (Sweden): It is difficult to be concerned about the radiation protection of animals that are being kept in order to be slaughtered in due course. Moreover, the international conventions which are of interest to us relate to the preservation of nature, including the preservation of animals and plants in their natural habitats; they do not address the question of the radiation protection of domestic animals.

R.M. ALEXAKHIN (Russian Federation): In his presentation, Mr. Mundigl seemed to be suggesting that there be two sets of dose limits — one for the environment and one for humans. What would be the relationship between the two sets?

S. MUNDIGL (OECD/NEA): I did not suggest that there be two sets of dose limits. I said that there should be a similar level of protection for the environment as for humans and that humans and the environment should be protected in the same way.

Perhaps Mr. Alexakhin was referring to what I said about optimization after a major accident, when you decide that you must protect not only humans but also the environment and you may adopt two different optimization schemes. In optimization, you should also take into account the transfer of risks between the public, workers and the environment.

S. SAINT-PIERRE (France): To what extent are the different existing tools being compared during the move towards the reference organism approach — or is the reference organism approach being developed on a completely separate track? Canada has an approach, the United States has an approach, Australia seems to have an approach, and so on. Are they all the same approach?

L.-E. HOLM (Sweden): As I said in my presentation, the Task Group has adopted the approach which was proposed by Mr. Pentreath and subsequently refined by Mr. Pentreath and Mr. Woodhead.

There are many approaches with similar names. We are going to develop a system based on Mr. Pentreath's ideas as a reference point that will allow different national approaches to be compared and the differences identified.

I think the use of reference animals and plants will improve the options for benchmarking between different approaches as well.

T.E. HARRIS (United States of America): Are there plans for further collaboration between ICRP and OECD/NEA with regard to stakeholder involvement issues?

S. MUNDIGL (OECD/NEA): Following the OECD/NEA-ICRP forums in Taormina and on Lanzarote to which I referred in my presentation, there are plans to hold a joint forum after ICRP has published its recommendations — to discuss how the recommendations should be implemented.

L.-E. HOLM (Sweden): Collaboration between OECD/NEA and ICRP is important. However, the membership of OECD/NEA is much more limited than that of the IAEA, so ICRP must find ways of reaching out to countries which are Member States of the IAEA but not of OECD/NEA.

ICRP will participate in meetings at which it can discuss its draft material with experts from such countries, and then it will put the improved draft material on the web for international comment.

H. VANMARCKE (Belgium): Will consideration be given to environments where no biota is present — space, the stratosphere, deep geological strata?

L.-E. HOLM (Sweden): The previous Task Group, with a lot of support from corresponding members of ICRP, decided that the focus should be on the biotic component of the environment — on the interaction between ionizing radiation and living matter. It did not identify any radiation effects on the abiotic component of the environment that, in its view, needed to be dealt with.

S. MUNDIGL (OECD/NEA): When the general principles of environmental protection are applied, with the focus not just on radiation protection, efforts will be made to reduce impacts on vulnerable regions like the stratosphere. The issue is, in my view, one of the justification of practices.

Round Table 4

DISCUSSION

J. LOY (Australia – Chairperson): In the light of the presentation made by Ms. Robinson of the IAEA during Topical Session 5, I should like to broaden the topic of this round table to "Do the ICRP proposals and the directions of the IAEA's thinking provide an appropriate way forward to the development of an approach to the protection of non-human species?"

Also, I invite the panellists to answer that question, at the beginning or the end of their remarks, with, if possible, a maximum of two words — perhaps "No", "Yes". "Yes, but ..." or "No, but ...".

R.L. ANDERSEN (World Nuclear Association): I should like to start by making three points. In the opinion of the World Nuclear Association (WNA):

— The practices regulated within the present radiological protection framework are protective of the environment;
— The conceptual gap in that framework calls for a practical solution; and
— International leadership is needed in order to ensure clear direction and coordination in filling the conceptual gap and expanding the framework.

Regarding the first point, please note that I said "are protective of" and not "protect"; the words "protective of" suggest a tendency, whereas the word "protect" suggests an end state, and we have not yet defined the desired end-state (that is to say, "protection of the environment").

Regarding the words "are protective of", I should also like to make three points. In the nuclear industry:

— We keep releases at levels that are indistinguishable from background in the ambient environment irrespective of limits or criteria;
— We utilize best available technology and best practices, and through research we are continuously seeking to improve the technology, so that the trend is one of declining releases into the environment, to the point that some nuclear facilities no longer discharge liquid material; and
— We employ continuous monitoring to verify and validate the assumptions and models that we use, and generally our sampling and monitoring are not confined to exposure pathways leading to humans — in many cases we sample abiotic pathways (for example, we sample air and sediments).

Regarding my reference to “a practical solution” (and I think “practical” is a tricky word — like “conservative”), we believe that the framework which evolves should characterize the risk to the environment posed by a given situation. Please note that I said “characterize the risk” — not “determine whether the risk is acceptable”. The framework needs to be flexible enough to cover a wide range of activities (operations, decommissioning, waste management and so on), and its applicability should be commensurate with the risk. Moreover, it should promote optimization in the use of resources versus the expected benefits. Finally, it should increase clarity and transparency and enhance the ability to communicate how and to what extent the environment is being protected.

Regarding my reference to “international leadership”, I would note that there are many initiatives under way, and we would like to see UNSCEAR, ICRP and the IAEA — bearing in mind their respective missions — producing a roadmap that describes the joint way forward. In our view, the roadmap should indicate the shared objectives, should provide for a logical sequence of activities, should include milestones (so that the progress being made is clear), should define responsibilities and — most importantly — should state when stakeholder input is to be sought and how it is to be used; this last feature would enable stakeholders to plan and to provide maximum value.

As to the question asked by our Chairperson, my answer is “Yes — let’s get on with it!”.

S. CARROLL (Greenpeace International): My answer to that question is “Yes, but ...”.

We welcome the recognition on the part of ICRP, the IAEA, OECD/NEA and others that there is an issue needing to be addressed and the start of efforts to develop a fairly concerted approach to identifying what the problems are. Greenpeace recognized the issue in the 1980s, in the context of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the London Convention).

