NATIONAL DOSE ASSESSMENT WORKING GROUP

PAPER 6-02: PROTECTION OF THE ENVIRONMENT FROM IONISING RADIATION – CURRENT STATUS AND ONGOING DEVELOPMENTS

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1. Introduction

The current recommendations of the International Commission on Radiological Protection (ICRP, 1991) state that:

"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."

Whilst this statement may well be true in circumstances where pathways to man are present in the environment in which other species are exposed (IAEA 1992; UNSCEAR 1996), there has been a growing acceptance that it is not a sufficient basis to demonstrate positively that the natural environment is protected from the impacts of anthropogenic radioactivity.

The Rio Declaration on Environment and Development (United Nations, 1992) set out important philosophical principles for the protection of the environment and established the concept that the environment should be protected in its own right, additional to the requirement to protect it as a resource for humans to inhabit and exploit. During the 1990s, and indirectly as a result of the Rio Declaration, national regulatory bodies in Canada and Sweden came under pressure to consider the impact of anthropogenic radioactivity on the natural environment because their regulatory framework for radioactive emissions and waste disposals explicitly required protection of man and the environment to be considered. Largely as a consequence of this, a series of symposia on the protection of the environment from ionising radiation (the SPEIR conferences) were convened in Stockholm (1996), Ottawa (1999) and Darwin (2002). In parallel, the regulatory agencies began to develop methodologies to assess the impact of anthropogenic radioactivity on the natural environment and they began to apply these methodologies as part of their normal regulatory activities.

This report summarises subsequent developments in this area, sets out likely future developments and trends, and identifies potential implications for both regulators and operators in the UK.

2. The current conceptual basis for protection of the environment from ionising radiation

Before summarising specific developments, it may be helpful to discuss the general problems faced by any framework or methodology which attempts to demonstrate protection of the natural environment from adverse impacts attributable to anthropogenic radioactivity.

The first major problem is, of course, the complexity and variety of the natural environment. Protecting man from the impacts of anthropogenic radioactivity released into the environment also involves a great deal of complexity, but this can be managed because only pathways back to a single species *(Homo sapiens)* need to be considered. Anatomical and biokinetic models for 'standard man', together with coefficients of radiation risk from human epidemiological studies, can be used as the basis of a scientifically based assessment of risk.

In the case of the natural environment, it would clearly be impossible to consider every possible species of organism which may be affected and simplification is essential if any approach is to be workable. The currently accepted approach is to simplify matters by considering 'reference organisms' which inhabit 'reference ecosystems'. Reference organisms are intended to be representative of the range of habitat occupancies, radionuclide uptake behaviours, and sizes and shapes (affecting dosimetric calculation) which would characterise a real ecosystem.

The second major problem is deciding what the objectives and criteria for protection should be. Clearly the aim should be to ensure 'no deleterious effect', but there are areas for debate on whether populations or individual organisms should be the object of protection. Here there appears to be some consensus that the main focus should be on protection of populations, but at the current state of knowledge this can only be assessed by considering likely effects on individual organisms and using generalisation to assess how any likely effects at the individual level may become manifest at the population level. There is general agreement that the effects, or endpoints, at individual level which will need to be considered are:

- Enhancement of mortality
- Enhancement of morbidity
- Reduction of reproductive success
- Enhancement of scorable cytogenetic effects

The third major problem is how to assess the likelihood of these effects in individual organisms within an exposed population. The generally accepted approach, following on from the radiological protection framework for humans, is to:

- Determine the distribution of radionuclides in the ecosystem by measurement or modelling
- Calculate the absorbed radiation doses to organisms
- Assess the likelihood of effects from dose-response relationships derived from laboratory experiments or field studies of heavily exposed populations

The principal variation in approach here is whether the approach is to explicitly evaluate the likelihood of effects and consider whether the result is acceptable (as, for example, the FASSET approach - see below) or whether to evaluate the results of the assessment against pre-set criteria in terms of dose (as, for example, the UK Environment Agency and US-DoE approaches - see below).

Although the concept of basing protection on the assessment of radiation dose is broadly accepted, gaps in the data required to perform a comprehensive assessment of dose to exposed organisms has prompted debate about whether simpler approaches based on toxicity testing and environmental concentration standards would be preferable - however, closer examination suggests the possible alternatives offer no real simplification.

3. State of the art at the end of the 20th century

Coincidentally, the turn of the century has marked a point at which practical developments in this area have accelerated substantially. The state of the art in 2000 may be summarised as follows:

Reference organisms and reference ecosystems: the concept of reference organisms had been promulgated in a number of publications (e.g. Pentreath, 1999), but no examples of an assessment using this approach had been published.

