BIOPROTA

Key Issues in Biosphere Aspects of Assessment of the Long-term Impact of Contaminant Releases Associated with Radioactive Waste Management

Comparison of Safety and Environmental Impact Assessments for Disposal of Radioactive Waste and Hazardous Waste

Report of an International Workshop

Asker, Norway, 10 – 12 February 2015

Version 2.0
6 May 2015

PREFACE

BIOPROTA is an international collaboration forum which seeks to address key uncertainties in the assessment of radiation doses in the long term arising from release of radionuclides as a result of radioactive waste management practices. It is understood that there are radio-ecological and other data and information issues that are common to specific assessments required in many countries. The mutual support within a commonly focused project is intended to make more efficient use of skills and resources, and to provide a transparent and traceable basis for the choices of parameter values, as well as for the wider interpretation of information used in assessments. A list of sponsors of BIOPROTA and other information is available at www.bioprota.org.

The general objectives of BIOPROTA are to make available the best sources of information to justify modelling assumptions made within radiological assessments of radioactive waste management. Particular emphasis is to be placed on key data required for the assessment of long-lived radionuclide migration and accumulation in the biosphere, and the associated radiological impact, following discharge to the environment or release from solid waste disposal facilities. The programme of activities is driven by assessment needs identified from previous and on-going assessment projects. Where common needs are identified within different assessment projects in different countries, a common effort can be applied to finding solutions.

This report describes presentations and discussions held during an international workshop on 10-12 February 2015, hosted by NRPA in Asker, Norway. Technical support was provided by a wide range of organisations via presentations and discussions, as described in this report. The financial support provided for the workshop by NRPA (Norway), ANDRA (France), ENSI (Switzerland), LLWR and RWM (UK), NUMO (Japan), POSIVA (Finland), FANC (Belgium), NWMO (Canada), SKB and SSM (Sweden) is gratefully acknowledged.

Version History

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Executive Summary

This report describes presentations and discussions held during an international workshop on 10-12 February 2015, hosted by the Norwegian Radiation Protection Authority in Asker, Norway**.** The workshop was attended by 25 participants from 6 countries, representing a range of operators, regulators, researchers and technical support organisations. Additional presentations were provided by interested persons that were unable to attend the workshop and were presented on their behalf by the BIOPROTA Technical Secretariat.

Emerging Issues

It is clear from presentations that there has been a separate development of the science, management strategies and regulations for radioactive and hazardous waste materials. The idea that the non-radiological hazardous features of radioactive wastes need be considered is not a new concept, but the converse is relatively new, for example, management of asbestos which is found to be radioactively contaminated.

Hazardous waste disposal appears to focus on controlled release of leachate from managed landfill to ensure that benchmarks are not exceeded. Hazardous waste landfills tend to have a membrane installed to prevent the release of hazardous material to groundwater, but leachate production occurs and is required to be managed prior to any release to the wider environment. In the case of radioactive wastes, there appears to be a stronger focus on containment. It is acknowledged that there may be some limited contaminant release from radioactive waste disposal facilities, but the intention is contain the wastes until radioactive decay has reduced the hazards to an acceptable level.

Assessments for radioactive waste disposal facilities typically extend into the future for at least 1,000 years. For hazardous wastes, assessments are usually for timeframes much less than 1,000 years. The timeframe associated with management of waste natural occurring radioactive materials (NORM) is more variable. Waste from the oil and gas industry is normally of small volume and may therefore be subject to containment in a disposal facility. However, other NORM wastes can be of very large volume and containment is unlikely. NORM is not classified as radioactive waste in all countries.

The period of active or passive institutional control at sites varies considerably. The period of institutional control for radioactive waste disposal sites is commonly around 300 years. For hazardous waste sites however, the period of institutional control will vary according to the hazards. For example, in the UK there is no institutional control concept, but the release of a site from a permit would only occur if it can be demonstrated that the site does not pose a risk to people or the environment and that leachate control measures are no longer required. The periods of authorisation and active control have been aligned in the UK for radioactive waste facilities such that both are terminated at the same time. In some countries, a long-term stewardship approach is taken to some NORM sites, which effectively poses an indefinite management requirement on future generations. This appears to be a very different policy from that taken for radioactive and hazardous wastes.