In the opinion of Greenpeace, the issue should be addressed from the “top down” rather than from the “bottom up”. In other words, instead of a mechanism that is based on previously known numbers Greenpeace would like to see a mechanism for which the numbers are determined after the mechanism has been established.

I believe that the reference organism approach is useful, particularly for purposes of analysis, but I do not believe that it is sufficient for management purposes — for the taking of proper management decisions in particular circumstances.

I regret that ICRP has made no reference to the abiotic environment. In the presentation made by him in Topical Session 2, Mr. Johnston spoke about

Kakadu National Park, a World Heritage Property in Australia, and said that any radioactive release into it might be considered unacceptable even if it caused no damage at a biotic level.

A further point about ICRP's proposals is that, in my view, they need to be complemented with inputs regarding activities at the practice and system levels in addition to the contaminant and organism levels.

Finally, I think there is much more to be learned from the approach to non-radioactive contaminants and to complex mixtures of contaminants. I hope that what emerges in 2005 will be forward-looking and at least reflect best current practice. I feel that ICRP's proposals as they stand at present could be said to "lag behind" best current practice in dealing with non-radioactive contamination.

H. FORSSTRÖM (European Commission): My answer to the question asked by our Chairperson is "Probably, but ...".

I have not really been involved in environmental protection activities, so that I read ICRP publication 91 with "fresh eyes" — like the little boy looking to see whether the Emperor was wearing clothes. Having read it, I feel that, while the Emperor is wearing clothes, there are some articles of clothing missing. Accordingly, there are some issues which I should like to raise.

First, in a number of places in ICRP's report it is implied that the objectives are clear. They are not clear to me. They are described in a very complicated manner, and I believe that the descriptions should be made much simpler.

Second, although various international agreements relevant to the objectives are mentioned, I am not sure that the objectives reflect common sense. This issue is important for stakeholder consultation — and by "stakeholders" I have in mind not just the stakeholders who have been consulted already.

Third, what level of effects should be considered. It has been stated that that is not for ICRP to decide. I find this statement rather strange, as I have difficulty in understanding how one can apply a system without considering the level of effects that is acceptable.

Fourth, which things in the environment should be protected? Should we try to protect smallpox viruses or the microbes that could develop near a radioactive waste repository? This issue will have to be dealt with at some time, and I raise it because I am responsible for funding research and am concerned that future research should focus on the needs of protection and not be determined by the ease of study.

Fifth, there is the issue of cooperation with those who are dealing with protection of the environment against the harmful effects of chemicals. I see a lot of advantages in the human protection system in the field of radiation protection, but I wonder whether it is absolutely essential to be in the forefront of developing environmental protection approaches. This should perhaps be done in much closer cooperation with those responsible for other environmental protection issues.

Lastly, how do we decide on research needs and on the best way of using the money available for research? Let us assume that a great deal of research is necessary. How do we decide what type of research is necessary? That is where the developments within ICRP are going to be very important.

N. GENTNER (UNSCEAR): My answer to our Chairperson's question is "Yes — definitely!". There may be other possible ways forward, but I do not know of any marked out by an authoritative international body.

There appear to be two points of view at this conference:

— According to one point of view, we know enough already to set up a system which, although not perfect, can demonstrate protection of the environment;
— According to the other point of view, there are significant data gaps — we do not know enough.

Regarding the second point of view, I would note that research scientists are never going to say that they know enough. This issue may be an opportunity for obtaining research funds for five–ten years.

In my view, the system will not be perfect, but it will show the way, making clear what areas need to be examined in greater detail.

I believe that there is a need for consistency — not only with some of the better aspects of the system for environmental protection against the effects of chemicals, but also with the system for the radiation protection of humans. Also, there is a need for consistency at the international level; otherwise there will be apparent disagreement among experts or among jurisdictions.

The system must be as simple and practicable as possible, with regulations and monitoring requirements commensurate with the scale of the problem; otherwise we may be spending resources unwisely.

I see nothing wrong with conservatism, but let us not have conservatism in three or four places. Let us have it in one identifiable place — perhaps in the dose estimation.

On the question of dose rate versus dose, I am pleased that we are finally thinking in terms of dose rate — this allows for consistency with the regulation of chemicals. These are regulated on the basis of concentration, and concentration means dose rate in the case of ionizing radiation. We should be regulating on the basis of dose rate, and we would be if there had been more radiobiologists — as opposed to health physicists — involved in radiation protection from the outset.

When carrying out environmental assessments, we need to be sure that, if we want to evaluate the effects of ionizing radiation, we know that we are making the assessments appropriately. We could handle high LET radiation and low LET radiation separately, but I think it would be very useful to use a radiation weighting factor.

Lastly, I think we need some starting parameters for the development of a protection system — a dose rate criterion, some recommendations. Otherwise we are shirking our responsibilities vis-à-vis our constituents.

J. LOY (Australia – Chairperson): The four panellists seem to agree that the time has come to start establishing a system for radiation protection of the environment, accepting the fact that things may go wrong initially, and that the establishment of such a system must be a collaborative effort on the part of all relevant bodies.

L. KEEN (Canada): Could Mr. Carroll elaborate on what he said about Greenpeace's preference for a "top down" rather than a "bottom up" approach?

S. CARROLL (Greenpeace International): Greenpeace believes that the first step should be the establishment of a management approach to nuclear activities. Once the management approach has been established, one could do the basic scientific work necessary in order to arrive at the constraints.

H. FORSSTRÖM (European Commission): Further to what Mr. Carroll just said, I would recall Mr. Gentner's comment to the effect that research scientists are never going to say that they know enough if there is a chance of obtaining funds for further research work. There must first be a framework defining what really needs to be done.

H.H. LANDFERMANN (Germany): As a regulator, I would like to know how regulators will benefit from the envisaged system of environmental radiation protection

J. LOY (Australia – Chairperson): Also as a regulator, I do not think that there will initially be a "book of rules" which regulators can apply. Regulators will have to exercise judgement in deciding to what extent they should make use of the emerging guidance in the situations which they are dealing with.