Radionuclide transfer models and parameters: No radionuclide transfer models, or compilations of associated transfer parameters, intended for the assessment of radionuclide uptake by organisms other than those forming part of the human food-chain were available. Derivation of appropriate transfer factors required basic searches of the radioecological literature.

Dosimetric models: Basic methods for the calculation of radiation doses to organisms of various sizes, represented as ellipsoidal shapes with uniform internal distribution of radionuclides, were documented (e.g. NCRP, 1991). However, result tabulation was limited to a series of energy dependency curves for a limited number of organism sizes and dimensions.

Dose-effect relationships and dose rate criteria: Effects of ionising radiation on organisms of many kinds had been considered in reviews by IAEA and UNSCEAR, and broad conclusion reached that exposure of populations of terrestrial organisms to dose rates of 40 μGy h^{-1}, and exposure of populations of aquatic organisms to dose rates of 400 μGy h^{-1}, would be unlikely to lead to observable effects in populations (IAEA, 1992; UNSCEAR, 1996). However no general guidance was available on dose rates at which particular effects (e.g. enhancements of mortality and morbidity, reduction in reproductive success, enhancement of the incidence of scorable cytogenetic effects) might be observed in different taxa.

Subsequent advances on the state of the art, both in terms of the framework for protection and the technical and scientific basis for carrying out assessments, are described in the sections which follow.

4. Developments at the national level

4.1 UK

During 2000, the UK Environment Agency faced questions from English Nature, in their role as a statutory consultee on the determination of radioactive waste discharge and disposal authorisations under the Radioactive Substances Act 1993. English Nature asked, not unreasonably, how they could sensibly take a view on the acceptability of proposed discharges when no assessments were being made of the potential impact on wildlife. The need to implement the EU Birds and Habitats Directives (see below) in the UK raised the same issue. As a result, the Environment Agency and English Nature jointly commissioned a study to develop an approach for assessment of the impact of ionising radiation on wildlife, including development of the necessary tools to permit Agency site inspectors and other interested parties to carry out assessments for specific cases.

The resulting report (Copplestone *et al.,* 2001) comprised:

- A review of pathways for the exposure of plants and animals to ionising radiation;
- A review of the effects of ionising radiation on biota;
- A review of existing regulatory frameworks for environmental protection;
- A review of methods for dose calculation, including review of the relative biological effectiveness of different radiation types and its treatment in dose calculations;
- Description of a methodology for calculation of radiation doses in ‘reference’ terrestrial, freshwater, and coastal marine ecosystems, including the specification of ‘reference organisms’, default values for radionuclide transfer factors, and dose coefficients for radionuclides uniformly distributed within the organism (internal dose coefficients) and uniformly distributed within the surrounding environmental medium (external dose coefficients);
- Recommendation of dose rate criteria which could be used to judge the acceptability of the assessed doses;
- Incorporation of the methodology into an Excel workbook based dose calculator suitable for use by Agency site inspectors.

The dose calculation methods, and some aspects of the overall approach, were based on further development of techniques established during an earlier work on a pilot assessment of the impact of a generic deep repository for low and intermediate level radioactive waste in the UK (Jones *et al.,* 2003).

The review of effects essentially underlined the IAEA/UNSCEAR dose rate criteria; however the report recommends that, as uncertainties in dose assessment can be substantial, situations in which assessed doses exceed 5% of the IAEA/UNSCEAR criteria (i.e 2 μGy h^{-1} for terrestrial ecosystems, 20 μGy h^{-1} for aquatic ecosystems) should be subject to more detailed examination in order to reduce uncertainty.

Subsequent to the report by Copplestone *et al.* (2001), the EA assessment method was extended to incorporate additional radionuclides and now comprises:

The ***marine coastal ecosystem.*** This includes as reference organisms benthic bacteria, phytoplankton, zooplankton, macrophytes, fish eggs, benthic molluscs, benthic crustacea, pelagic fish, benthic fish, seabirds, seals and whales. Concentration factor data and dose coefficents are provided for these organisms for the radionuclides ^{3}H, ^{14}C, ^{32}P, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{125}I, ^{129}I, ^{131}I, ^{137}Cs, ^{210}Po, ^{234}Th, ^{238}U, ^{239}Pu and ^{241}Am. However, there are significant gaps in the concentration factor data for a number of these organisms.

The ***freshwater ecosystem.*** This includes as reference organisms benthic bacteria, phytoplankton, zooplankton, macrophytes, benthic molluscs, benthic crustacea, pelagic fish, benthic fish, aquatic mammals, and waterbirds. Concentration factor data and dose coefficients are provided for the same radionuclides as the marine ecosystem. Here also there are significant gaps in the concentration factor data for a number of organisms.

