NERC Report Dec 2009

Environment, Pollution and Human Health: Radioactivity

Prof. R J Pentreath

1. Introduction

This report briefly attempts to:

(a) advise upon the research needs relating to radioactivity in the environment over the next 10 years, taking account of likely UK developments in the nuclear power industry, nuclear decommissioning, and the storage of radioactive waste;

(b) identify that part of the research which would most appropriately be supported by the NERC; and

(c) recommend priorities for research considered to fall within the NERC remit.

In attempting to address these issues, advice and comments have been invited from the following: EA, SEPA, HPA, FSA, NDA, CoRWM, COMARE, COGER, NDA, UKAEA, and CEFAS. A number of individuals at research institutions and universities were also contacted. A list of those from whom information and ideas was provided is given at the end of this report.

Before attempting to address the three issues above, however, it is probably necessary briefly to review the history of this research area, examine who is now responsible for what, and consider what is likely to happen in the near future.

2. Background

Research into radioactivity in the environment in the UK essentially began at the end of 1947 with the establishment of the Fisheries Experimental (later renamed Radiobiological) Laboratory, Lowestoft, by the Ministry of Agriculture and Fisheries (MAF), which was set up in anticipation of discharges into the sea from the Ministry of Supply's factory at Sellafield (later known as Windscale). The research consisted of experiments on the effects of radiation on fish, the uptake of radionuclides by fish, and the migratory patterns of fish in the Irish Sea. Discharges from the Sellafield site began in 1952. Advice was given in relation to discharge control by MAF and, in 1954, with the formation of the UK Atomic Energy Authority (UKAEA), disposals from this and other sites were formally authorised by MAF and the Ministry of Housing and Local Government (MHLG). In 1959 the Nuclear Installations Inspectorate was formed (and then incorporated into the Health and Safety Executive (HSE) when it was created in 1974).

Over the subsequent decades the UK became one of the world leaders in the field of radiological protection and (due in part to its relatively large discharges) on the study of the behaviour and effects of radioactivity in the environment, a subject now generally referred to as radioecology. It also became a major international player in reactor technology, nuclear fuel production and reprocessing and radioactive waste conditioning. The first nuclear power station ever to generate electrical power on an industrial scale went on line in 1956, and the UK's first commercial reactor (Berkeley) came into operation in 1962. Spent nuclear fuel was also reprocessed at Sellafield. A number of experimental reactors were also built on various sites within the UK. Direct discharges to the environment were made from all sites, and some packaged wastes were disposed of directly into the deep sea (from 1949 onwards). Regulatory authorities remained those of MAF (which became MAFF in 1956) and MHLG (which became part of the new DoE in 1970), with special arrangements being made with regard to Scotland and Wales. The National Radiological Protection Board (NRPB) was also set up in 1970 to provide advice and disseminate information about the protection of people from radiation hazards, and it also conducted some environmental research in relation to human exposure pathways, as did the UKAEA at Harwell. The UKAEA also undertook an extensive monitoring programme in relation to fallout from the atmospheric testing of nuclear weapons. Regulatory bodies, particularly MAFF, maintained full and active research programmes to complement environmental monitoring.

But sentiment was to change, due to a number of factors. The last public enquiry that resulted in a reactor actually being built, Sizewell B, began in 1983. (It came on stream in 1995. A subsequent enquiry was also conducted with regard to the proposed Hinkley Point C, with a positive outcome, but the project was abandoned.) By that time discharges to the environment, particularly from Sellafield, had been greatly reduced, and the sea disposal of packaged radioactive waste had ceased in 1982. Research related to its potential continued use was, however, maintained by MAFF for several years. The UK had also played a major role in an extensive international programme to explore the feasibility of the disposal of high-level packaged radioactive wastes into the deep water sediments of the tectonic plates although, in 1981, the government had decided that the research drilling programme for the geological disposal of high level wastes should cease. Towards the end of the Sizewell B enquiry, in November 1985, the Committee on Medical Aspects of Radiation in the Environment (COMARE) was established in response to the final recommendation of the 1984 Black report in relation to the incidence of childhood leukaemia and other cancers at Seascale near Sellafield.

And then on the 26th April 1986 a disastrous experiment by the operators of the badly-designed Chernobyl reactor in Russia resulted in an airborne plume of radionuclides that contaminated much of Europe, including the UK. This reawakened an already flagging research interest in the subject of environmental radioactivity, particularly within the NERC. Its support for such studies had been fairly low key during the development of the nuclear industry, probably because of the role played by MAFF, and probably because it was regarded as essentially applied research that should be funded by the regulatory authorities. There were some notable exceptions, however, such as the work carried out at IMER (now PML) and in isolated university departments.

But as a result of Chernobyl, the NERC established a Special Topic on radioactivity in 1987. This resulted in a much needed boost to terrestrial ecology and resulted in highly successful studies of aerial deposition, radionuclide behaviour in soils and mycorrhizal effects, transfers through heather, and from soil to grass to sheep, and a range of dynamic modelling. The NERC set up and contributed funding to a Co-ordinated Group on Environmental Research (COGER) shortly after the Chernobyl incident, but withdrew funding about a decade ago. [Its current web site is not functioning, being 'redeveloped'.]

Throughout the whole of this period radioactive wastes were accumulating, notwithstanding the packaged quantities disposed of at sea, and at the low level waste repository at Drigg in Cumbria, which had been operating since 1959. In 1978 the Radioactive Waste Management Advisory Committee (RWMAC) was established to offer independent advice to ministers on radioactive waste management issues. In 1982 the Nuclear Industry Radioactive Waste Executive (NIREX) was set by the UK nuclear industry to examine safe, environmental, and economic aspects of deep geological disposal of intermediate and low level radioactive waste. It became UK Nirex Limited in 1985. During the mid 1980s proposals for nuclear waste repositories at five sites were all abandoned due to local opposition. In October 1992 Nirex announced plans to build a Rock Characterisation Facility (RCF) at Sellafield, but in 1997 the Secretary of State for the Environment rejected Nirex's case. [The Nirex geological archive was transferred from Nirex to the British Geological Survey (BGS) during 2000/2001. The archive consists of borehole cores and samples, thin and polished sections, digital data and paper records acquired by Nirex during its investigations at Sellafield and Dounreay. There are no restrictions on academic access to the archive.]

Changes had also been made to the regulatory bodies, and with it the responsibilities for supporting R&D. The majority of environmental radioactivity research had been carried out by MAFF but, in 1995, with the creation of the Environment Agency (EA), MAFF’s role was reduced to that of a statutory consultee, and the inspection role went to the EA (combined with that of the DOE’s Her Majesty’s Inspectorate of Pollution (HMIP)), together with the responsibility to conduct the necessary R&D, in relation to England and Wales. At the same time the Scottish Environmental Protection Agency (SEPA) took on responsibility for the environmental aspects of nuclear regulation in Scotland. By this time environmental radioactivity research work had already been scaled down throughout the UK, and whereas the research/monitoring work in MAFF had far exceeded that of its inspectorate’s role, the amount spent on R&D relative to inspection and monitoring was by then in steady decline.

3. Current situation and its key players

In 2003 the UK Government’s energy white paper stated that nuclear power *was unlikely to be* part of the UK energy mix [1]. It sold off Westinghouse, one of only five companies building nuclear power stations in the world, with a large and growing order book. Then, in 2007, the Government’s energy white paper [2] stated that nuclear energy *would definitely be* part of the UK’s future energy mix, and in 2008 [3] stated that energy companies were to be invited to come forward with proposals for new build. By July 2009, and with only five months to go, the Government stated in ‘The Road to 2010’ [4], that nuclear was considered *key to tackling climate change and energy security*, and had a current global market value of £30 billion per year. In view of such vacillation by the Government, it is hardly surprising that the research community has been confused.