At present, I am considering a licence application for a low-level waste repository, and the guidance which is emerging will be useful to me.

H.H. LANDFERMANN (Germany): We already have a reference environment, a reference man and so on for licensing purposes. Are they not enough?

J. LOY (Australia – Chairperson): I think many people are asking that question. Ultimately, you in Germany will have to answer it for yourselves.

There are developments taking place at the international level, and it will be up to you how you use the results.

A.J. GONZÁLEZ (IAEA): Regarding the remarks of Mr. Carroll, I believe that Greenpeace prefers a "top down" approach because it would like to put a stop to nuclear power generation — with a "top down" approach it would be easy to impose constraints such that there would have to be zero radioactive releases to the environment.

Regarding the roadmap advocated by Mr. Andersen, I believe that it would have to meet the needs of regulators, stating how the nuclear industry should design, build and operate nuclear facilities and how regulators should regulate what the nuclear industry does.

For the IAEA, "roadmap" means "action plan", and I expect that in the light of the findings of this conference we in the IAEA Secretariat will — with the help of outside experts (from the nuclear industry, government departments, organizations like Greenpeace and elsewhere) — try to put together an action plan which spells out what additional information is needed from UNSCEAR, what still needs to be done by ICRP to the framework proposed by it and how the IAEA should go about formulating international standards that can constitute the basis for regulations.

R.L. ANDERSEN (World Nuclear Association): In response to Mr. Landfermann's first question, I would say that the envisaged system of environmental radiation protection will benefit regulators by enabling them to better justify to the public in their countries why they are focusing more on certain issues and less on others.

S. CARROLL (Greenpeace International): Regarding the first comment just made by Mr. González, I would note that, if we were still applying the guidelines for the dumping of radioactive at sea which were developed from the "bottom up" in connection with the London Convention, we would quite legally be dumping more radioactive waste at sea now than ever before.

Fortunately, the political community decided that the dumping of radioactive waste at sea was simply unacceptable and should be stopped — it adopted a "top down" approach.

I believe that this conference should face up to an issue which is similar to the issue which we faced up to in the 1980s in connection with the London Convention. It is not sufficient to perform calculations and then say that everything is alright as long as certain organisms are not irradiated to above certain levels. One must also consider the practice giving rise to the irradiation and decide whether it is acceptable. This "top down" approach is not irrational or unscientific, and it is more likely to be accepted by the community at large.

R. NICKERSON (United Kingdom): As a representative of a "green" NGO, I should like to associate myself with what Mr. Carroll just said.

In my view, society at large does not have much confidence in the scientific community, and I was wondering whether the envisaged system of environmental radiation protection will help to bridge the “confidence gap”, which I consider to be more important than any data gaps.

I was also wondering whether the precautionary principle, which is now accepted as a fundamental principle in the field of environmental protection, will be reflected in the envisaged system.

H. FORSSTRÖM (European Commission): In my view, Mr. Nickerson has, in talking about a “confidence gap” between society at large and the scientific community, made an important point about acceptance. I am sure that the scientific work to be done in developing the envisaged system of environmental radiation protection will be done in an excellent manner. However, will the results be accepted? I believe that, for them to be accepted, the scientific work will have to be done as part of a broad approach to environmental protection involving more than just organizations like ICRP and the IAEA.

With such a broad approach the results may take longer to emerge, but they are more likely to be generally accepted.

N. GENTNER (UNSCEAR): I believe that the envisaged system of environmental radiation protection will help to bridge the “confidence gap” to which Mr. Nickerson referred. For example, the fact that all monitoring and other data will be made generally available will, in my view, increase public confidence.

Regarding the precautionary principle, to which Mr. Nickerson also referred, we could argue all night about whether it should apply to ionizing radiation and to deterministic effects.

Regarding the broad approach to environmental protection, I would note that for all ionizing radiation types there is a unifying concept, dose, whereas there are hundreds or thousands of chemicals being regulated separately — often only in a single medium. Consequently, I believe that there will always be differences between the way in which we approach the protection of humans and the environment from the effects of ionizing radiation and the way in which we approach their protection from the effects of chemicals.

R.L. ANDERSEN (World Nuclear Association): The envisaged system of environmental radiation protection may be incomplete, with various gaps, but so was the system introduced many years ago for the radiation protection of humans. For example, at the time when it was introduced stochastic effects were not understood — a very big gap! I do not think, therefore, that a hundred years from now people will be saying that the system of environmental radiation protection was fundamentally flawed.

S. CARROLL (Greenpeace International): As I indicated earlier, Greenpeace welcomes the nuclear community's initiative — however belated — of trying to establish a system for radiation protection of the environment. It must have taken a lot of courage on the part of the nuclear community to challenge assumptions on the basis of which it had been operating for some 50 years and to admit that things ought perhaps to be done differently in future.

T. HARRIS (United States of America): In my view, the system of environmental radiation protection should be practicable, cost effective and commensurate with the problem.

Regarding what Mr. Gentner said about dose rates, I believe that it would be easier to regulate on the basis of secondary limits such as activity discharged or radionuclide concentrations in various environmental media.

N. GENTNER (UNSCEAR): I also believe that. Once you have a dose rate value, you can reverse-engineer it to give a derived activity concentration.

In this connection, I think that attention should be paid to the question of the time integration period used. There has been a lot of talk about so many micrograys per hour, but is an hour the appropriate length of time? Certainly a year is not; if you were to set a protection criterion in terms of absorbed dose per year, you would fail to protect short lived species and species which have very radiosensitive stages in their life cycles. An hour may be too short in the case of, for example, a mobile species that encounters a temporarily higher than normal radioactivity level.

I think a day is about right, and there is a biological basis for using a day; a period of the order of a day is necessary for the repair of what radiobiologists used to call "potentially lethal damage" — damage which is not easily repaired and where the chances per lesion of deleterious effects arising are higher than normal.

R.M. ALEXAKHIN (Russian Federation): As I understand it, ICRP is going to recommend dose limits for various reference organisms. Given the many climatic zones and the huge number of ecosystems that exist in the world, how will regulators be able to make use of ICRP's recommendations?