The ***terrestrial ecosytem.*** This includes as reference organisms soil bacteria, lichens, trees, shrubs, herbs, seeds, fungi, caterpillars, ants, bees, woodlice, earthworms, herbivorous and carnivorous mammals, rodents, birds, bird eggs, and reptiles. Concentration factor data and dose coefficents are provided for ^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{41}Ar, ^{60}Co, ^{85}Kr, ^{90}Sr, ^{106}Ru, ^{129}I, ^{131}I, ^{137}Cs, ^{226}Ra, ^{234}Th, ^{238}U, ^{239}Pu and ^{241}Am. As for the aquatic ecosystems, there are significant gaps in the concentration factor data for a number of organisms; for the terrestrial system the lack of concentration factor data is particularly marked.

Having developed a methodology, the EA are now routinely asking site operators to consider the effects of proposed discharges on wildlife during the process of determining radioactive discharge authorisations.

Implementation of the EU Birds and Habitats Directives in the UK, through the Conservation (Natural Habitats) Regulations 2000, has provided the EA with a further impetus to extend the methodology. These Regulations require the Agency to ensure that no authorised emissions (radioactive or otherwise) have an adverse impact on conservation sites designated under the Regulations (collectively referred to as the Natura 2000 sites. In order to achieve this the Agency has further extended the methodology of Copplestone *et al.* (2001) by:

- Identifying the organisms which are of prime conservation significance at each of the Natura 2000 sites ('feature organisms');
- Determining which of the reference organisms from the Copplestone *et al* (2001) methodology provides the best surrogate for each 'feature organism' in terms of dose coefficients;
- Identifying from the literature, where available, suitable concentration or transfer factor values for radionuclide uptake by 'feature organisms';
- Where (as is often the case) reliable concentration or transfer factors cannot be derived, assigning pessimistic concentration or transfer factor values for use in a 'screening' assessment.

Full details are given in Copplestone *et al.* (2003). In addition, the EA have produced a compilation of basic radionuclide data relevant to the assessment of impacts on wildlife (Kelly and Thorne, 2003).

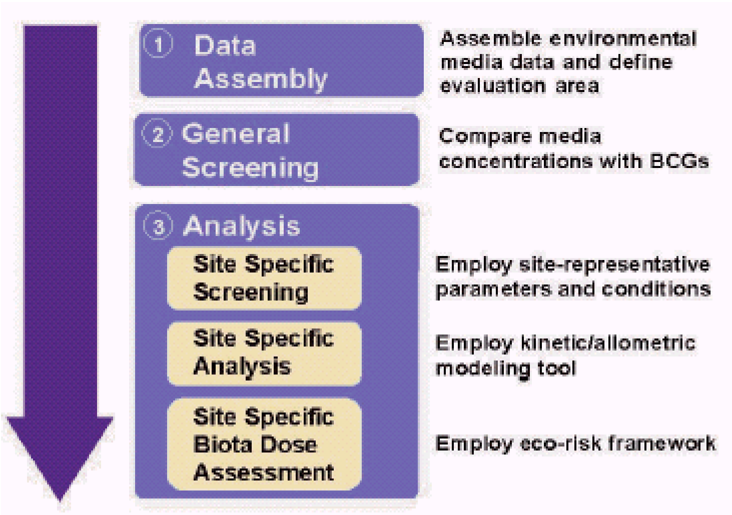
Finally, the EA recognise that basic data on the effects of irradiation are scarce or non-existent for some taxa, particularly in the case of chronic irradiation and in the case of high LET irradiation. They have produced guidance on protocols for experimental studies of this type (Wood *et al.,* 2003), as a precursor to calling for tenders for such studies.

4.2 USA

The US Department of Energy (USDoE) has set internal criteria and procedures for the protection of wildlife both on and around the extensive facilities for which it has responsibility. Criteria are based directly on dose standards; a limit of 10 mGy d^{-1} has been set for aquatic biota (USDoE, 1993) and consultation documents propose extension to include limits of 10 mGy d^{-1} for terrestrial plants and 1 mGy d^{-1} for terrestrial animals (USDoE, 1996).

An extensive assessment manual, with accompanying software (USDoE, 2002) has been developed.

The methodology is based on a 'screening' approach in which site conditions are first tested against derived soil and water concentrations (Biota Concentration Guides, BCGs) before (if necessary) proceeding to more sophisticated analyses:



Biota Concentration Guides are derived using pessimistic organism:media concentration factors, and conservative dose coefficients which assume the organism is simultaneously infinitely small (for calculation of external doses), and infinitely large (for calculation of internal doses.