Methods are available that allow the release of chemicals from radioactive waste facilities to be assessed, but corresponding risk or other relevant criteria are not always available and those that are available may not necessarily be consistent with the criteria applied to radionuclides. Since assessments tend to address compliance with criteria, and the criteria are absent or different, this

makes understanding and/or comparison of the radiological and other risks difficult. Optimisation of protection from all the hazards may also be hindered.

The chemical impact of hazardous waste has the potential, to be greater than that associated with radioactive waste. This is particularly the case for low-level and very low-level radioactive waste or VLLW, in which there are comparatively low levels of radioactive constituents and may also be the case for nuclear facility decommissioning wastes, in which the hazardous waste content can be comparatively high compared with operational wastes.

Safety indicators and criteria for radioactive and hazardous waste are not always consistent in terms of the concepts that they are based upon and the level of protection afforded. This may be appropriate in terms of detailed analysis of concepts since there are different mechanisms for production of harm. Nevertheless, stakeholders might expect the level of protection afforded to be consistent.

The categorisation of hazardous and radioactive wastes is changes from time to time and without reference each to the other. It is not just waste disposal where these apparent irregularities have an impact. The issue also applies to legacy site management for which assessments are needed either to determine appropriate off-site disposal routes or to support decisions to eleve materials in place.

The Groundwater Daughter Directive was raised as a potential issue for waste disposal. A greater understanding of the approaches being taken in different countries to address the requirements of the Directive was identified as being beneficial.

Conclusions and Ideas for Addressing Key Issues

Ideally, radionuclides and hazardous materials should be assessed on a common risk management basis such that consistent assumptions are employed in assessments and consistent criteria used in the evaluation of risk. Some technical differences may be necessary, and in this case, there should be a clear understanding of the reasons for the different approaches to allow differences to be understood and communicated. For example, differences in the approaches to dealing with NORM waste often arise as a direct result of the differences in waste volumes for different types of NORM.

The basis for separation in approaches within a country may be regulatory or institutional. There is the potential for a mismatch in regulatory frameworks where different ministries or agencies are assigned to the management and/or regulatory supervision of radioactive and hazardous wastes. However, even where there is a single organisation responsible for both, it is often the case that there are different groups within that organisation specialising in the different areas. Improving communication between the respective groups would help drive toward consistency in assessment approaches and in the management of risks. The development of a common set of objectives and, hence, assessment endpoints and timeframes for the different waste types would be very beneficial. Such development would support coherent risk management and allow alternative options to be compared on an equal basis. This is particularly important when considering radioactive and non-radioactive hazards associated with the same facility. For example, environmental impact assessments for radioactive waste repositories tend to be undertaken separately from safety cases. This can give rise to differences and inconsistencies, even though the assessments are in support of the same facility. Where possible, a pragmatic way of maintaining consistency should be identified and followed such that a holistic approach to disposal assessments for individual sites is achieved rather than hazardous materials being something of an afterthought to radioactivity, or vice versa. There may necessarily be differences in how assessments are made, but those differences should be transparent and the reasons for them should be clearly explained. A holistic approach to assessment would also support the proportionate application of resources to the different hazards presented by a waste.

Similarly, development of a common language to addressing issues would be very beneficial to avoid the use of different terms that could not only be confusing and lead to errors, but also lead to mistrust. It may be useful to investigate the feasibility of developing a single common toxicity index for both radioactive and hazardous substances, including presenting complementary considerations such as comparisons with natural levels of contaminants.

The development of international guidance on criteria for long-term chemical safety of the hazardous waste component of radioactive waste would also be useful, ensuring that the criteria are consistent with those for the radiological impact. This would help with addressing public perception toward radiation, by indicating that radiation is just another hazard associated with waste. The development of such guidance should not only be beneficial to the radioactive waste disposal community, but would also support those working in NORM and hazardous waste management fields.