And yet even in 2003, notwithstanding its anti-nuclear frame of mind, the Government had recognised the need to address its nuclear fuel waste legacy, irrespective of whether it was to generate any more. With the devolved administrations it therefore set up a new Committee on Radioactive Waste Management (CoRWM) to review the options for managing the UK’s higher activity radioactive waste, and to make recommendations on the option, or combination of options, that could provide a long-term solution, providing protection for people and the environment.

CoRWM concluded that geological disposal represented the best available long-term approach to the disposal of high level waste, compared with other forms of management, and that further R&D should be carried out, aimed at reducing uncertainties and satisfying people's concerns. Government accepted these recommendations. RWMAC was disbanded and CoRWM now has the role of providing independent scrutiny and advice to UK Governments on the long term management, including storage and disposal, of all radioactive waste. [It reports to the Department of Energy and Climate Change (DECC), the Scottish Government, the Welsh Assembly Government, and the Department of the Environment in Northern Ireland.]

The government had also reconsidered its responsibilities with regard to the legacy of reactors that had performed well beyond their design criteria, and reactors that had fulfilled their research objectives, and needed to be decommissioned. Under the Energy Act 2004 [5] it therefore created the Nuclear Decommissioning Authority (NDA) to be responsible for the decommissioning and clean-up of the UK's civil public sector nuclear sites under the Department for Energy and Climate Change (DECC) and, for some aspects of its functions in Scotland, being responsible to Scottish Ministers. The NDA is now responsible for developing UK-wide nuclear Low Level Waste (LLW) strategy and plans; the long-term management arrangements for the UK's higher radioactive wastes; plus 19 former UKAEA and BNFL sites. It does not directly manage the facilities that it owns, but contracts out the delivery of site programmes through management and operation contracts with licensed operators, the Site Licence Companies (SLCs), at each site. The SLCs manage sites, and their Parent Body Organisations (PBOs) own shares in the SLCs for the duration of their contract with the NDA. Each PBO is responsible for managing the delivery of site programmes. The ownership of Nirex was transferred from the nuclear industry to DEFRA and DTI in April 2005, and then to the NDA in November 2006. Nirex's staff and functions were integrated into the NDA in April 2007 to form their Radioactive Waste Management Directorate. This is responsible for the delivery of the UK's geological disposal facility (GDF). Other changes included the incorporation of the NRPB into the newly created Health Protection Agency (HPA) in 2005. The HSE still regulates the nuclear industry through its Nuclear Directorate (ND). It is responsible in the UK for the safety regulation of nuclear power stations, nuclear chemical plants, decommissioning, defence nuclear facilities, nuclear safety research and strategy and, since 2 April 2007, for civil nuclear operational security and safeguard matters.

As of 2009, the government is developing a National Nuclear Policy Statement (NNPS) to assist the new Infrastructure Planning Commission (IPC) processes, and making sure that a fund for the full costs of decommissioning and waste disposal will be available at the end of station lives. The HSE and EA are working together to assess new nuclear power station designs. This is being done via a Generic Design Assessment (GDA), which is expected to be completed by June 2011. [Two reactor designs are being looked at in detail: the AP1000 from Westinghouse, and the EPR from Areva.] The GDA is expected to be completed in mid 2011.

Work is also in progress by the EA and DECC to develop criteria to help decide if sites are, or are not, suitable locations for new nuclear power stations. This process is called the 'Strategic Siting Assessment' (SSA) and its objective is to make sure that only suitable sites are put forward for planning permission. Eleven sites have been nominated by the NDA and by power generation utilities. EDF [through its purchase of British Energy] has secured the sites on which it proposes to build (Hinkley Point and Sizewell) plus additional land at

Bradwell purchased during the NDA auction when RWE and EoN also purchased land at Oldbury and Wylfa. RWE has also nominated two sites in Cumbria that are not existing nuclear sites. Other sites likely to be considered, and used, are Bradwell and Dungeness. The present best guess is that, subject to successful planning applications, construction could start on at least one site as early as 2013, with full operation by 2020 or earlier. Consideration of several other sites could take up until 2015 or more.

With regard to waste disposal, the somewhat novel approach now being taken, following a white paper published in June 2007 [6], is that communities are invited to express an interest in entering into discussions with Government about the possibility of 'hosting' a geological disposal facility at some point in the future. Upon receipt of an Expression of Interest, 'opening discussions' would begin and BGS would be asked to apply sub-surface screening criteria in order to eliminate from the process any area that is obviously unsuitable and so avoid further unnecessary work. This would be the first step in a detailed process to establish if the area is suitable. So far three local authorities (Copeland Borough, Allerdale Borough, and Cumbria County) have entered into discussions with the Government.

The BGS report would then feed into ongoing community engagement. To progress to the next stage (a Decision to Participate) the engagement and consultation process would need to be shown to be credible, with evidence of appropriate community engagement and meaningful feedback on any concerns of those affected. The process to site the facility following this Decision to Participate will be the setting up of a Community Siting Partnership with the NDA and other relevant interested parties towards agreed objectives. Meanwhile, more detailed assessments of the impact on a community hosting a facility based on geological and other characteristics would be undertaken. Such further steps would include the production of a Strategic Environmental Assessment (SEA), a Sustainability Appraisal (SA), and an Environmental Impact Assessment (EIA) as well as adhering to the necessary planning requirements. The development of a candidate site for eventual use would be subject to the granting of permits by the Ea and HSE.

Finally, it is worth noting that the Government is to establish [no date given] a Nuclear Centre of Excellence as an "..... *innovative partnership amongst industry, academia, government and international partners to improve the access to the peaceful use of nuclear energy by further developing proliferation resistant nuclear technology*" which will presumably involve the issue of nuclear 'waste'[4].

4. Expected differences in approach to new nuclear build

It is now over 25 years since the last public enquiry began in relation to building a new nuclear reactor. Much has happened since then. There are now more legislative requirements with regard to protection of the environment, and the public is generally more sceptical, partly due to Chernobyl and partly fuelled by an anti-nuclear lobby. And because of the overall decline in research into radioactivity in the environment, the knowledge and skills base in the UK is much reduced. The last of these would not be so critical if there was a reserve of expertise within the UK academic community to draw upon; but the subject of radiation in an environmental context has, surprisingly, never really caught the UK academic imagination.

It is worth looking at these issues in a little more detail. In addition to many generalised statements in national legislation concerning the need to have regard to conservation in various ways, many of the UK's major estuaries, and much of its coastline, are now (ie since the Sizewell B inquiry) covered by the *Conservation (Natural Habitats &c.) Regulations 1994* (the Habitats Regulations) which implement Council Directive 92/43/EEC on 'the conservation of natural habitats and of wild fauna and flora' (the Habitats Directive) [7]. The Habitats Directive aims to establish a network of the most important sites in respect of natural habitats and species of wild fauna and flora and requires measures to be taken to maintain them at favourable conservation status or, where necessary, restore them by taking remedial action. The Habitats Regulations also require that the EA reviews existing permissions/authorisations that have been issued with regard to their effects on all European Sites, and it has recently done so. It is therefore likely that, under any form of Environmental Impact Assessment with regard to new build, the potential impact of any releases on fauna and flora are likely to be questioned in some detail. And, in view of the Chernobyl experience, such questions are likely to be raised not only with regard to normal operations but also as to what the consequences for the environment would be in the event of an accident.