If the assessment proceeds to more detailed stages, radionuclide uptake by the site specific organisms are assessed by kinetic-allometric models. These models make assumptions about the variation of food (and hence radionuclide) intake and clearance rates, based on power functions of body mass. Even at the more detailed stages of analysis, organism geometry does not appear to be taken into account when assessing doses.

The methodology is very well documented and clear guidance is provided for assessors. However there are some technical weaknesses, principally:

- The kinetic-allometric models lack detailed justification and are unlikely to provide accurate predictions of radionuclide uptake by biota, unless validated at a site specific level;
- The assessments appear to focus attention at organisms from the higher trophic levels - e.g. fish, terrestrial mammals - without considering whether effects on lower

trophic levels - e.g. phytoplankton, soil invertebrates - may compromise ecosystem function;

- The treatment of dosimetry remains simplistic and conservative even at the more detailed levels of assessment.

The methodology has now been incorporated into the RESRAD-BIOTA code, which addresses the weakness in dosimetry by introducing size dependent dose conversion factors (USDoE, 2004).

These methods are being applied systematically at all USDoE sites.

4.3 Canada

The Canadian Environmental Protection Act (1999) and the Canadian Environmental Assessment Act (2003) require the identification, assessment and management of toxic substances (including radionuclides and ionising radiation) and require ecological risk assessments to be carried out for major new 'projects' and major existing facilities. These requirements apply to most major nuclear activities in Canada.

The responsibility for ensuring that assessments are carried out falls to the Canadian Nuclear Safety Commission, which in turn requires assessments to be carried out and submitted by the site operators.

A radionuclide-specific methodology is to be published in 2004. However, at present there is no prescriptive methodology; the approach taken is to undertake a generic human health and ecological risk assessment, considering both radioactive and non-radioactive stressors (see, for example, Swami *et al.*, 1999).

A number of significant issues have arisen from experience in carrying out these assessments (Mihok, 2004). For example:

- Industry does not accept the ecological risk assessment approach as a mature science because it not infrequently identifies risk where no ecosystem stress is apparent. This, presumably, results from use of conservatism in the assessment as a response to lack of firm data.
- There are major difficulties in translating risk quotients based on individual effects to Canadian criteria in terms of 'magnitude, extent, duration, frequency and permanence' of effects at the population level.
- Public concern focuses on particular organisms at individual sites ('Valued Ecosystem Components') and use of reference or surrogate organisms, or data from another site, does not create confidence.

4.4 Australia

The Supervising Scientist Division of the Australian Department of the Environment and Heritage has carried out an ecological risk assessment of impacted aquatic ecosystems for the Ranger uranium mine in the Northern Territories (Johnson, 2004). Their stated objective (derived from Australian criteria for regulation of chemical stressors) was to ensure that 99% of potentially affected species would be protected.

The assessment included both radioactive and non-radioactive stressors. For non-radioactive stressors the results of extensive site-specific toxicity research were used as the benchmarks of harm; for ionising radiation, in the absence of clearer criteria, the IAEA/UNSCEAR value of 400 μGy h^{-1} was used.

Extensive site-specific measurement data were available for concentrations of both radioactive and non-radioactive stressors. For radionuclides, dose rate calculations were made using the spreadsheets of Copplestone *et al.* (2001).

The main findings were:

- Chemical toxicity of mine effluents was more limiting than radiological effects for protection of both humans and wildlife.
- For radiological effects, protection of wildlife was more limiting than protection of humans, largely because human exposure pathways were more remote from the source than were wildlife exposure pathways.

However, early work by the Australian Nuclear Science and Technology Organisation (Twining *et al.,* 2003) in applying the Australian criteria for protection from chemical stressors to available effects data for radionuclides suggests that dose rate criteria on this basis may be substantially lower than 400 μGy h^{-1}.

In addition, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has published a brief review of the issues surrounding radiation protection of the environment (Cooper, 2003). This concludes that, in developing the Australian National Radioactive Waste Repository:

"……it is proposed to rely on the ICRP system of radiation protection and the framework of dose limitation for members of the public to ensure that non-human biota are provided an adequate degree of protection. It is recognised that adherence solely to established dose limits does not ensure total protection of non-human species, and other strategies are in place to provide the required level of protection."

However, it is not clear from the report what these additional strategies comprise, and how their efficacy or otherwise would be assessed.

4.5 France

There are currently no regulatory requirements for assessing impact of radionuclides on wildlife. However, COGEMA have carried out two significant case studies. These consider impacts on the Rhone due to discharges from the Marcoule site (St-Pierre *et al.,* 1999), and impacts on the coastal waters around the Cotentin peninsula due to discharges from the Cap de la Hague reprocessing plant (COGEMA, 2003).