It was considered that NORM management may be a convenient place to start in addressing some of the issues raised. NORM management is a significant interest area for many countries and would also conveniently address many of the issues relating to regulation of all the different hazards. Even in the case that NORM management falls under a contaminated land regime, there is nonetheless a need to consider waste management as wastes will be generated as a result of contaminated land remediation activities.

It was noted that the assessment community is not always able to undertake the quality of assessment necessary to support regulatory and other decisions, due to a lack of supporting information and science. Being able to reach out to the research community would help address these data and knowledge gaps. The Centre for Environmental Radioactivity (CERAD), a partnership of a range of Norwegian academicand regulatory institutions, was noted as having a ten year programme to undertake radioecology and other research potentially relevant to the issues discussed above. The International Union of Radioecology (IUR) also provides an opportunity to further knowledge through research and networking. A FORUM network has been set up by the IUR to promote networking between networks working in the field of radioecology and ecotoxicology so that knowledge may be shared and developed and to promote consistency, integration and harmonisation in research and assessments. The IUR FORUM also provides a mechanism by which research needs can be communicated.

Various legislation exists specifically related to protection of groundwater, e.g. the European Commission's Groundwater Daughter Directive, which has implications for the disposal of radioactive and hazardous wastes. An international view of what is being done to address the requirements of the Directive and state of application of the 'prevent' requirement would be useful both for the radioactive waste and hazardous waste disposal communities including the regulatory authorities. Understanding the approaches that are being applied to address the issue would provide a basis for developing a consistent approach. The degree to which radionuclides are classed as 'hazardous' under the terms of the Groundwater Daughter Directive at an international level may also be worth further investigation.

CONTENTS

1. INTRODUCTION

Safety and environmental impact assessments are used to support decisions on the management and disposal of radioactive and hazardous waste. These assessments have to address a wide range of protection objectives related to different ecosystems and timeframes. This creates significant challenges to the design of such assessments and in the provision of corresponding relevant scientific support.

An international workshop was held in May 2013 in Ljubljana, Slovenia, on the 'scientific basis for long-term radiological and hazardous waste disposal assessments' and a report incorporating presentations, discussions and recommendations produced and made available at www.bioprota.org. As a general conclusion it was suggested that a holistic approach should be used in the management of different hazards presented by waste materials and that further development of the interfaces between assessment communities concerned with hazardous waste disposal, NORM management and disposal, and post-disposal safety of radioactive wastes would be beneficial. Accordingly, a follow up workshop was organised. The workshop 'Comparison of safety and environmental impact assessments for disposal of radioactive waste and hazardous waste' was hosted by the Norwegian Radiation Protection Authority (NRPA) in Asker, Norway, from 10-12 February 2015. The workshop was comprised of two days of presentations and discussions with a field trip to the NOAH disposal site for inorganic hazardous waste taking place on the third day.

This report provides a summary of the presentations and discussions during the workshop, an overview of the NOAH disposal site and operations, and presents recommendations arising from those presentations and discussions.

1.1 OBJECTIVES AND SCOPE OF THE WORKSHOP

The overall objective of the workshop was to provide a forum for discussion and comparison of assessments made of disposal of radioactive and hazardous waste, taking into account:

- Assessment methods for disposal of radioactive and hazardous waste;
- Comparison of assessment endpoints;
- Comparison of timeframes over which these endpoints are assessed;
- Key processes dominating the release and disposition of radionuclides and other pollutants within the environment, following disposal;
- Approaches to address the environmental change;
- Methods for assessing effects on human health and the environment (individual, population or ecosystem level);
- Assumptions for human behaviours and land use planning;
- Approaches to addressing uncertainties (precautionary principle, optimisation); and,

- Approaches to addressing low probability events that have high consequences.

Kristin Elise Frogg from the Norwegian Radiation Protection Authority (NRPA) opened the workshop with an overview of perceptions around assessments for the management of both radioactive and hazardous wastes. A range of different principles, assessment objectives and endpoints are in operation for both waste types and may vary internationally. There are nonetheless more similarities than differences with approaches tending to be driven by tradition rather than science. In Norway, a Pollution Control Act is in force that aims to regulate operations giving rise to discharges and disposals, both radioactive and hazardous in an integrated ecosystem based approach.