J. LOY (Australia – Chairperson): That question is no doubt going to be asked very widely by regulators, who prefer to regulate on the basis of radionuclide concentrations in various media rather than dose limits.

As I understand it, however, what ICRP aims to provide is a framework or approach for the conduct of assessments — not simply a table of numbers.

R.L. ANDERSEN (World Nuclear Association): I imagine that ICRP's reference organism approach will take account of the infinite spectrum of life. After all, in the radiation protection of humans, account is taken not only of the fact that some people are bigger than others but also of the fact that some people are more radiosensitive than others.

L.-E. HOLM (Sweden): ICRP's reference organism approach will aim to do that.

N. GENTNER (UNSCEAR): The more I learn about ICRP's reference organism approach the more I like it. For example, it addresses dosimetric questions like that of "observed dose". It is only a tool — but an informative one.

H. FORSSTRÖM (European Commission): With regard to the usefulness of the envisaged system of environmental radiation protection for regulators, I was wondering whether the relationship between effects on individuals and effects on populations was an area where research is needed in order to make the system useful for them.

S. CARROLL (Greenpeace International): I see the reference organism approach as a tool — not as the answer. I believe that it will help us to understand what we are looking for — and even to understand the questions which we shall be asking of ourselves — and that it will be valuable in policy discussions, decision making and the development of standards.

However, the reference organism approach will not help in dealing with situations at sites like Kakadu National Park, where the objective should be to keep the site in a condition as near to pristine as possible — not to engage in damage limitation on the basis of a cost-benefit analysis.

P.A. THOMPSON (Canada): The aim of the ICRP Task Group report was to make recommendations to ICRP about the role of ICRP in environmental protection and to indicate whether it had to change its basic premise. I do not think that ICRP or the IAEA can tell society what its societal objectives in terms of environmental protection should be. The objective of the Task Group was to develop a tool for analysing the available information and to identify gaps in knowledge, so as to assist countries and relevant agencies in taking decisions. In the future development work, it is important that we do not forget that science is not the only thing which informs the decisions that society has to take. The approach will be more readily accepted if it is understandable and easy to communicate.

J. LOY (Australia – Chairperson): I think that is a worthwhile comment.

L.-E. HOLM (Sweden): Regarding the comment just made by Mr. Carroll about Kakadu National Park, I do not consider it to be a role of ICRP to make recommendations for keeping nature pristine. That is a "top down" matter for governments, parliaments or whatever.

In this connection, I recall that earlier Mr. Forsström asked which things in the environment should be protected — a question that was considered by the ICRP Task Group. He mentioned smallpox viruses, which society has decided should be exterminated with the exception of some kept safely in a few ampoules for research purposes. If society had decided that smallpox viruses were of value for the future existence of humans on earth, ICRP would have had to take that decision into account. It cannot act in isolation from societal expectations and demands.

J. LOY (Australia – Chairperson): Perhaps ICRP's final proposals could have a preamble stating the limitations of what is being presented and the decisions which society will still have to take itself.

H. FORSSTRÖM (European Commission): I think it is important that those proposals be comprehensible not only to "insiders" but also to the general public. Making them comprehensible to the general public will not necessarily be a task for ICRP; it might be a task for, say, Mr. Holm as head of the Swedish Radiation Protection Authority.

The general public must understand the proposals and agree that, as they are in line with what is being done in other areas, they make good sense.

S. CARROLL (Greenpeace International): In agreeing with Mr. Forsström, I would note that we have been talking about "protecting the environment" and about "protecting non-human biota" as if these two ideas are identical. However, saying that a certain course of action will ensure that the environment is protected is not the same as saying that it will ensure that — for example — dose rates are kept below certain limits in order to protect reference organisms. The difference may seem trivial, but it is important from the point of view of how the course of action will be accepted by the general public.

ICRP publications are not "best-sellers", but the proposals made by ICRP are widely noted and considered by non-specialists in the field of radiation protection. I am therefore attracted by the idea — put forward by Mr. Loy — of a preamble. I should like the preamble to state in plain language what ICRP hopes to achieve with its proposals and also what the proposals are not designed to accomplish.

A. JOUVE (France): I believe that ICRP's environmental protection initiative is welcome from a very practical point of view, as we are rather out of date as regards the environmental monitoring demands which we make of nuclear power utilities. For example, we require that they monitor for fission product radionuclides in tomatoes grown near nuclear facilities, but it takes quite a long time for some of the radionuclides to reach the fruit via the plant, so that a lot of useless measurements are performed. With the envisaged system of environmental radiation protection we should be able to make more meaningful demands of the utilities.

J. SUTCLIFFE (United Kingdom): One of the drivers of this work has been European Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, which requires that specific habitats and species not have their integrity damaged.

My answer to the question asked by our Chairperson is “Not quite — yet”, because I think there are some very fundamental gaps in the research. Much of the research on wildlife species to date has been incidental and, in my opinion, not very developed. It worries me that the EC Directive and its requirements are not being backed by some fundamental research money.

H. FORSSTRÖM (European Commission): I think it is important that research be directed to fulfilling appropriate objectives, and one of important results of the establishment of the framework under discussion should be to set those objectives and define research priorities.

J. SUTCLIFFE (United Kingdom): I think Mr. Strand identified the key gaps in the information needed to support the initiative. Perhaps the way in which these gaps are prioritized should be discussed further.

J. LOY (Australia – Chairperson): I think the points made by Ms. Sutcliffe are valid, but the consensus among the panellists seems to be that, despite the gaps, it is time to go ahead and develop a framework. At the same time, of course, the research community should continue to identify gaps and fill the high priority ones to the extent possible.

S. SAINT-PIERRE (France): I believe communication is an important issue that we need to think about even at this early stage. We need to be careful when discussing limits or guidance values, but can you imagine a tool without guidance values? Values of various sorts have been discussed, including derived concentration limits and background, but I am not clear how guidance for protection will develop over time.

Regarding Mr. Carroll’s comments about Kakadu National Park, we would not be here today if a “pristine approach” had been enforced generally regardless of the needs of humankind.