There are other changes of relevance. Virtually all of the regulations relating to radiation exposure stem ultimately from the Recommendations of the International Commission on Radiological Protection (ICRP). These Recommendations then flow down through such organisations as the International Atomic Energy Agency (IAEA), which is required to have regard to them, to regional bodies such as EURATOM, and through them, or directly, to national bodies. The ICRP produces revised Recommendations about every 15 to 20 years (reports on specific aspects of the subject are produced every year), and these take some time to percolate down through the international legal system. The latest ICRP Recommendations were issued in 2007 [8], and drafting is already taking place at international level to translate them into more formal (and obligatory) guidance for nuclear states. The 2007 Recommendations provide a more inclusive protection framework for different exposure situations, and have also included objectives with regard to protection of the environment. Specifically, the ICRP's objectives now include those of preventing or reducing the frequency of deleterious radiation effects to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities and ecosystems.

The new ICRP Recommendations also include changes to the description of situations in which exposures to radiation may occur. It now recognises three types of exposure situations: *planned* exposure situations, involving the planned introduction and operation of sources; *existing* exposure situations, where a decision on control has to be taken – for example in relation to contaminated land; and *emergency* exposure situations, which are unexpected situations, such as those that may occur during the operation of a planned situation - or from a malicious act, or from any other cause - that requires urgent attention.

There have also been some developments in the provision of advice with regard to how assessment of doses to the public can be made to determine compliance with the relevant values, to guide decisions on the level of control of exposure, and to help identify actions that could be taken to reduce exposure. Of particular relevance is the introduction of new concepts with regard to the use of *reference levels* to aid in the process of optimisation for both emergency and existing human exposure situations.

In 2009 this general approach has also been extended to protection of the environment by way of the production of set of Derived Consideration Reference Levels (DCRLs) for Reference Animals and Plants (RAPs) [9].

In the past, the ICRP has used the 'critical group' concept to characterise individuals receiving a dose that is representative of the more highly exposed persons in the population, and dose restrictions have been applied to the mean dose in the appropriate critical group. The ICRP has now slightly changed this approach to the use of a 'Representative Person'. The UK may also wish to consider the need to derive more precisely defined animals or plants to serve as 'Representative Organisms' in relation to DCRLs.

A third issue is that of the lack of a sound 'academic' base with regard to the study of radiation in an environmental context. Much of the subject matter that forms the basis of 'radioecology' has been gathered by regulatory bodies, and other researchers mainly supported by them, in relation to specific sites or specific problems. The 'ology', however, in terms of there being a recognisable and self contained branch of knowledge to encompass or underpin the subject, is not yet fully formed. The subject – particularly with regard to radiation affects on animals and plants – is long on observation but short on explanation. There is little in the way of a set of underlying theories or hypotheses that have been experimentally tested. This lack of basic knowledge, both theoretical and experimental, does little to help build public confidence.

It is also likely that, in the future, science produced or funded by organisations close to the nuclear industry, or its regulators, is likely to be questioned with regard to its independence and neutrality. The research councils will therefore be expected to have a larger role to play in providing more basic, underpinning, and independent research relating to the important decisions that will have to be made.

And finally there is the continuing issue of who does what research with regard to the legacy and future arisings of radioactive wastes.

5. Research needs relating to radioactivity in the environment over the next 10 years, and the UK's ability to meet them

5.1 Planned exposure situations relating to nuclear power plants

Pathways leading to human exposure

The science relating to the radiation doses received by humans, from whatever source, and their consequent effects, is not within the NERC's remit. But the transfer of radionuclides through environmental media resulting in such doses is a legitimate area of interest. Under planned exposure situations, new reactors are not expected to release significant quantities of radionuclides that have not previously been the subject of study. There are, however, some aspects of radiation exposure of the public that the HPA has identified as warranting future research. These include the need for more data on the interception of certain radionuclides by, and retention on, crops and their translocation to edible parts. This therefore includes consideration of interception of wet and dry deposition, particularly in relation to particle sizes different from those normally considered. Data to support assessments of doses from resuspension and inadvertent ingestion of dust loadings, and the transfer of material onto skin, and from skin to mouth, is also considered deserving of further study. The partitioning of radionuclides within waste water and sewage treatment processes, and the waste products arising from them, are also areas of interest. Recent studies have focussed on a limited set of radionuclides, and the HPA believes that such work could be usefully expanded to investigate the behaviour of a wider range. With regard to longer lived radionuclides, there are still deficiencies in ^{14}C modelling (including global circulation) and, in particular, the impact of increasing levels of carbon in the environment and how this may affect the carbon cycle.

Once sites for new build have been approved, then assessments could be improved in the sense of using more site related data rather than reliance upon generic data for key, or the more sensitive, model parameters with regard to influencing the dispersion and accumulation of radionuclides in the environment, and hence consequent exposure of the public. An example of a key model parameter is the K_d distribution coefficient which determines to what extent radionuclides adsorb onto soils/sediments in relation to aqueous media, which in general terms affects the mobility of radionuclides in the environment. Chemical speciation, and factors affecting it, needs further study for many radionuclides. There are also various dependencies amongst different parameters; for example, reconciling the K_d values selected for radionuclides in soil in relation to the equilibrium concentration factors selected for radionuclide uptake from soil to plants.

Obtaining site related data will also be valuable in order to undertake uncertainty studies with regard to radiological assessments. In the past, many such assessments have been carried out using a deterministic model with best estimate parameter values. Many assessments, particularly for waste disposal sites, now have to demonstrate a more systematic approach to dealing with the uncertainty inherent in the assessment models, which manifests itself in a number of ways, such as: the future scenarios chosen for assessment; the conceptual and numerical model functionality; and parameter uncertainty (from measurement errors to sampling errors due to natural spatial/temporal variability). It may thus be more convenient in certain situations to undertake experimental studies rather than field scale studies: for instance, to have more control over factors affecting the experimental situation and the conceptual modelling of it. For these cases, research needs to be undertaken to quantify how experimental findings can be rescaled and made more meaningful in the context of the actual environment to be modelled.

And no site assessments for new build (or waste repositories) are likely to escape questions with regard to the potential impact of climate change/global warming. This would include consideration of such issues as the potential impact of rising sea levels, changes in sea currents, storm surge, exposure of seabed and so on, as well as the transfer of radionuclides from sea to land, and changes to the nature of soils. Assumed pathways leading to human exposure could therefore usefully be modelled on a variety of potential future agricultural and food pathways, as drawn perhaps from information obtaining in countries ‘warmer’ than the UK.

With regard to modelling, it is also worth noting that in order to evaluate a range of potential future biosphere environments and land use, transfer parameters developed for long-lived radionuclides must be applicable over a large spatial area and to a variety of future scenarios. Thus if detailed “mechanistic” studies of, for example, root uptake or soil adsorption and fixation are carried out, there must be some practical and robust means of “rescaling” such information to make long term predictions for a variety of plant/crop types and soil environments.

On the subject of human exposure, and in order to gain a better perspective of radiation exposure, the SEPA has suggested that a comprehensive study of sources and fate of naturally-occurring radioactive materials (NORM) in the environment would be timely. One area in which the UK has in fact made good progress in the recent past is in relation to natural radiation, especially in the context of radon, for which the BGS (and hence NERC) deserves credit for its radon mapping programme and the general collection of data on background radiation levels. This work should be used as a basis from which to further increase our understanding of the natural radiation background, and the sources and processes whereby naturally occurring radionuclides find their way into water supplies, the atmosphere, and the built environment.

Any research by the NERC relating ultimately to consequences for human health should obviously be done in close liaison with DH and the HPA in order to ensure that there are no inadvertent overlaps and to obtain maximum synergy. A recent report by the High Level and Expert Group on European Low Dose Risk Research [10] gives a good idea of where the main uncertainties and research challenges exist in this field. The EA are currently collaborating with HPA on a research project entitled “Uncertainties associated with dose and risk estimates for internal emitters”.