The sharing of experience and discussion between the hazardous and radioactive waste assessment communities at the workshop was intended to provide an important opportunity to develop ideas for complimentary, integrated and consistent approaches to assessments for use in different waste management contexts.

1.2 PARTICIPATION

The workshop was attended by 25 participants from 6 countries, representing a range of operators, regulators, researchers and technical support organisations. Additional presentations were provided by interested persons that were unable to attend the workshop and were presented on their behalf by the BIOPROTA Technical Secretariat. Participants, other contributors and their organisations are listed in Appendix A.

1.3 REPORT STRUCTURE

Presentations from workshop participants and associated discussions are summarised in Section 2 for the workshop session on protection objectives and regulation and Section 3 for the session focussing on assessment approaches and scientific support. An overview of the site visit to the NOAH disposal facility for inorganic hazardous waste is provided in Section 4. Areas of commonality and key issues and lessons learned are then presented in Section 5, along with recommendations for future activities to address key areas.

2. PROTECTION OBJECTIVES AND REGULATION

The first session of the workshop focussed on protection objectives and regulations. Presentations from participants and associated discussions are summarised below.

2.1 PROTECTION OBJECTIVES, REGULATION AND ASSESSMENT METHODS

Graham Smith (BIOPROTA Technical Secretariat) presented.

The alignment of radioactive and hazardous waste assessments is not a new issue; the European Commission was interested in this topic in the early 1990's and commissioned a series of studies, including:

- Post-Disposal Safety Assessment of Toxic and Radioactive Waste: Waste Types, Disposal Practices, Disposal Criteria, Assessment Methods and Post-Disposal Impacts. EUR 14627, 1993.
- Application of Procedures and Disposal Criteria Developed for Nuclear Waste Packages Involving Chemical Toxicity. EUR 16745, 1996.
- Post-disposal Safety Assessment of Toxic and Radioactive Waste: Development and Testing of the SACO Methodology and Code. European Commission Nuclear Science and Technology, EUR 16871, 1996.

The report EUR 14627 provides a review of assessment methods in different countries for different waste types, both hazardous and radioactive. Whilst the situation has moved on since the publication of the report, many of the issues identified are still relevant today. One issue identified was the need for explicit consideration of environmental protection whilst acknowledging that risk may not be high. Whilst, at a detailed level, there have been improvements in relation to assessment approaches, there are still problems with implementation. The scope for sharing techniques and experience for assessments relating to radioactive and hazardous wastes was highlighted as a way forward.

The BIOPROTA forum was set up in 2002 with the remit to address "*Key Issues in Biosphere Aspects of Assessment of the Long Term Impact of Contaminant Releases Associated with Radioactive Waste Management*". The focus is therefore not solely upon radionuclides, but also includes some non-radioactive contaminants within radioactive wastes. During the initial meeting of the BIOPROTA forum participants, issues of interest were identified and discussed and a common interest in addressing non-radioactive contaminants within radioactive waste was identified[a]. Particular elements of interest were identified as uranium, lead and boron. Whilst the issue of non-radioactive contaminants in radioactive waste was identified at the outset, collaborative programmes have not yet been implemented to address assessment issues. Synergistic effects of multiple contaminants were also noted as being potentially important, however it was not considered practical at that time to consider such effects due to a general lack of scientific understanding of associated mechanisms.

[a] BIOPROTA (2002). Report of Workshop held 12 – 14 June 2002, Hosted by ANDRA, Chatenay-Malabry, France. Available from www.bioprota.org.

At a workshop marking 10 years of BIOPROTA activities[b], non-radioactive contaminants in radioactive waste was revisited as a topic that had been raised at the outset for discussion as to whether progress could now be made. The range of protection objectives in place and timeframes over which environmental impact and human health assessments are required in relation to varied national and international regulations were noted as particularly complex. In response to discussions, a topical workshop was held in Ljubljana, Slovenia, in 2013 on 'Scientific Basis for Long-term Radiological and Hazardous Waste Disposal Assessments'[c]. A range of different perspectives and examples of different assessment approaches were presented and discussed. Whilst harmonisation was considered to have a range of merits, not least of which would be public confidence, it was recognised that not every aspect of assessment approaches would necessarily need to be harmonised, but an understanding of the reasons behind differences in approaches would be useful.