S. CARROLL (Greenpeace International): What I actually said just now was that the objective in the case of sites like Kakadu national Park should be to keep them as near to pristine as possible. Such sites warrant specific approaches that one would not adopt in the case of, say, downtown London or Paris. One size does not fit all.

Earlier on, Mr. González said that, in his view, Greenpeace preferred a “top down” approach because it would like to put a stop to nuclear power generation. That is not the reason. We believe that there are circumstances which require very specific approaches that would not be provided for by a general framework.

J. LOY (Australia – Chairperson): Regarding Mr. Carroll’s last comment, it is for society to decide what levels of protection should be accorded to different environments. In Australia, the same level of protection is not accorded to the Parramatta River, which flows into Sydney Harbour and into which a great deal of industrial effluent is discharged, as to Kakadu National Park.

I do not think that we should discuss the issue of "pristineness" any further as, in my view, we would be side-tracked by it.

A.J. GONZÁLEZ (IAEA): I believe that discussion of the "pristineness" issue is important for answering the question asked in the title of this round table, since "pristineness" should be fundamental to what ICRP is trying to do.

I would be very concerned if there was widespread dogmatic insistence on "pristineness", and I would like to see Greenpeace reconsidering its position. At a meeting held nearly four years ago in Warrenton (near Washington, D.C.) Mr. Carroll argued very convincingly, not in favour of the "pristine approach", but in defence of ICRP's justification principle. In my view, if the justification principle is part of the system of environmental radiation protection, there will be no need to talk about "pristineness".

J. LOY (Australia – Chairperson): I think we are indeed being side-tracked. Like other organizations, Greenpeace recognizes that, since Adam and Eve were expelled from the Garden of Eden, humans have had to earn their bread by the sweat of their brow.

R.L. ANDERSEN (World Nuclear Association): With regard to Mr. Saint-Pierre's comment about reference values, even if ICRP wants to avoid prejudging the values which should be adopted, recognizing that this informs the decision making process, I do not believe that reference values are very important for equating expected effects given a certain concentration or a certain exposure. However, given the logical approach you are taking to different aspects of species or individuals — as outlined by Mr. Holm — one can certainly derive reference values that imply effects to individuals from which one can begin to extrapolate in terms of larger systems or smaller systems.

I think reference values are very important, because I share Mr. Saint-Pierre's point of view. In my view, the framework would be meaningless if one could not relate a given situation to an expectation of effects.

A. JOHNSTON (Australia): If ICRP ultimately just recommends a particular dose rate as being safe, I do not see how we shall be able to apply its recommendation across vastly different ecosystems ranging from the highly disturbed to the pristine.

L.-E. HOLM (Sweden): That is an issue which ICRP has not yet addressed.

J. LOY (Australia – Chairperson): This is not merely a technical issue. We have talked about consistency with the protection of the environment from other pollutants and stressors — protection decisions are often taken in a broader context. The Australian Government did not decide that Kakadu

National Park was of high conservation value just out of concern about radio-activity.

Round Table 5

DISCUSSION

P. RICKWOOD (IAEA – Chairperson): In 1999, in a study conducted by the First Amendment Center in the United States, 89% of the scientists polled has "only some" or "hardly any" confidence in media reporters getting the facts right. I suggest, however, that this conclusion could point to a failure on the part of scientists as much as to a failure on the part of the media.

At this conference it has several times been stated that the environmental radiation protection initiative being considered here will not succeed without extensive support from stakeholders, and I believe that "stakeholders" must include the general public. One way of conveying messages to the general public is through the media, and I hope that by the end of this round table the scientists present here will have a better idea of how the process of communicating with the general public through the media works.

J. DÍAZ PONT (Autonomous University of Barcelona, Spain): For a long time, the media have been the most important intermediary for the transmission of information to the general public, but this is changing. With the advent of the Internet and of electronic networking, society itself is becoming an actor in information transmission.

The media have not been particularly successful in transmitting scientific information about the environment to the general public. They were successful in triggering widespread concern about depletion of the Earth's ozone layer, but they have not made people generally aware of the problem of global warming and consequential climate change — let alone the problem of the effects of ionizing radiation on the environment.

The reason why the media have not been particularly successful in this respect is that they have their limitations. For example, it is generally believed that the media "control the agenda" of the environmental debate, but their ability to do that is limited by events like the tremendous heat wave that affected Spain and several other European countries this past summer; the environmental debate was affected more by the heat wave itself than by the media reports on it.

Another major limitation relates to journalists: few of them have more than a general knowledge of science; they are rarely given enough time to delve into the scientific issues they have been told to report on, which are often complex rather than spectacular; they risk being overwhelmed by the amount of paper (press releases and so on) that finds its way to their desks; with most environmental issues there are differing points of view, and journalists have to strike a balance between them in a prevailing atmosphere of scientific uncertainty; and many of them work for media corporations involved in political or economic alliances with organizations which want certain things to be reported on in certain ways.

With the limitations of the media and with society itself becoming an actor in information transmission, scientists need to and now can communicate more directly with the general public. However, the ability of communities, associations and individuals to select and judge is increasing, they know what they want and how to get it, and scientists will therefore have to give a lot of thought to how they package and deliver the messages which they wish to convey to the general public. In addition to research, information dissemination is going to be part of the scientist's job.

S. CONNOR ("The Independent", United Kingdom): The job of newspaper journalists is to write stories which the readers will find interesting; this is true both for general newspaper journalists and for specialized ones like myself — a science graduate who has specialized in science journalism.

The stories which we write are made up of words. Some of the words which we use can have a particular emotional impact and therefore should be used with care. I will speak briefly about just three such words, which may be relevant to the subject of this conference — they are "nuclear", "chemicals" and "natural".

Recently, the 2003 Nobel Prize for Medicine was awarded to two physicists who played an important role in the development of the magnetic resonance imaging scanner. The name of this piece of equipment originally contained the word "nuclear", which was dropped some years ago because of people's fear of all things nuclear.

People are also afraid of chemicals, and the general public is not happy about the fact that there are chemicals in the environment. However, as any chemist will tell you, the environment is full of natural chemicals — and the general public likes what is "natural", because Nature is good. But what about smallpox? That is part of Nature.