In both cases the reports were based on measurements from the routine site monitoring programmes together with any available data from special investigations or other studies. As a result, the assessments are focused on those organisms for which monitoring data exist; although this gives quite comprehensive coverage the studies do not attempt an *a priori* categorisation of organisms which are likely to be present in the ecosystems studied and be important from the viewpoint of ecosystem function and/or conservation. The dosimetric approach was similar to that of Copplestone *et al.* (2001), and cross-checks in the course of peer review have confirmed close agreement in the dose coefficients used.

The reports conclude in both cases that radiation dose rates to the organisms studied from anthropogenic radioactivity are only a small fraction of the dose rates due to background sources and are well below the IAEA/UNSCEAR guidance values. As a result no adverse effects could be expected.

5. Developments at the international level

5.1 EU Frameworks 5 and 6 - the FASSET and ERICA projects

The FASSET project[1] commenced in November 2000 under the EC 5th Framework programme, and concluded in October 2003. Its objective was to develop a framework for the assessment of environmental impact of ionising radiation in European ecosystems. It has produced six scientific reports, all of which are available from the FASSET web site (www.fasset.org):

Deliverable 1 (main report and two appendices): Identification of reference organisms from a radiation exposure pathways perspective (2001).

Deliverable 2 Part 1: Formulating the FASSET assessment context (2002).

Deliverable 2 Part 2: Overview of programmes for the assessment of risks to the environment from ionising radiation and hazardous chemicals (2002).

Deliverable 3: Dosimetric models and data for assessing radiation exposures to biota (2003).

Deliverable 4 (report and database): Radiation effects on plants and animals (report), (2003); FASSET Radiation Effects Database (FRED), (2003).

Deliverable 5 (main report and two appendices): Handbook for assessment of the exposure of biota to ionising radiation from radionuclides in the environment (2003).

Deliverable 6 (report): Framework for the assessment of environmental impact of ionising radiation in major European ecosystems (2004).

In addition to the above deliverables, FASSET participants have produced a number of papers for publication in a special issue of the Journal of Radiological Protection; the expected publication date is the Autumn of 2004.

The FASSET framework is based on a conventional stepwise environmental assessment approach, comprising:

1. Planning the assessment: regulatory requirements, stakeholder views, aims and objectives;
2. Problem formulation: describing practice or activity and potentially impacted ecosystems, initial hazard analysis, decision on complexity of assessment required;
3. Exposure and effects analysis: quantifying exposure of relevant organisms to stressors, determination of prevalence and severity of any effects which may be expected;
4. Risk characterisation: identifying, evaluation and prioritising resulting risks to the environment;
5. Decision and management: determining appropriate management action - permissions and consents, remediation, amelioration.

The FASSET project has focussed on steps 2 and 3. It has provided a basis for describing ecosystems in terms of the 'reference' systems of forests, semi-natural pastures and heathlands, agricultural land, wetlands, freshwaters, marine waters, and brackish waters. These systems are 'populated' by reference organisms which are broadly similar

[1] Participants in the FASSET project were the Swedish Radiation Protection Authority (SSI); the Swedish Nuclear Fuels and Waste Management Company (SKB); the Environment Agency of England and Wales; the German Federal Office of Radiation Protection (BfS); the German National Centre for Environment and Health (GSF); the Spanish Research Centre in Energy, Environment and Technology (CIEMAT); the Finnish Radiation and Nuclear Safety Authority (STUK); the Norwegian Radiation Protection Authority (NRPA); Kematka Consult AB, Sweden; Stockholm University, Sweden; the Centre for Ecology and Hydrology, UK; Westlakes Scientific Consulting, UK; the Centre for Environment, Fisheries and Aquaculture Sciences, UK; the University of Reading, UK; and the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France.

in nature and range to those used in Copplestone *et al.* (2001). Data are provided on available radionuclide transfer factors; dose coefficients are provided as a basis for calculation of dose rates; and example models of radionuclide transfer are provided. The FRED database provides a basis for assessing the likely prevalence and severity of any effects which may be expected on the basis of calculated dose rates.

It should be noted that the FASSET framework explicitly avoids setting 'dose limits' for biota, instead aiming to identify whether any effects may be expected so that their acceptability may be considered.

The FASSET project involved no new experimental work and radionuclide transfer factors were extracted from the available literature. Thus, the conclusions of earlier work, described above, that there are significant data gaps for the terrestrial environment and, to a somewhat lesser extent, the freshwater aquatic environments, have been confirmed. Deliverable 5 contains some guidance on how allometric relationships may be used to fill gaps in certain limited circumstances, but this is still an area which requires attention.