Some perspectives on the similarities and differences in assessments for hazardous and radioactive waste disposal were presented for discussion.

For radioactive waste, protection objectives are set at an international level by the ICRP and standards by the IAEA with UNSCEAR addressing scientific aspects. Protection objectives with regard to chemicals within the radioactive waste are not provided. For hazardous waste there are clear policy objectives (keep it safe) and numerous Directives and related standards. The issue is therefore complex as hazardous waste disposal can be a multi-media problem, but there are clearer links to land use planning than there are for radioactive waste. Again, the issue of radioactivity within hazardous waste does not appear to have been addressed.

In terms of assessment methods, there is plenty of guidance on how to address radiation protection objectives and standards when disposing of radioactive waste, including scenario analysis, site and waste characterisation and detailed prognostic modelling. Lists of FEPs (features, events and processes) are readily available and there has been substantial research to support assessment models. For hazardous wastes, greater modes of toxicity must be considered, but there tends to be fewer resources applied to assessments per site than there are for radioactive wastes. There is a lot of international science to support assessments, but there does not appear to be the equivalent of ICRP, IAEA and UNSCEAR offering high level guidance. Risks associated with radioactive waste are likely to be lower than for hazardous wastes and yet greater resources appear to be spent on radioactive waste disposal. There is furthermore a discrepancy in the assessment endpoints with the focus of radioactive waste disposal assessments being a healthy 20 year old whereas for hazardous waste the focus tends to be on those most at risk in the population such as the elderly or individuals with asthma. The timeframes over which endpoints are assessed also vary greatly with those for radioactive waste extending up to 1 million years, although the level of detail in the assessment changes for longer timeframes. For hazardous wastes it appears that the approach is to consider leaching and for this to dictate the type of facility required for disposing of those wastes with the assumption that barriers remain

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[b] BIOPROTA (2012). Report of the Fourteenth BIOPROTA Workshop, Nancy, France, 21-24 May 2012. Available from www.bioprota.org.

[c] BIOPROTA (2014). Scientific Basis for Long-term Radiological and Hazardous Waste Disposal Assessments. Report of an International Workshop. Available from www.bioprota.org.

intact. The timeframe for assessment tends to be significantly less for hazardous waste assessments than for radioactive wastes. The key processes leading to the release and disposition of contaminants are largely similar for both waste types, focussing on groundwater and gaseous release to the surface. For radioactive wastes however, human intrusion, erosive releases and natural disturbance events are also considered; it is unclear as to whether such processes and events are considered for hazardous waste disposal. The findings from such assessments can lead to redesign of a disposal facility. For example, where human intrusion poses too great a risk then deeper disposal of radioactive waste may be considered.

In terms of effects assessment, radioactive waste assessments consider a critical group or representative persons that are assumed to be in the wrong place at the wrong time, taking into account their habits. Radiation exposure is then determined based on those habits and the concentrations of radionuclides in environmental media. Conversely, hazardous waste standards are designed to protect the most at risk in a human population rather than healthy 20 year olds and there is less consideration of how critical exposures occur. Effects are evaluated on the basis of concentrations in environmental media combined with safety factors that vary according to the mode of toxicity. Differences are also observed with regard to environmental change and landscape evolution considerations; there is not the same level of investigation given to hazardous waste as there is for radioactive waste. This appears to be counter-intuitive…where the same processes occur it would seem appropriate to assess these in the same way, irrespective of whether the waste is radioactive or hazardous. Assessing processes in the same way would also lead to greater knowledge for both assessment communities as information could be readily exchanged with regard to key processes such as how materials migrate through the surface environment.

A distinction is required between demonstrating that limits or constraints are not exceeded and actually assessing the degree of impact. This distinction is not always recognised in assessments or in the evaluation of data.