A concluding remark about the word "nuclear" — I have the feeling that public fear of things nuclear is decreasing or is being overshadowed by public fear of things that have been genetically modified.

What makes news? The best, the biggest, the fastest, the longest — we are addicted to superlatives. It can be significant, exclusive, counter-initiative ("dog bites man" is not a news story, "man bites dog" is), relevant or irrelevant. News stories about science have to compete with news stories about crime, politics, legal issues and so on for space in newspapers. I have no guaranteed space reserved in "The Independent" for science news stories written by me.

Where do I get my ideas for news stories from? In many cases from articles in reputable periodicals like "Science" and "Nature" — articles which have undergone quality control in the form of peer review and which can therefore be trusted. But I also get ideas from — for example — conversations. A story by me which gained considerable prominence derived from a conversation with someone who told me that workers at British Nuclear Fuels (BNFL) were making false declarations about the size of MOX fuel pellets. The story led to the return of MOX fuel rods from Japan to the United Kingdom (at great expense) and to the resignation of the then head of BNFL. It was a science-related story which competed successfully with stories of other kinds.

P. RICKWOOD (Division of Public Information, IAEA – Chairperson): There is a saying in the media that journalists are only as good as their sources. In the case of environmental radiation protection, the scientists attending this conference are the sources.

A. LAVERTY (BBC Horizon, United Kingdom): I am not a specialized science journalist, but the stories in which I am interested at the moment happen to be about science.

When I began working with BBC Horizon, I asked an experienced colleague what scientists were like to deal with. His reply went roughly as follows — "The first thing they tell you is what they do not know; then they explain footnotes; and then they tell you how important their colleagues' work is." This is very honourable, but clearly the culture of scientists is very different from that of journalists.

Science is to a great extent based on doubt and uncertainty, and on a strong sense of collective endeavour, whereas journalism is based on clear-cut stories about individuals. When people read a science story in a newspaper, as with other stories they want to get out of it something of practical significance for themselves.

I have found that collaboration between journalists and scientists on a science story works best when both sides are honest about what they want to achieve. For our part, we try to mould our descriptions of scientists' work to our objectives.

A typical television news bulletin consists of about ten stories, of which some are self-selecting as they are about major events of the day. The competition for inclusion among the remainder is intense. The first thing a television journalist must have is a "top line" summarizing the story that he/she is proposing — a short sentence designed to justify the story's inclusion in the news bulletin. A "top line" might start "A fierce row has broken out over ...". The "top line" for a science story might start "A discovery that holds the promise of ...". At all events, the discovery will have to compete with the fierce row for inclusion.

The journalist whose story has been selected for inclusion has about 90 seconds in which to tell it to the viewers. Typically about 30 seconds of that time will be devoted to people — for example, scientists — talking on camera, quite possibly three of them with about ten seconds each. Ten seconds corresponds to about 30 spoken words — not very many. The journalist has about 60 seconds, 180 words, for his/her commentary — again not very many. It is not surprising, therefore, that the journalist simplifies or exaggerates.

So, when the world of scientists and the world of journalists meet in the context of a television news story, something that may well be very important for humankind gets boiled down to, say, 15 short sentences written by a journalist and three to four sentences spoken by scientists.

Moreover, the fact that something is very important for humankind does not necessarily mean that it will make a good television news story. It will not if there are no pictures available. There is a saying in the television business that if something happened without television cameras present it did not happen.

With television documentaries on science issues, the situation is a little different, but compaction is still necessary — with resulting competition between what the scientists want to say and what the journalist must write.

A problem which scientists in particular have in communicating with the general public stems from the fact that they are so accustomed to communicating with their peers. My advice is "Imagine that our stories are addressing an intelligent 19 year old who wants to learn something about what you do."

A final comment — when the world of scientists and the world of journalists meet in the context of a television news story or a television documentary, if there is a disagreement it is likely to be the journalists who will get their way.

L. CHARBONNEAU (Reuters): My first job in journalism was as the assistant to an editor of a New York newspaper, 12 years ago. Twice a week I used to sift through the press releases which the editor had received, in each case throwing away all but the first page of the press release. I would then collect the first pages of those press releases which I considered to be of interest for the newspaper, discarding the rest, and write on each of them a brief note about why I considered it to be of interest. My editor would finally sift through the annotated first pages and throw away most of them, keeping three of four "to be followed up".

That account illustrates how newspapers — and news agencies and other media organizations — deal with the mass of information which they receive. They take quick decisions about what is worth following up, and the competition for their attention is intense.

I have been working for Reuters in Vienna for two and a half years, mainly covering IAEA matters. The big stories about the IAEA during the past few years have had to do with Iraq, Iran, North Korea and nuclear terrorism ("dirty bombs" in particular). This suggests that we focus on the negative. However, I have written a number of stories about the IAEA which were entirely positive — for example, a story about the radiation sterilization of human skin tissue for storage prior to use as skin tissue grafts and one about the use of the sterile-insect technique in combating the tsetse fly. The IAEA presented the facts relating to these two stories very well, and the stories received a great deal of newspaper coverage worldwide. So good news, if presented well, can find its way into newspapers.

In journalism, as in other professions, there are good and bad practitioners. If you know a journalist who is prepared to hear you out and seems able to convey your message, you should work with him/her closely.

P. RICKWOOD (Division of Public Information, IAEA – Chairperson): the final point made by Mr. Charbonneau is very important. When scientists communicate with journalists, as in human relationships generally a great deal depends on the establishment of trust.

L. KOBLINGER (Hungary): With regard to Mr. Connor's comment about the emotional impact of the word "nuclear", I recall that at the end of the year 2000 a group of journalists produced a list of the major catastrophes which had occurred during that year. The list consisted of 19 catastrophes, mainly floods and earthquakes, which had claimed large numbers of victims, plus the nuclear accident at Tokaimura, Japan, which ultimately resulted in the death of only two people. That accident was not a catastrophe, and I believe that the journalists were acting irresponsibly when they included it in their list.

L. CHARBONNEAU (Reuters): I agree that the Tokaimura nuclear accident should not have been included in that list. The fact remains, however, that when someone dies as a result of a nuclear accident the emotional impact on the general public is greater than when several people die as a result of — say — a car accident.