Environmental protection

As noted above, there are now legal and other pressures to demonstrate that the environment will be protected under normal exposure situations and, no doubt, questions will arise via Environmental Impact Assessments with regard to the likely consequences of nuclear accidents for the natural environment, and the adequacy of the data base necessary to predict and thus manage such situations satisfactorily. The basis of international guidance is the data base relating to a set of Reference Animals and Plants (RAPs), which consists of twelve types of animals and plants, generalised to the taxonomic level of family [9]. There are many data gaps in this set and it is clearly in the UK’s interests (because it will eventually be subject to regulatory guidance based on this information) to ensure that the science upon which this information is based is sound, and that the important gaps in it are filled. All twelve RAP types occur in the UK, and are amenable to study under controlled laboratory conditions.

The EA considers that addressing such data gaps is a priority. But the principal facility in the UK where experiments on the effects of ionising radiation on wildlife could be conducted - within the CEFAS laboratories, Lowestoft - was decommissioned in 2007 because of the lack of perceived future need. (What happened to ‘foresight’?) Capabilities in other UK establishments were detailed in an EA report (Review of UK Research Capabilities in Radiation Protection to Wildlife) back in 2003 [11]. Given the international interest in this subject (IAEA and ICRP) there is clearly an urgent need to co-ordinate efforts to avoid duplication, and to ensure that there is a prioritised programme of research in place. Work on biological effects would provide a more robust basis for setting numeric criteria or standards. The International Union of Radioecologists’ (IUR) Task Group on Protection of the Environment has also investigated research capabilities and research needs as identified by radioecologists from around the world [12].

It is particularly unfortunate in this regard that an academic base for the subject is missing, especially in view of the fact that life on Earth has evolved based on the DNA molecule, and that the one thing known to disrupt DNA is ionising radiation. All life is, and always has been, subject to a highly variable dose of radiation from external and internal sources, and thus one would have thought that the subject would have attracted much greater interest than it has within the environmental sciences. Cosmic radiation from a supernova in the Scorpius-Centaurus association has been cited as a possible factor in the abrupt change between the Pleistocene and Pliocene [13]. Be that as it may, if the subject did have a sounder scientific foundation, this would greatly enhance confidence in its predictions and thus, perhaps, greater confidence by the public.

The vast majority of studies on the effects of radiation have been made on mammals, and these have largely been made for the purposes of extrapolating the knowledge to human radiological protection. As a result, there is a lack of understanding, or even a consistent means of describing, the effects of radiation on living things in general. At elevated doses the knowledge base is very poor in places, and there is a lack of any theoretical or conceptual models against which further observations could be tested. Even at the very basic level, apart from mammals, it is not clear what the actual cause of death is in relation to most animals and plants, and how this relates to differences in anatomy, physiology, or metabolism. Thus even LD_{50} data are difficult to compare. And without a better underlying, theoretical, understanding of the effects of radiation in general on animals, or on plants, it is unsafe to extrapolate and interpolate over too wide a range of biotic types, biological end points, and dose rates, tempting though it is to do so, given the limited amount of data available [14]. In common with human studies, underlying aspects such as ‘DNA repair’, ‘delayed’, and ‘trans-generational’ effects also need attention. There may also be some relationship between the prevailing theory that the genome of different biotic types has copies of critical genes, so that if mutations or damage spoil one, there is a backup.

All of this could help in elucidating some fundamental aspects of radiation biology, and perhaps could be more easily done in invertebrate species. Links also need to be established between molecular damage, reproductive success and survival, and other ‘umbrella’ endpoints. Very little work has been carried out using environmentally realistic concentrations of radionuclides and routes of exposure, and there is a lack of studies investigating differences between chronic and acute exposures.

Although much is spoken about the need for an ‘ecological approach’ to environmental protection, with regard to radiation (and probably other chemical contaminants) the greatest immediate challenge is to derive a much better understanding of the relationships between dose, effects at different stages in the life cycle, and the consequences for different types of populations. Various population models exist that could be applied to some of the RAPs, but not all, and in this regard it would be useful for the ‘radioecology’ community to develop some against which various ideas could be tested. Such models would need to characterise such factors as birth rate, death rate, sex ratio, and age structure. They also need to specify what, precisely, are the characteristics of the population being considered.

There are two other areas needing attention. Many models and data sets exist in order to describe the distribution of radionuclides in the environment, and the vast majority of these relate, necessarily, to pathways that lead to human exposure. They may be confined to certain fractions of the total inventory, because they are concerned with estimating exposures to 'representative persons', or they may relate to the total quantities present in order to estimate collective doses. But, by and large, the measurements made with respect to the biota are dominated by those of concentrations of radionuclides in the tissues that are consumed by humans (such as muscle tissue) rather than tissues that are of relevance to the biota themselves (such as reproductive organs). Recent work on radiological assessments for non-human species has highlighted the fact that the largest source of uncertainty in the assessments involves the environmental transfer of radionuclides. The relevant parameter uncertainties can be several orders of magnitude. Again there is a need to address data gaps on transfer, particularly for those biota and radionuclides where there are few, if any, data available. Transfer factors (concentration factors, or ratios) are needed for a range of animal and plant types relevant to UK environments, and a basic part of such assessments should be a thorough study of the elemental composition of some basic RAP types. This is now much easier and cheaper to undertake than it would have been a couple of decades ago.

Some new basic approaches to radioecology are required here. Generalised conceptual models need to be developed that will describe the total distribution of nuclides in the environment in a manner that would enable estimates to be made of the resultant dose to different components of it, as well as to human beings – particularly with regard to potential accidental releases. Thus basic differences in source characteristics, chemical speciation and so on, may well predetermine the relative risk to different types of biota at different stages in their life cycle within any given habitat. Better data sets are also required that would enable estimates of expected dose to be made by way of such models, again in relation to the tissues that matter to the relevant biota rather than to the consequences for human consumption. And although dosimetry for animals and plants has improved greatly, the basic solid ellipsoid models have not changed for decades, and fall well short of what is needed to relate exposure to dose for those tissues of greatest interest. It is clearly time for the development of better models (such as voxel phantoms) for the larger (> 1kg) animals and plants.

As an example of the lack of academic input to this subject, it is worth noting that, in human radiological protection, the unit of dose (Sv) incorporates radiation 'weighting factors' to allow for different types of radiation and their effects, particularly Relative Biological Effectiveness (RBE). But although RBE occurs in different types of animals, there is insufficient data available to create a similar exposure unit for at least some types of animals, for which only the basic absorption unit of Gy can currently be used. This is a failure of basic science. It also results in an inability to describe confidently even the background radiation to biota in different natural environments. In fact, there is a need to describe background radiation to different types of biota in order to put the ICRP's DCRF values into perspective.

It might be considered that basic research on the effects of radiation at a molecular, cellular, and tissue level would be applicable to a variety of animals, even if developed for human radiation protection. In the last three decades the field of radiation biology has been in decline, courses have closed, journals have vanished and funding for research has ceased. In 2007 COMARE was asked by the Department of Health (DH) to establish the current status of radiobiology research in the UK, and to advise all interested parties on the concerns raised and the recommended actions. [The DH itself runs a Radiation Protection Research (RPR) Programme on a budget of ~£1.2 million per year. It has a specific research strategy for the programme, which is updated every three years to incorporate current areas of radiological protection, both for ionising and non-ionising radiation. COMARE's work programme includes an involvement in the review of the RPR Programme, which maintains the committee's vested interest in the field of radiobiology research.]