The ERICA project is an EC 6th Framework project which started on 1 March 2004 and which will complete by the end of February 2007[2]. It aims to extend the work of FASSET into the risk characterisation and management steps, and also to fill gaps revealed by the FASSET project where this is feasible within the project scope. ERICA does make some provision for additional experimental work and field studies on radionuclide transfers to biota, and radiation effects; however the scope has been limited by available funding.

An important part of the ERICA project is a series of case studies which will initially evaluate the utility of the FASSET approach and data at a number of sites, feeding back significant issues into the ongoing ERICA work, and subsequently evaluate the improvement achieved by the results of ERICA. These case studies comprise:

- Conservation sites on saltmarsh and dunes impacted by emissions from Sellafield, UK;
- Agricultural land impacted by emissions from Sellafield, UK;
- Marine ecosystems impacted by emissions from oil and gas platforms, Norway;
- Freshwater ecosystems (river Loire) impacted by emissions from nuclear power plants, France;
- Terrestrial ecosystems impacted by deposition from the Chernobyl accident, Ukraine;
- Terrestrial ecosystems impacted by emissions from uranium extraction industry, Komi, Russia.

5.2 The EC MARINA II project

The original EC MARINA project considered the radiological impact on humans of radioactive discharges to the marine environment from all EU member states. The Marina II project, completed in 2002, updated this original study but also included an assessment of the impacts on marine biota (Sazykina and Kryshev, 2002). This extension was driven in part by the interest of the OSPAR Radioactive Substances Committee in 'environmental quality' as related to radionuclides.

The report concludes:

[2] Participants in the ERICA project are the Swedish Radiation Protection Authority (SSI); the Swedish Nuclear Fuels and Waste Management Company (SKB); the Environment Agency of England and Wales; the German National Centre for Environment and Health (GSF); the Spanish Research Centre in Energy, Environment and Technology (CIEMAT); the Finnish Radiation and Nuclear Safety Authority (STUK); the Norwegian Radiation Protection Authority (NRPA); Stockholm University, Sweden; the Centre for Ecology and Hydrology, UK; Westlakes Scientific Consulting, UK; the University of Liverpool, UK; Electricité de France (EdF) and the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France.

- An adequate methodology has been developed for the assessment of doses to marine organisms;
- Doses to marine organisms varied within a very wide range up to 10^{-4} Gy day^{-1} in the most impacted zones;
- The highest doses were found for biota close to the Sellafield plant and also for biota close to industries processing naturally occurring radioactive materials;
- For these areas of highest dose, deterministic effects on organisms would not be expected;
- Doses to organisms due to discharges from the offshore oil industry require further investigation.

5.3 Activities of the International Union of Radioecology

The International Union of Radioecology (IUR) is an international professional organisation for those involved in the field of radioecology. As a result, its membership is heavily biased towards researchers from academic and government research institutions. It has limited funds and does not sponsor a significant amount of research from its own resources; rather, it convenes meetings and workshops and provides limited funds for travel to facilitate the co-ordination of research activities.

Since 1997, the IUR has been quite active in the area of radiation impacts on ecosystems, not least because the issue is likely to drive radioecology research requirements over the next decade.

Significant publications from the IUR over this period are:

- a compilation of data on calculation of doses to, and effects on, biota (IUR, 2000);
- output of a consensus conference on the general principles for protection of the environment from ionising radiation (Strand and Oughton, 2002);
- a report on the current status and future work in this area as of 2002 (IUR, 2002).
- a Statement of the IUR: Protection of the Environment in the 21st Century: Radiation Protection of the Biosphere including Humankind (IUR, 2003).

These IUR publications are useful as a summary of the issues, and the consensus conference makes a useful contribution to overall principles, but contribute relatively little substance to the process of developing an assessment compared to the national level and FASSET work described above.

The 2002 report on current status and future work concludes that:

- The IUR has played a major role in developments
- The approach is now being taken forward by ICRP and IAEA
- IUR shall be at the forefront of identifying research needs and coordinating scientific actions
- The IUR is well placed to help develop and implement the new approach.

The 2003 Statement draws attention to the knowledge gaps that exist, and the consequent need for continuing research.

IUR is moving to establish a network of research organisations to promote collaboration and resource-effective research that will address these knowledge gaps. The network is expected to be ready to operate in 2005. However, IUR will not be funding the work; the purpose of the network is to utilise available sources of funding at, largely, national level.

5.4 Activities of the Nuclear Energy Agency

In parallel with the developing work of the ICRP (see below), the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development has determined that it should provide a series of fora for stakeholders to debate the issues relating to radiological protection of the environment and provide input to ICRP's development of recommendations.

Three fora were planned - at the beginning of ICRP's development, following the issue of draft considerations by ICRP, and following the issue of recommendations.