I. PRLIC (Croatia): It would be interesting to know whether journalists have a definition of what is "worth" publishing.

S. CONNOR ("The Independent", United Kingdom): They do not. Journalism is an art form — not a scientific discipline. Decisions are normally taken in a hurry, and mistakes are sometimes made. Scientists do not work under the kinds of pressure that journalists work under.

Regarding the Tokaimura nuclear accident, perhaps the journalists who included it in their list of catastrophes were trying to convey their feelings about what could have happened at Tokaimura. Many journalists share the general public's fear of things nuclear. I am one of the few journalists who know that, if you go for a holiday to Cornwall, you will receive a higher radiation dose than if you were to spend the same length of time near

Sellafield. A quality newspaper like “The Independent” tries to explain the real risks in life.

A difficulty about reporting on science is the fact that the human aspects of a story tend to have a greater impact than the scientific aspects. Imagine a situation where a child has fallen seriously ill following a vaccination and its parents are convinced that it is ill because of the vaccination, whereas reputable publications like the British Medical Journal or Lancet state that there can be no link between the vaccination and the illness. The journalist’s interview with the parents and the picture of the sick child will almost certainly have a greater impact than the quotations from the British Medical Journal or Lancet.

L.-E. HOLM (Sweden): Except perhaps in the case of sports news, people seem to prefer bad news to good. Why is that?

L. CHARBONNEAU (Reuters): I attribute it to human nature. A story about a decent man who treats his family well, does his job well and leads a pleasant life is not likely to be found interesting by the general public.

That having been said, the two positive stories about the IAEA which I mentioned earlier — both of them good news — were given very wide circulation, presumably because editors thought that the general public would find them interesting.

S. CONNOR (“The Independent”, United Kingdom): There is a theory that we are genetically programmed to be on the lookout for anything dangerous in our environment. If that theory is true, it would help to explain why we generally pay more attention to bad news than to good news.

A. LAVERTY (BBC Horizon, United Kingdom): I think we prefer bad news to good news because we like to read about or watch things which are dramatic. Nobody would pay to see a movie about a family outing during which everyone had a nice time and nothing dramatic happened — however pleasant such an outing might be as a personal experience. The challenge for people with good news which they would like the general public to be interested in is to make that good news relevant to individual members of the general public.

In most situations, scientists are members of the general public. They are unlikely to be interested in good news that does not relate to their work or to fields of activity connected with their work.

A. SUGIER (France): It seems that scientists are usually going to have great difficulty in conveying their messages to the general public through journalists. How else could scientists convey their messages?

J. DÍAZ PONT (Autonomous University of Barcelona, Spain): As I said earlier, scientists will have to give a lot of thought to how they package and deliver the messages which they wish to convey to the general public. New mechanisms now exist for packaging such messages and delivering them to communities, associations and individuals, and scientists should learn how to avail themselves of them.

L. KEEN (Canada): Going to Cornwall for a holiday is a voluntary act, whereas living near a nuclear facility may well not be. Risks incurred in connection with voluntary acts are accepted more readily than risks which cannot easily be avoided. How is that fact reflected in the media?

A. LAVERTY (BBC Horizon, United Kingdom): The media tend to reflect the fact that people have rather irrational ideas about risks.

The situation was complicated in the United Kingdom during the BSE (mad cow disease) crisis by what scientists and politicians said. Essentially, both groups said “Eating beef is safe”. However, when a scientist says that it means that the risk is negligibly small and that you should behave in a certain way, whereas when a politician says it (and lets his children eat beef burgers in front of the television cameras) the message sounds much more categorical. A tabloid newspaper is unlikely to draw attention to the distinction, whereas in — say — a television documentary you may have time to explain some aspects of risk. A problem in this connection is that, in the United Kingdom and a number of other countries, scientists no longer command the respect which they used to command, and the views put forward by a scientist in a discussion relating to his/her special field may well carry no more weight than the view of a non-specialist.

S. CONNOR (“The Independent”, United Kingdom): The BSE crisis led in the United Kingdom to a complete loss of public faith in government scientists working in the area of food safety. The Food Standards Agency, which was established after the crisis, asks itself the question “Is this something which people could reasonably avoid?” when making risk assessments. I believe its view is that the general public should be given the information and then be left to choose — a sensible approach.

What does one do, however, about the theoretical possibility that BSE exists in sheep in the United Kingdom? Public alarm could lead to enormous/unnecessary economic damage. If nothing is done to inform and advise the general public, on the other hand, if BSE is ever found in sheep it will be too late — people will have been exposed.

A. LAVERTY (BBC Horizon, United Kingdom): A simple half-truth can destroy trust, especially in regulatory areas. Regulators must constantly prove their independence.

L. CHARBONNEAU (Reuters): When there is only a very slight risk associated with — say — a nuclear facility, the owners or operators may be tempted to keep completely silent about that risk, thereby conveying the impression that there is no risk at all. It is very likely, however, that somebody or other will talk about that very slight risk — and journalists may follow up what has been said and produce an exaggerated and distorted story. The best policy is to be frank about the risk, while endeavouring to ensure that the journalists realize how slight it is.

A. LAVERTY (BBC Horizon, United Kingdom): Perhaps the scientists at this conference should ask themselves whether their policy is to be frank about risk or whether they shred all compromising documents at the end of each day.

A.J. GONZÁLEZ (IAEA): Scientists have learned to live with the fact that journalists prefer bad news to good news, but they still cannot understand why the bad news is always reported wrongly in the mass media.

By “mass media”, I do not mean serious newspapers, television channels and news agencies, but — in particular — sensationalist popular newspapers. Every time I read a report in such a newspaper about something with which I am to some extent familiar, I find that the report is wrong.

I believe that there is a gap about which something needs to be done — not the gap between scientists and the serious media, but the gap between scientists and the real mass media.

A. LAVERTY (BBC Horizon, United Kingdom): In response to Mr. González I would note that in the United Kingdom the number of copies sold each day of the most popular newspaper (that is to say, the newspaper with the largest circulation) is roughly equal to the number of people who regularly watch BBC’s main evening news bulletin.