COMARE noted [15] that although the Oxford Initiative of Radiation Oncology and Biology has recently been established within Oxford University (bringing together researchers from the Gray Cancer Institute, Northwood and the MRC Radiation and Genome Stability Unit, Harwell with Oxford based researchers) the present funding initiatives leave voids in areas of basic and applied radiobiology funding. At present, research priorities of funding bodies appear to focus on 'translational' radiobiology and radiotherapy. COMARE believes that the Oxford work is clearly not able to address the lack of research in areas of basic and applied radiobiology and radiation protection. It therefore recommended that funding bodies should be made aware of priority areas for radiobiology research that are not currently being funded, and should be encouraged to increase resources in these fields, including research into acute effects of ionising radiation and basic and applied radiobiology research at all levels – molecular, cellular and tissue. It would be useful for the NERC to be involved in these developments.

It would also be useful if the NERC could make better use of the Chernobyl area to test hypotheses and models, if this could be done by way of international cooperation. Eight organisations (IRSN, STUK, NRPA, CEH, CIEMAT, SCKCEN, BFS, and SSM) doing radioecological research within Europe have recently (August 2009) signed a Memorandum of Understanding on co-operation amongst them and are currently defining a Strategic Research Agenda. There will also probably be a call for a radioecology network, but the funding will be limited to only 4 million Euros over 4 to 5 years. [The NERC's CEH is the only UK laboratory participating in it, the UK's marine radioecology expertise having gone from world leader status to one of complete collapse.]

With respect to specific radionuclides, it is generally acknowledged that tritium behaviour and impacts need to be investigated in more depth. Other radionuclides with scant data relevant to either human or biotic exposure include ^{36}Cl, ^{79}Se, ^{99}Tc, ^{129}I, ^{210}Pb, ^{210}Po, ^{226}Ra, ^{230}Th, ^{237}Np, and ^{238}U.

5.2 Wastes and related issues

In terms of basic science needed for radioactive waste disposal, an area which falls logically within NERC's remit for the geosciences, but in which it seems to have played a relatively small part in recent years, is that of the geochemical processes affecting the migration of radionuclides through geological media. These are the very processes by which any planned or accidental loss of nuclear materials in the Earth's crust are likely to cause (or could be prevented from) contaminating the deep geological, near surface, and human environments. Constructing a more complete and coherent understanding of these processes is considered to be one of the major research challenges facing the earth sciences [16], and NERC should clearly be at the centre of the UK's contribution.

With regard to R&D relating to higher activity radioactive wastes, CoREM has conveniently just published its own consultation draft document in relation to its Managing Radioactive Waste Safely (MRWS) programme, which refers to the role of Research councils [17]. The UK has a vast array of various types of radioactive waste, a legacy of its early lead in military and civil power generation nuclear programmes. Higher activity wastes currently being stored include vitrified high level waste (HLW) in over 4300 steel canisters in a specialised store at Sellafield. There are also about 40,000 packages of conditioned intermediate level waste (ILW) including several thousand drums of Magnox Encapsulation Plant (MEP) wastes containing reactive metals such as Magnox (a magnesium-aluminium alloy used to clad uranium metal fuel in Magnox reactors) and some uranium. Other ILW includes ion exchange resins, graphite, steels, plutonium contaminated materials (PCMs) and some soils. In addition there are some ill-characterised legacy wastes (predominantly at Sellafield), many existing as sludges for which immobilisation routes are being developed. In due course some spent fuels, plutonium, and uranium may ill-advisedly be declared to be waste rather than potential future fuel.

CoREM has concluded that because of the diversity, complexity and, in some cases, the poor level of characterisation of the UK's wastes, fundamental and applied research specific to the complex UK inventory is required to support waste conditioning, packaging, storage and disposal programmes. It believes that R&D must be directed to those UK-specific wastes for which other countries are unlikely to develop appropriate treatment processes.

The total direct and dedicated support via the NERC responsive mode funding (1998-2010) into topics related to interim storage and geological disposal amounts to just over £1M. The research falls into three topic areas: 'abiotic' considerations on waste immobilisation and geosphere character; organic complexation of uranium and related elements; and biogeochemical interactions and radionuclide mobility in near-surface environments. [On behalf of MoD, the NERC had managed a depleted uranium (DU) thematic research programme, which awarded £928k of funding over the period 2004 to 2008 in support of research aimed at characterising and understanding DU behaviour in the environment. The results of this are also of relevance to the decommissioning and surface soil contamination aspects of NDA work, but are considered by CoREM to be of very limited applicability to the long-term management of radioactive wastes.]

The NERC's main contribution to research that is relevant to CoREM's MRWS programme is through BGS, which conducts three ongoing projects relevant to geological disposal within its NERC Science Programme remit. These are: *Bio-Tran*, investigating microbial transport and microbial indicators of mass transport through geological media; *Geosphere Containment*, developing fundamental understanding of the mass transport properties and hydromechanical behaviour of low permeability media (anthropogenic and natural) with application to radioactive waste disposal, carbon dioxide sequestration, gas storage and contaminant transport; and *Paleohydrogeology*, developing paleohydrogeology techniques to support geological disposal. Direct support from the NERC for these programmes was about £470k over a seven-year period from 2003-2010.

BGS is also involved in, and in some instances leads, research programmes directed at understanding the behaviour of the engineered components of a GDF in the sub-surface and characterising host rock masses and their fracture systems. The areas include projects on bentonite, the engineering disturbed zone (EDZ), fracture transmissivity and near-field chemical containment. Research studies related to geological disposal have also been carried out by the BGS for Japanese contractors, focussed on the characterisation of fluid pathways and fluid-rock interactions in the Mizunami URL site, Honshu, Japan.

The CoREM review concluded that strategic coordination is required amongst the Research Councils, and between the nuclear industry, its regulators, and the Research Councils. At present there is no process for identifying where fundamental research is needed to underpin and complement applied research on the management of higher activity wastes. [Apparently only the EPSRC has a clear mechanism for obtaining input from the nuclear industry to its programmes. This mechanism is not focused on fundamental research, nor does it involve contact between the prospective researchers.]

CoRWM believes that, in general, there is an *overemphasis* on *applied* research within the Research Councils, to the detriment of the MRWS programme. CoRWM also found that there is insufficient co-ordination between the various Research Councils at a strategic level on radioactive waste management related issues, and insufficient co-ordination between the Research Councils, the nuclear industry and the regulators. In particular, CoREM concluded that the NERC seems to have been slow to respond to the needs of the MRWS programme.

Thus while some international research, particularly that of a more fundamental nature, will be helpful to the UK's geological disposal programme, much of the required R&D will be site-specific and hence cannot be conducted until candidate sites are identified. However, there are several underpinning non-site specific areas, both applied and fundamental, where strategic investment in R&D is required. Many of these are well known and have been the subject of research programmes worldwide for many years. The current state of the UK R&D scene was highlighted at a meeting supported by CoRWM at the University of Sheffield in April 2009 [18]. They include the following.

After a GDF has been closed and sealed off it will resaturate with groundwater. The waste containers will slowly corrode and the radionuclides will be released from the wasteforms to the near-field GDF environment. They will then interact with that environment, which includes the near field (which may be backfilled with cement, clay and other minerals and rocks); the engineering and chemically disturbed zones around the GDF; and the host rock itself. The nature of the escaping radionuclides will be complex because they may be dissolved in fluids, associated with colloids, or present in other forms. Their behaviour and their rate of migration to the far field will depend on their ability to react with, and become trapped on, the various materials through which they pass, and the water flow behaviour through the GDF. Many of the elements which are important in geological disposal (*e.g.* I, Tc, U, Np, Pu) can form different oxidation states with very different chemical properties, and thus may be present as different complexes with water and other ligands. The chemical form will control solubility and subsequent sorption. In the extreme (for example, ^{14}C), speciation changes may even affect whether a radionuclide is present in the solid, liquid or gas phases. Chemical speciation is also influenced by biological processes, either directly through entrainment of a radionuclide in active metabolic processes, or indirectly, through reaction of a radionuclide with a biogenic chemical species.