The first forum was held in Taormina, Sicily in February 2002 and brought together operators, regulators, scientists, politicians and NGOs. A summary report and workshop proceedings are available from the NEA (NEA, 2002; 2003). Conclusions from the forum were:

- The environment should be protected. In general, the environment has been protected by current radiological protection principles and the regulation which has flowed from them but the level of protection has not been demonstrated.
- There is sufficient knowledge to proceed with the development of recommendations on which regulation could be based. Scientific studies, such as the FASSET programme, will be needed; their role should be to identify gaps in knowledge and fill them in a prioritised way in support of policy and regulatory needs.
- Environmental stresses from radiation should not be considered in isolation from other pollutants and stressors in the environment. The resources devoted to protection of the environment from ionising radiation should be proportional to the scale of the hazard.
- ICRP is the organisation best placed to address the development of recommendations. ICRP's development should include wide circulation of draft materials, conducting of 'feasibility testing' and accommodation of comments from stakeholders.

The principal strategic output from this first forum was the 'legitimisation' of the involvement of ICRP in the issue and, effectively, positioning ICRP as the lead organisation internationally.

5.5 Activities of the International Commission on Radiological Protection

In May 2000 the Main Commission of the ICRP established a Task Group, reporting directly to it, in order to produce a report on the protection of the environment. The Group, chaired by Lars-Eric Holm of Sweden, was tasked with the aim of developing both a protection policy and suggesting a framework for environmental protection based on scientific and ethical-philosophical principles.

The report of this Task Group is now available as ICRP Publication 91 (ICRP, 2003). The main recommendation of the Task Group is that:

"the Commission therefore needs to revise its current system of protection, and particularly:

- *develop a comprehensive approach to the study of the effects on, and protection of, all living matter with respect to the effects of ionising radiation;*
- *develop a system of radiological protection that includes protection of non-human species with a clear set of objectives and principles, and an agreed set of quantities and units applicable to all living things;*
- *interpret basic knowledge of radiation effects in species other than humans so that they can be used in an environmental context, for example, in setting criteria or benchmarks of protection at the appropriate level of hierarchy (individuals or populations);*

- *develop a small set of primary reference fauna and flora, plus their relevant data bases so that others can develop more area and situation specific numerical approaches to assessment and management of risks to non-human species;*
- *show its commitment to protection of non-human species and let this be reflected in the organisation of work and in the composition of experts;*
- *plan regular reviews and revisions of this new system as new knowledge develops."*

ICRP's thinking as set out in the Task Group report is clearly aligned to the reference organism - reference ecosystem approach although indications are that ICRP will consider a more limited range of reference organisms[3] than have been used in the FASSET and UK Environment Agency approaches. There is a tension here between simplicity of the system of protection and making it sufficiently comprehensive to be convincing. If the range of reference organisms is too restricted, it may not be possible to adequately 'map' the actual organisms of interest at a particular site onto the set of reference organisms (see, for example, Copplestone *et al.* 2003).

The indications are also that ICRP may not recommend specific dose limits. Their thinking appears aligned towards a system of 'derived consideration levels' expressed as multiples of natural background exposures, for example:

Derived Consideration Level	Relative Dose Level (Incremental Annual Dose)	Likely Effect on Individuals	Aspects of Concern
Level 5	>1000 normal	Early mortality	Possible remedial action considered
Level 4	> 100 normal	Reduced reproductive success	Concern dependent on what fauna and flora, and their numbers, likely to be affected
Level 3	>10 normal	Scorable DNA damage	Concern dependent upon size and nature of area affected
Level 2	Normal back-ground range		No action considered
Level 1	< Normal background	Low	No action considered

This is, perhaps, in anticipation of the difficulty in interpreting radiation effects data for a sufficiently wide range of organism types. However, it will demand that levels of natural background exposure are well understood; this is not the case at present, and it is clear that natural background exposures cover a wide range and vary substantially between taxa (e.g. Brown *et al.,* 2004).

Recently ICRP have announced that they are to set up a new Committee, chaired by Jan Pentreath of the UK (who also becomes a member of the ICRP Main Commission), to further develop their recommendations in this area. Establishing a new Committee is a major step for ICRP and clearly signals the importance they attach to this topic.

[3] The reference organisms being considered by ICRP are rodent, duck, frog, freshwater fish, marine flatfish, bee, crab, marine snail, earthworm, pine tree, grass, seaweed (ICRP, 2004)

5.6 Activities of the United Nations Scientific Committee on the Effects of Atomic Radiation

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has published a substantial review of the effects of ionising radiation on biota together with data on radiation doses to which biota have been exposed, both from anthropogenic and (to a limited extent) from natural sources (UNSCEAR, 1996). UNSCEAR's current work programme includes identification of dose response relationships for effects on biota and case studies at contaminated sites. A further report is planned for 2006.