A further potential discrepancy in assessment approaches is evident between radioactive waste disposal and NORM management. There may be reasons as to why assessment approaches are different, but these may not necessarily be the correct reasons. It is evident that, whilst there are numerous similarities in the way in which assessments could be undertaken for radioactive and NORM wastes, experience is not often shared and there would be merit in bringing together these different assessment communities.

The intention of the workshop reported herein was therefore to identify where complementary and consistent approaches to assessments would be beneficial and to identify those instances where integration is not feasible or appropriate and to consider how consistency in approaches could be implemented. The management of NORM wastes may be a good starting point in this regard since both hazardous and radiological aspects require consideration. Legacy sites could also provide a good basis for the sharing of knowledge between assessment communities.

Discussion

More is done with regard to hazardous waste disposal than outlined in the presentation. Barrier integrity is taken into account in assessments and there are numerous pre-disposal requirements for treatment to be undertaken to reduce hazards as required under the Landfill Directive. Sea level rise and coastal erosion are not considered in enough detail however with greater focus on these issues being afforded to radioactive waste disposal.

There are lots of landfill facilities for conventional wastes and models such as LandSim can be applied across these different sites. The Environment Agency in the UK commissioned research a number of years ago into barrier degradation in landfill sites for a range of different barriers and the output of this research has been included within the LandSim model. Groundwater and surface water tend to be the receptors considered and, as presented, it is not common to consider human intrusion or erosion although erosion may be acknowledged as an issue at some sites.

In the UK there are different regulatory regimes for landfill and radioactive waste disposal sites, but recently there has been a move to allow low activity level radioactive waste (LA-LLW) to be disposed of in conventional landfills. Safety cases are being developed to support LA-LLW disposal. The Low Level Waste Repository (LLWR) in the UK is also required to make safety cases and, recently, have been asked by the regulator to consider the hazardous materials within the facility. In addressing the hazardous materials within the LLWR, inconsistencies in the regulatory regimes for the different materials (radioactive and hazardous) have been observed. For radionuclides, contamination of groundwater and subsequent use of that groundwater for irrigation are considered and the long-term implications of potential radionuclide accumulation in soils on humans. This largely isn't done for landfills, rather, concentrations in groundwater are assessed and considered in relation to groundwater limits and criteria. The traditional focus for hazardous waste therefore appears to be more focussed on the environmental impact as opposed to the more human focus of radioactive waste assessments, although with the latter there is a change to more environmental considerations with biota dose assessment methods having recently been developed. It has been agreed in Norway that landfills can dispose of VLLW and regulations for disposal are already in place.

One possible driver for the differences in approaches to radioactive and hazardous waste disposal may relate to the frequency and quantity of waste generation; all countries have hazardous wastes that must be disposed of, but not all have radioactive wastes. Where radioactive wastes are generated, there is a tendency for these to be associated with large enterprises such as nuclear power plants or hospitals. This provides the possibility to focus understanding on how to handle and dispose of wastes whereas the risks from hazardous wastes are highly variable according to the waste type and heterogeneity and different assessment, consultation and treatment approaches may be required for each. Such differences should be born in mind when considering the different approaches. Alternatively, it could be viewed that radionuclides are in fact just another form of hazardous waste and the same approach to assessment could be taken with differences at the end in terms of risk evaluation to account for dose versus toxicity.

It was considered that there may be merit in undertaking an in-depth study of the different approaches for radioactive and hazardous wastes, starting with an analysis of the EUR 14627 report and taking into account more recent developments (e.g. the Landfill Directive). Such a study would provide a clearer understanding of how different aspects are addressed and whether these are consistent for the different waste types.

2.2 METHODS FOR SAFETY ASSESSMENT OF GEOLOGICAL DISPOSAL REPOSITORIES

Graham Smith presented on behalf of Gloria Kwong of the Nuclear Energy Agency (NEA-OECD).

Geological disposal of radioactive waste is defined as being at depths greater than 50m and there is international consensus that geological repositories can provide a solution for the disposal of radioactive waste. The safety of a geological repository is demonstrated through a safety case, which provides a quantitative measure of performance to demonstrate compliance with radiological protection and other criteria. Safety assessment is an essential component of the disposal safety case, providing the technical evidence to achieve confidence in the decision making process.