But facilities are not readily available to study such processes. Most of the UK's civil research facilities where significant quantities of radioactive materials can be used are operated by the National Nuclear Laboratory (NNL). As far as CoRWM is aware, the only R&D that can be performed in these facilities is that funded by NNL customers, namely the NDA and other nuclear industry organisations. Such customers are unlikely to fund much fundamental research, thus universities do not have access to the facilities they need in order to play their part in a national R&D programme for the management of higher activity wastes. Within UK universities themselves there is very little capacity to work with radioactive materials relevant to the nuclear fuel cycle. Several groups (*e.g.* Sussex, Edinburgh, Oxford, Imperial College) work on fundamental aspects of the chemistry and materials science of uranium and thorium, but have no infrastructure to support experiments with transuranium elements. Loughborough University has dedicated radiochemistry laboratories, but only limited capacity to work with high hazard radioisotopes.

There are however several facilities in universities sponsored by British Nuclear Fuels Ltd (BNFL) by way of a series of University Research Alliances. These include the Materials Performance Centre (MPC) at Manchester University, and the Immobilisation Science Laboratory (ISL) at Sheffield University, both of which have the capacity to work with uranium-active materials (and irradiated graphite in the case of MPC), plus the Centre for Radiochemistry Research (CRR) at Manchester University which has some capacity for working with Np and Pu, including the UK's remaining supply of ^{242}Pu, whose long half-life allows work with milligram quantities in a limited range of conditions.

[Other issues which came up at the April 2009 meeting included the potential for crossover of knowledge from the oil, gas and mineral industries, including seismology and geophysics techniques for site characterisation; the testing of modelling predictions; and the assessment of the characterisation of geological environments.]

It is not for CoRWM to identify specific research needs, nor for it to recommend which Research Council takes the lead in different areas of research. But there is a strong feeling within the science community that the NERC should take the lead on the *geological disposal* of radioactive wastes. In particular in relation to the need to develop a predictive capability, based on a scientifically robust, mechanistic, understanding of key environmental processes in support of the geological disposal of higher activity wastes, particularly wastes other than "standard Nirex ILW", HLW glasses, Magnox or AGR spent fuel, plutonium, uranium, high burnup oxide fuel from new build, and possibly MOx from new build. This could include topics such as spent fuel corrosion, biogeochemistry, criticality, HLW glass leaching, colloid generation, geosphere transport, processes in the unsaturated zone, and the biosphere.

The NDA is apparently looking at the R&D needed for near-surface disposal of LLW, and may identify work required on near-surface disposal of ILW. But it is clear that the NERC also needs to help in the evaluation and development of alternative geological disposal concepts that may be useful for some part of the waste inventory e.g. boreholes or shallow geological disposal. The mined repositories currently proposed for geological disposal are not without their environmental down sides, both in terms of underground processes and surface impacts (mainly during construction and the 100 or more years for which the facility remains open). Alternatives, such as deep boreholes, are considered potentially much safer, less environmentally disruptive, and have much shorter operational lives and thus impacts.

Nationally critical programmes such as geological disposal draw on a wide range of non-nuclear expertise within the NERC remit, particularly quantitative geoscience disciplines. Examples include geophysics, underground engineering, and hydrogeochemistry. Many of these skills are in short supply and it is essential to ensure that they are available when required. In view of the lead time for the development of high level skills in these areas, and the competition from non-nuclear sectors, action is required now. And given the strategic national importance of radioactive waste disposal, NERC's current support for this topic seems disproportionately low. But unfortunately the UK science community does not presently seem to have the capacity to deliver a programme of appropriate scale, or even to use a substantial increase in funding effectively. There is therefore a need for a long term strategy to grow both the size and capability of the community to a level which should meet the UK's needs.

With regard to the ability (facilities, people, and financial support) to meet the research needs in relation to the disposal of, particularly, high level wastes, on all three counts the UK's ability is considered to be poor at present for geosphere research. Expertise has diminished since the 1990s and will diminish further as people retire. There are no underground research facilities in the UK and there are only limited opportunities for UK people to do relevant work abroad. Funding is very low for both fundamental and applied geosphere research. There needs to be a coordinated national exercise to identify research requirements, and a debate about what research the country must do over the next few years as the nuclear industry gets underway again, and how it is to be funded. [The possibility of including R&D in the funds to be set aside for disposal of new build wastes should be considered.] Because the UK is currently putting such little effort into geological disposal research, compared with other countries, there is an impression that it still does not take geological disposal seriously.

To conduct internationally-leading basic research with highly radioactive materials, of the type the Research Councils should be supporting, requires access to sophisticated infrastructure. There is however essentially no infrastructure in the UK which is available to support research by the NERC community (or indeed any other Research Councils) on higher activity materials. Facilities required include underground laboratory facilities; inert atmosphere negative pressure gloveboxes with the facility to control atmosphere composition (pCO_2, pH_2); hot cell facilities; synchrotron beamlines; electron and scanning probe microscopies; and surface analytical instruments. The ability to conduct long term (decades) experiments may be important. Such infrastructure is taken for granted in other countries (Sweden, Switzerland, Germany, France, USA, and Japan). And because it is, it is important for the UK not to repeat, unnecessarily, work that has been carried out elsewhere. Of course the NERC would not be expected to shoulder the responsibility for such facilities alone, but it should be actively engaged with EPSRC, and other relevant bodies, including the industry itself, to ensure that they are created, and to fund provision for those areas that are within its remit.

Common to all waste disposal options are the needs to study the factors controlling the long-term movement of radionuclides in groundwater. This could include distribution coefficients, movement of colloids, movement in fractured rocks, geochemistry of ground waters and natural analogue or chemical analogue studies. Eventually the focus of any research will be closely linked to testing the assumptions behind, and improving the safety case for, a defined waste disposal facility. New studies of radionuclide behaviour should be carried out with the direct aim of testing and improving model predictions for the safety case. Thus whilst a critical approach to current models is important, collaborative projects with organisations (e.g. the nuclear industry, EA , NDA and HPA) which require the improved risk assessment models should play an important role in any new funding initiative.

Overall then, apart from a few niche areas, the UK is seen as a minor player in the field of radioactive waste disposal by international standards. This reflects the lack of facilities, the long term shortage of funding, and the consequent decline in research activity, all of which makes it very difficult for UK scientists to participate in international programmes, such as the EU Frameworks, because they can contribute so little.

A further point worth noting is that there is a belief that the current peer review process is not truly "peer" review, in that many reviewers have had no practical experience of research in this area and have thus not appreciated the safety and management constraints of working with 'high hazard' radionuclides. Few members of the NERC peer review college apparently have such experience, and such expertise is rarely represented on panels – presumably because of their rarity and lack of perceived need. The absence of directly relevant expertise is also said to be notable in higher level management and advisory bodies, such as NERC's SISB.

5.3 Accidents, Terrorist events, and similar activities

The UK's legacy of contaminated land is fortunately small and generic research in relation to it is no different from that relating to low and intermediate level waste disposal, although ^{226}Ra may be an issue in some places. Accidents may (and probably will) occur in the future at some scale or other, creating contaminated areas, and again research here is no different from that which would be required to support an Environmental Impact Assessment which should encompass such eventualities. More difficult to plan for are, by definition, 'unplanned' events, including terrorist activity and the use of 'dirty' bombs.