Moreover, I believe that most readers of what Mr. González called “sensationalist popular newspapers” have a rather playful attitude towards them; they do not regard what is written in them as truths which should be taken literally.

S. CONNOR (“The Independent”, United Kingdom): When Mr. González says “wrong”, does he mean “factually inaccurate” or “overstated”. There are often overstatements in headlines, and it is normally headlines that scientists complain about.

A.J. GONZÁLEZ (IAEA): I mean “factually inaccurate”.

The problem is that, by and large, politicians read serious newspapers but most members of the general public read sensationalist popular newspapers. As a result, politicians are fairly well informed but most members of the general public are badly informed. However, politicians are constantly looking ahead towards the next elections and their decisions are strongly influenced by what the general public reads in the real mass media and less by what they themselves know to be true.

In Austria, where the IAEA is based, most politicians almost certainly know that the spa of Badgastein is more dangerous from the radiation exposure point of view than the nuclear power station at Temelin, in the Czech

Republic. They are afraid to say so, however, for fear of losing in the next elections.

J. DÍAZ PONT (Autonomous University of Barcelona, Spain): In this connection, I think scientists should bear in mind the fact that, in many countries, people are more and more reading local or regional newspapers, watching local or regional television channels and listening to local or regional radio stations. There is now less need to try conveying one's message via the major media.

Many commercial enterprises have realized that and, instead of contacting — say — national newspapers, they organize press conferences at the community level that are open also to local citizens.

A. LAVERTY (BBC Horizon, United Kingdom): Regarding what Mr. González just said about Austrian politicians, I would note that in the United Kingdom election results appear not to be affected very much by what people read in what he called "sensationalist popular newspapers".

In my opinion, the important thing about such newspapers is that they deal with issues from a very personal and practical point of view, answering readers' questions like "How will that affect me?" However, science stories can be tailored to answer such questions; in order to find their way into such newspapers, they must be.

B.E. CEDERVALL (Sweden): It is not only sensationalist popular newspapers that distort. I have a list of some 60 pop music songs that contain words like "nuclear" and "radioactive" and convey a very wrong impression of what ionizing radiation is. For example, according to one song there are "Hot Frogs on the Loose" in Tennessee that are radioactive as a result of "Slurping nuclear debris" and will make your car wheels radioactive if you run them over.

A typical sensationalist technique is to make very free use of the word "could", as in "X could be due to Y". This technique was used in a recent newspaper story about an 85 year old lady who died two weeks after a mobile phone relay station was set up near her home — her death "could" have been due to the setting up of the station. How can one prevent such stories from finding their way into newspapers?

S. CONNOR ("The Independent", United Kingdom): Newspapers like "The Independent" have someone like me who filters out such stories.

For example, I was very suspicious about the story that circulated widely some time ago regarding illnesses due to depleted uranium from munitions used in fighting in Yugoslavia, and I advised against the story being carried in "The Independent".

H. FORSSTRÖM (European Commission): In Sweden there are still newspapers which, over periods of several weeks, run "discussions" in which numerous people participate — it is a kind of stakeholder involvement. Could something like that be done in the field of environmental radiation protection?

S. CONNOR ("The Independent", United Kingdom): Running such "discussions" would not be a task for newspaper journalists, whose job is, as I said at the outset, to write stories which readers will find interesting.

A story about radiation and the environment which I wrote and which was widely considered to be interesting related to the Chernobyl exclusion zone, which has become a haven for wildlife because the most destructive element in the environment — humans — has been removed.

J. DÍAZ PONT (Autonomous University of Barcelona, Spain): I think scientists are the last group of people to realize that you cannot use the major media as a tool in stakeholder involvement. Business enterprises, local governments, NGOs and others are all successfully involving stakeholders without using the major media.

Most scientists still seem to think that their work is so difficult to understand that the only way of involving stakeholders without sacrificing scientific rigour is simply to provide the major media with their results and hope that the major media will do the job of explaining them which they themselves should do. Fortunately, there are exceptions — for example, I know of some scientists working in the field of climate change who are recruiting mountain hikers to collect glacier samples in accordance with a carefully worked out sampling protocol.

Scientists must start developing new communication strategies.

L. CHARBONNEAU (Reuters): Scientists must never forget how terrified most non-scientists are of ionizing radiation. We have all seen pictures of mushroom clouds and of Hiroshima and Nagasaki atom bomb victims, and those images are never going to disappear from the popular imagination. You can counteract people's fears with positive stories like the two which I mentioned, but only to a very limited extent.

H. FORSSTRÖM (European Commission): I was wondering what Mr. Charbonneau's "lead" would be for his editor about this conference.

L. CHARBONNEAU (Reuters): Perhaps something like "In our struggle to protect people from the harmful effects of radiation, we may have forgotten what we all need in order to survive on this planet — the environment."

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Round Table 1	L. KEEN	Canada
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	A. SHPYTH	Canada
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Topical Session 2	L.B. ZONDO	South Africa
Topical Session 3	L.B. ZONDO	South Africa
Round Table 2	D. CLEIN	Argentina
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Topical Session 4	J.-C. BARESCUT	France
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Topical Session 5	Z. PAN	China
Round Table 4	J. LOY	Australia
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	S. CARROLL	Greenpeace International
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Round Table 5	P. RICKWOOD	IAEA
Panellists:	L. CHARBONNEAU	Austria
	S. CONNOR	United Kingdom
	J. DÍAZ-PONT	Spain
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INDEX OF PARTICIPANTS IN DISCUSSIONS

Over the past two decades awareness of environmental issues has increased, prompted by evidence of the harm caused in the environment by industrially derived pollutants. In the context of radioactive materials as environmental pollutants, this has led to a reconsideration of the assumption on which current standards are based, namely that if humans are adequately protected, then other species will also be adequately protected. The objective of this conference was to review recent scientific and policy developments in the area of protection of the environment against the effects of ionizing radiation and the implications for further work at the national and international levels. These proceedings include the opening speeches, overall findings of the conference, presentations, topical discussions and summaries of each session. The contributed papers are provided on a CD-ROM that accompanies this volume.

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