5.7 Activities of the International Atomic Energy Agency

The IAEA has published some of the earliest substantial material on the topic of protection of biota from ionising radiation (IAEA, 1988; 1992) and so has a long history of engagement with the topic. More recently, IAEA has convened expert's meetings in 2000 and 2001, and has used a group of consultants to produce a number of technical documents.

TECDOC-1091 (IAEA, 1999) sets out to examine the need for development of criteria and approaches for protection of the environment from the effects of ionising radiation, and to promote discussion which might eventually lead to the development of an IAEA Safety Standard. It reviews developments occurring in IAEA member states, concludes that development of guidance and criteria is desirable, and that the state of knowledge is sufficient to move forward although improved knowledge will be required in certain areas.

TECDOC-1270 (IAEA, 2002) discusses ethical considerations involved in protecting the environment from ionising radiation. From this report a number of general principles have been drawn:

- *any radiation exposure should not affect the capability of the environment to support 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 of the source of the radiation exposure and the 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 the decisions should be taken into account (principle of respect for human dignity)*.

IAEA sponsored an international conference on the protection of the environment from ionising radiation in Stockholm in October 2003 (IAEA, 2003). This conference was well attended, and reached the conclusion that:

"While accepting that there remain significant gaps in knowledge and that there needs to be continuing research…there is an adequate knowledge base to proceed and (the conference) strongly supported the development of a framework for environmental radiation protection"

and:

"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".

Most recently, IAEA have drafted an Action Plan (IAEA, 2004) on protection of the environment from ionising radiation which was discussed at an expert's meeting in the first week of June 2004. The draft Action Plan proposes:

- IAEA should establish a Steering Committee to review and co-ordinate the actions of UNSCEAR, ICRP, IUR and IAEA together with nominated senior experts;
- IAEA should continue to foster information exchange through workshops, conferences, training courses and other fora;
- IAEA should develop Safety Requirements that set out the principles for environmental protection. This should proceed in parallel with UNSCEAR and ICRP's work but should not be finalised until UNSCEAR and ICRP have published.
- IAEA will assist member states to develop capabilities to conduct assessments through case studies and model inter-comparisons.
- Following publication of ICRP's recommendations, IAEA will review its existing standards and guidance documentation to include consideration of the protection of non-human species.

6. Discussion - significance for regulators and operators in the UK

From the foregoing it is clear that a system for protection of the environment from ionising radiation will be developed, with substantive recommendations from ICRP being published in 2005 or 2006.

Moreover, in the UK the Environment Agency are already requiring site operators to consider the possible impact of proposed radioactive waste discharges or disposals on the environment when submitting proposals for Radioactive Substances Act authorisations, and are themselves assessing the impacts of radioactive discharges (in conjunction with those of other pollutants) on Natura 2000 sites, as required by the Birds and Habitats Directives.

However, it would be wise of both regulators and operators to assume that neither ICRP, UNSCEAR, IAEA nor the ERICA project will produce a complete and comprehensive set of data and methodologies to conduct such an assessment in specific circumstances. Considerable tensions still exist on the matter of 'knowledge gaps' between those who want a 'simple, robust and proportional' system and those who believe that substantial radioecological research is required before an acceptable system can be developed. In the opinion of the authors, the ICRP recommendations to be published in 2005/06 are likely to provide only a relatively simple basis for an assessment, which would require to be significantly enhanced and extended to carry out a fully defensible assessment for a particular case. At the same time, the mere existence of the recommendations will further emphasise the requirement for such assessments to be carried out.

In the view of the authors, case studies are the best way forward for site operators and regulators. Case studies such as the MARINA project, the studies by COGEMA, and the early study by Nirex (Jones *et al.,* 2003) have been very informative in identifying the specific knowledge gaps pertinent to a particular application, and focusing thought as to how these gaps might best be filled. The case studies being carried out in the first phase of the ERICA project are also expected to highlight the problems which need to be solved in applying generic methodologies and recommendations to specific sites.

Significant knowledge gaps exist for radionuclide uptake by biota and for radiation effects on biota, particularly in the case of chronic exposure. However, anticipating ICRP's approach to use 'derived consideration levels' based on natural radiation exposure, gaps in knowledge on effects (which would require extensive and expensive research to fill adequately) may be adequately covered by the alternative of an adequate knowledge of the range of natural radiation exposures for particular taxa.

The implication is that site operators and regulators, perhaps working jointly, need to be identifying through a case study approach the key issues which need to be addressed in assessing the impacts of radioactive discharges on biota at specific sites. Since this would be excessively onerous for small users of radioactive substances, some structured consideration is also required into methods by which the need to carry out assessments of the impact on biota may be excluded.

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