One issue here, however, may be the UK's capacity to analyse radionuclides. Radiochemists are a dying breed. Basic research is still needed into the development of methods and instrumentation to enable the detection and monitoring of radionuclides in the environment, and the measurement of radiation levels, particularly over large areas. The nuclear industry seems to have a significant analytical capability, but one gets the impression that detector time is currently at a premium. It is considered that the relationship between academia and industry could be better, and it is not clear how many universities have radiometric facilities that have ISO9001:2000 accreditation.

Two other needs have been identified. The first is for nuclear forensic capability, which some believe should, in the longer term, be bought into the open academic arena. The UK government itself has drawn attention to the fact that the acceptability of a new civil nuclear power programme needs to be related to the nuclear proliferation issue, and that the UK intends to play a full and active part [4]. There are continuing controversies over alleged nuclear weapons programmes in Iraq, Syria, Iran and North Korea. These are globally significant political issues which need to be informed, in part, by independent scientific evidence. There is little public trust in the various agencies that currently conduct these investigations in secrecy. It is therefore possible that some form of open academic capability may need to be developed. There is still much that can be learned from radioactive particulates using electron microscopy and isotope ratio mass spectrometry from our own UK sites. It is difficult to judge from the literature what the current UK academic capability is for nuclear forensics. [Relating to isotope ratios, Southampton published a paper [19] on global nuclear testing fallout in 2002. SUERC and the NERC isotope geosciences laboratory (NIGL) have also published [20, 21] on analytical method development.] Work is being done in this area outside the UK and the NERC should try to position itself to contribute open literature in the future, at arm's length from government institutions.

The second need is for bioassay development, as learned from experience with the issue of depleted uranium. ICP-MS is increasingly used in place of traditional radiometric techniques for such testing. The NIGL developed urine analyses to test Gulf War Veterans for potential depleted uranium exposure, concluding that none of them were significantly exposed. But legal claims still arise, and there will continue to be claims made over low-level radiation exposures and ill-health, and assumptions regarding exposure will need to be tested. It is therefore essential that open academic research capacity is available to test for exposure, in order to address such public concerns.

There is a connection between these two themes: particulates. These are important in terms of radioactive environmental pollution, transport and exposure pathways (especially inhalation). They also provide the majority of nuclear forensic evidence. Capability to examine large numbers of these particles individually could serve both human exposure and nuclear forensics interests.

6. Training and related skills

In view of the welcome role at last being assigned to nuclear power by the UK (and indeed by the wider international community) concerns about nuclear non-proliferation, and the related needs to extract nuclear raw materials and manage and dispose of nuclear wastes safely without undue damage to the environment, the UK's science capability is poor. In particular, the skills base in universities and research institutes needs to be considerably expanded from the low levels that it has currently reached. New entrants have to be attracted into the area, perhaps through targeted Fellowship schemes. At the same time, sufficient resources must be provided to secure existing capability. To achieve this, the NERC needs to develop a strategic approach, providing gradually increasing and sustained support for the development of these skills over the next decade.

Training is especially needed at post-graduate level, and recruitment to it. It is worth drawing attention here to the "Empower" scheme which has run for the past two years, whereby undergraduates on earth sciences courses have been encouraged to become involved with the nuclear industry and its problems. This seems to be working well and has great potential to create the interdisciplinary symbiosis between the geological and nuclear sciences needed for a successful resolution of the UK's nuclear waste disposal problems.

The training needs are not, however, restricted to those relating to nuclear power. There is a continuing need for the use of natural and artificial radionuclides for dating records of environmental change in natural archives, and as tracers for studying transport processes via atmospheric and terrestrial pathways. Studies of ^{210}Pb as an atmospheric tracer have identified a grave lack of data on this nuclide in the atmosphere. In the UK there have been no high altitude measurements since the 1960s.

7. Issues and priorities for the NERC

In view of the totally incoherent and short term policies on the role of nuclear energy within the UK by its governments over the last two decades or more, it is not surprising that the UK science community now finds itself considerably disadvantaged relative to other countries. Although technically not at a higher level in terms of quality, in terms of volume the UK is outstripped by research done in the USA, Japan, Germany and France. The main reason for the success in these countries has been a long term, strategic, and co-ordinated research funding environment that has been missing in the UK, although things do seem to be slowly getting better with some funding from the NDA and ESPRC now coming through. All of this is particularly galling in view of the leading role, and international respect, in which the UK scientific community operated from the outset of the nuclear era. Much needs to be done to recover lost ground. There are however, some fundamental issue that need to be addressed by the NERC (and the other research councils) if a coherent and cost-effective programme is to emerge. Time is not on the NERC's side.

Issues to be addressed include the following.

- The role that the NERC is prepared to play in the re-emergence of nuclear power energy generation, and in the disposal of its wastes, including the interface on all aspects of this subject between the NERC and:

  - relevant Government Departments, including the NDA within DECC;

  - the relevant regulatory bodies, particularly the EA, SEPA and the HPA;

  - advisory bodies, particularly CoRWM, but also COMARE;

  - the other research councils; and

  - the nuclear industry itself.

- It is important to note that a key element in the Government's future plans for energy supply in the UK via nuclear power has been the need for the acceptance of it by the general public. This, in turn, requires that the basic science behind it has a large component that is independent of the industry, in order to build public confidence in its safety and the industry's activities. A thriving programme of fundamental research would also offer the possibility of a step-change improvement in technology, improve our ability to respond to unforeseen problems, and attract high quality younger scientists into the area. This does however raise the issue of what, in this context, the NERC would regard as being fundamental research within its own remit. [Note that CoRWM believes that there is an *overemphasis* on applied research within the Research Councils. This issue is also being addressed by The House of Lords Science and Technology Committee, chaired by Lord Sutherland of Houndwood.] It is generally felt that there are many basic questions to be addressed that are not only of relevance to radioactive waste issues but are also fundamental to understanding what the natural environment is and how it works.

- Also of relevance here is the source of funding, which confuses the issue. Substantive changes in the Government's approach for the funding of public and regulatory science have required bodies such as Defra and the EA to seek leverage monies from Research Councils, Regional Development Agencies, the EU, Devolved Administrations and the like, by forming and bidding in partnerships. The Government's rationale for this seems to be that previous problems of 'community buy-in', of modifying societal behaviours to be more sustainable, and of the 'not -invented-here syndrome', may all be solved by developing the science in partnerships from the start. It also seems to have thought that the partnership approach is much more effective in persuading users to implement the 'science', rather than trying to convince users *after* the work has been done independently by public agencies using GiA; and that partnerships have the major political advantages of being more visible publicly and of engaging closely with communities and ‘electors’. But this, clearly, also muddies the issue with regard to the ‘independent’ nature of the research, particularly in such a sensitive area as nuclear power.

- Nevertheless, improved links with industry also need to be made. For some research areas there is a need for access to information from industry, and to samples of site-relevant material. The commonly held view is that there is more openness between industry and academics in other countries, and thus better links between research and “real world” problems, than there is in the UK. There is also greater support for research supporting radiation protection, which is not seen as high priority in the UK.

- Bearing in mind that the CoRWM has recommended to Government that it assigns to a single organisation the responsibility for providing national leadership and strategic direction for provision of R&D skills relevant to the long-term management of radioactive wastes, does NERC see itself as such a body? [There is certainly some expectation that the NERC should be *the* lead body with respect to all *geological* aspects (ie apart from the near-field engineering aspects) for *all* forms of waste disposal.]

- The need for a strategic approach, the shortage of expertise in the review process and in formulating Research Council strategy, the absence of infrastructure, and the need to grow a sustainable skill base apply not only to NERC, but seem to be a problem across more than one of the Research Councils; so who will take the lead in sorting this out?

- Perhaps a final issue is how to integrate the environmental sciences into a holistic research programme, addressing the technical, social, economic and political implications of nuclear power through, for example, coherent linkage with other Research Councils such as EPSRC (engineering, materials performance, wasteform development); ESRC (socio-economics, law, policy); BBSRC (biological processes); and MRC (low dose radiobiology, epidemiology). All of this is essential if the UK is to establish a credible scientific foundation on which to base its future plans for the nuclear industry.

Suggestions for resolving these issues would seem to include the need for the NERC to have a dialogue with all of the bodies mentioned above before investing again in this area of science. This would seem essential not just to avoid duplication of effort, but to ensure that the infrastructure exists for some of the more important work to be done, and to ensure that it is realistically costed.

Research priorities if the NERC is to play a major role in the new build programmes

It is clearly not possible in such a short review as this to give a detailed breakdown of very specific research needs; a larger, more inclusive exercise would be needed to do so, and this is not worth conducting until some of the ‘**issues**’ raised above have been addressed. It is evident that other bodies (CoRWM, COMARE, and the EA) are currently reviewing their own research needs. In particular, the EA is currently reviewing its research priorities for the next few years in the light of developments in the UK with respect to nuclear power generation, decommissioning and waste management, and has stated that it would be happy to provide this as additional input into any NERC action plan on radioactivity in the environment when it has been completed. Nevertheless, some areas are easily identified, and relate to what are generally perceived as necessary for the revival of the use of nuclear power within the UK. There are essentially the need to demonstrate that both humans and the environment will be adequately protected, that waste disposal issues can and are being addressed, and that both of these areas are underpinned by good, and independent (of the industry and its regulators) science. For the purposes of research programmes they can usefully be set as follows.

Environmental protection

- Transfer factor values in order to estimate doses that are, or could be, received by different types of biota (particularly the 'international' set of RAPs or 'representative' animals and plants as identified by the EA for specific UK application) – all of this is essential data for EIAs for 'new build'.

- Dose–effect relationships for the irradiation of RAPs, particularly in the ranges of dose that have been selected as being areas where Dose Consideration Reference Levels apply and yet for which there is little or no good quality data to support the values.

- More realistic dosimetry for larger (> 1kg) animals and plants.

- Population models relative to reduced reproductive success in RAPs.

Waste disposal *[NB These areas have not been elaborated on here because it seems that the EPSRC (by way of Stephen Elsby) is already liaising with the NERC on a planned EPSRC call for proposals in the field of geological disposal of radioactive waste.]*

- Geochemical processes affecting the migration of radionuclides through geological media.

- Fundamental and applied research specific to the complex UK inventory of radioactive wastes.

- Radionuclide behaviour in the near-field area of a GDF.

- Evaluation of alternative geological disposal concepts for non-high level wastes.

Basic radioecology and related radiobiology of wild animals and plants

- Models that describe the complete distribution of radionuclides under different exposure situations, allowing dose rate estimates to be made with respect to both humans and biota.

- Basic information on the effects of radiation generally in animals and plants, within a theoretical framework, for non-human species from molecular to tissue level.

- Characterisation and quantification of the natural background radiation to both humans and biota.

<u>Future environmental pathways of relevance to human radiation exposure</u>

- The impact of climate change on: the pathways leading to human exposure; the redistribution of longer lived nuclides around current nuclear facilities; and the implications for geological disposal of radioactive wastes of all forms.

- Obtaining a better understanding of the uncertainties in the dose received by humans from internal emitting radionuclides and in understanding the risks associated with radioactivity in a *particulate* form in the environment.

<u>Radioanalytical capability and basic expertise</u>

- Development of a nuclear forensic capability.

- Bioassay development for assessing exposures of people.

- The establishment of a marine/estuarine centre of expertise in radioecology, to complement the Freshwater/terrestrial centre of expertise at CEH.

- Advanced short courses in radioactivity, to build expertise.

- PhD grants specifically targeted at radiation based issues.

- Post-graduate training incentives (centred around the above research priorities).

Acknowledgements

Written information was kindly provided by the following, either in an individual capacity or on behalf of the organisations that they served. In no particular order: C. Williams, D. Copplestone, G. Hunter, J. Cooper, C. Curtis, C. Robinson, K. Simkiss, A. Jha, B. Howard, J. Vives i Battle, E. Petty, N. Bell, K. Morris, F. Livens, I. Croudace, N. Llyoyd, T. Lewis, M. Willans, B. Lee, F. Gibb, L. Tara, I. Burke, A. Tyler, P. Appleby, J. Smith, M. Wood and W. Camplin.

References

[1] Energy White Paper 2003: ‘Our energy future – creating a low carbon economy’, DECC, Feb. 2003.

[2] ‘Meeting the energy challenge, a white paper on energy’, DECC, May 2007.

[3] ‘Meeting the Energy challenge: a white paper on nuclear power’, BERR, Jan 2008.

[4] ‘The road to 2010: addressing the nuclear question in the 21st century’, Cabinet office, July 2009.

[5] Energy Act, UK Government, 2004.

[6] Managing radioactive waste safely, DEFRA, June 2007.

[7] EC Directive on the conservation of natural habitats and of wild fauna and flora. (92/43/EEC) 1992.

[8] ICRP The 2007 Recommendations of the International Commission on Radiological Protection. Publication 103, Pergamon Press, Oxford and New York, 2007.

[9] ICRP Environmental protection: the concept and use of Reference Animals and Plants, Publication 108, Pergamon Press, Oxford and New York, 2009.

[10] Report by the High Level and Expert Group on European Low Dose Risk Research, EC, 2009.

[11] Review of UK research capabilities in radiation protection to wildlife. R&D Tech. Report P3-101/SP6 Environment Agency, 2003.

[12] IUR Report 5, Radiological Protection of the Environment: research, facilities and priorities, 2006.

[13] A Briefer History of Time, S Hawking and L. Mlodinow, Transworld Publishers, 2005.

[14] Pentreath, R. J. Radioecology, radiobiology, and radiological protection: frameworks and fractures. J Env. Rad. 100: 1019 – 1026, 2009.

[15] COMARE Statement on Radiobiology Research in the UK, Nov., 2008 comare@hpa.org.uk

[16] USDoE, Basic Research Needs for Geosciences: Facilitating 21st Century Energy Systems. Bethesda Workshop (Feb 21-23 2007), US Department of Energy, Office of Basic Energy Sciences, 2008.

[17] CoRWM Report to Government on Geological Disposal of Higher Activity Radioactive Wastes. CoRWM docs. 2550 and 2543 July 2009.

[18] CoRWM Note of Radioactive Waste Immobolisation Network (RWIN) technical meeting on geological disposal R&D, 23 April, 2009.

[19] Warneke, T., Croudace, I.W., Warwick, P.E. & Taylor, R.N. A new ground-level fallout record of uranium and plutonium isotopes for northern temperate latitudes. Earth Planet. Sci. Lett. 203, 1047-1057, 2002.

[20] Ellam, R.M. & Keefe, K., MC-ICP-MS analysis of non-natural U isotope ratios using a 229Th/232Th external mass bias correction. J. Anal. At. Spectrom. 22, 147-152, 2007.

[21] Parrish, R.R., Thirlwall, M.F., Pickford, C., Horstwood, M., Gerdes, A., Anderson, J. & Coggon, D. Determination of $^{238}U/^{235}U$, $^{236}U/^{238}U$ and uranium concentration in urine using SF-ICP-MS and MC-ICP-MS: an interlaboratory comparison. Health Phys. 90, 127-138, 2006.