There is a range of guidance available to support safety case development such as MeSA (Methods for Safety Assessment) and a range of EC projects have been undertaken to demonstrate application of the safety case methodology. NEA publications in support of safety assessments are available from http://www.oecd-nea.org/rwm/igsc/.

The starting point for any assessment is to consider the purpose and context of the safety case, which involves considering the assessment timeframe and the overall scope such as whether the focus is solely on radioactivity or whether other hazardous materials are to be evaluated. The NEA has developed a list of features, events and processes (FEPs) relating to the long-term safety of geological disposal facilities that can be used to support assessments. This FEP list is currently being updated and will be made electronically accessible by the end of 2015, allowing project-specific FEPs to be uploaded by members. The NEA is also developing a thermodynamic database for selected chemicals. More information on the database is available from http://www.oecd-nea.org/dbtdb.

The largest part of a safety assessment is focussed on the geosphere and the near-field (i.e. within the repository itself). Biosphere considerations can vary considerably. For example, some assessments may use groundwater activity concentrations as a measure of safety thus avoiding human behaviour assumptions whereas others may give detailed consideration to the behaviour of radionuclides in the environment and interaction with people. In the United States, human impact and groundwater protection requirements are in place.

A FEP list can be used to develop scenarios for assessment with the MeSA report providing guidance on this. A common approach to assessments is to develop a reference case and alternative cases to address uncertainties in repository development etc. What-if scenarios may then be evaluated for those events that cannot be planned for or controlled (e.g. earthquakes or human intrusion). An NEA workshop on scenario development is being organised and will be held from 1st to 3rd June 2015 in Paris. This will consider regulatory perspectives on developing scenarios, latest scenario developments in member countries and the completeness, comprehensiveness and sufficiency of scenario development.

With the timescales of assessment being of the order of tens to hundreds of thousands of years (and up to 1 million) it is difficult to verify models and assumptions, and uncertainties increase with the time period of assessment. Any long term dose assessment will therefore be extremely speculative. It is necessary therefore, for all assumptions applied in assessments, transparency is required and all assumptions should be justified. To improve confidence in assessment models there may be merit in the repository assessment community sharing knowledge with those undertaking assessments and managing legacy sites. Such sites have been subject to continued monitoring for several decades and this data could be used to help verify models by comparing model predictions to monitoring data. This would only provide partial validation however.

Within a safety assessment, natural and man-made barriers and other safety features of a repository design must be considered. Complementary safety and performance indicators are also applied and can be an important component of a safety case, providing multiple lines of reasoning. Such indicators can be beneficial in terms of communication and can be used to support site selection.

There is some disparity in the level of protection required for geological repositories. For example, the amount of alpha radiation that can be released from a repository to the surface environment is much lower than the exposure arising from the digging up of granite rocks and uranium mining. The reasons behind such disparities may warrant investigation.

Within an assessment, uncertainties should be evaluated. This relates not just to parameter values, but uncertainties throughout the assessment process, including whether scenarios are correct and sufficient numbers evaluated and whether the models are appropriate for evaluating the different scenarios.

Further information on the work of the NEA Integrated Group for the Safety Case and related information can be obtained from http://www.oecd-nea.org/rwm/public-documents.

2.3 REGULATION OF HAZARDOUS WASTE

Henrik Ness Mikkelsen (Norwegian Environment Agency) presented.

The Norwegian Environment Agency is the authority responsible for hazardous and chemical waste in Norway whereas the NRPA is the authority responsible for radioactive waste.

The largest fraction of hazardous waste generated in Norway is from the offshore oil industry. Some of this waste is also radioactive. Hazardous waste is defined as containing substances harmful to health and the environment. In 2013, 1.3 million tonnes of hazardous waste was generated in Norway. Since 2000 there has been an increase of 140% in waste generation, but this is explained by an increase in collection for treatment; the fact that more wastes are now categorised as hazardous; and, that a greater volume of waste is generated from the petroleum sector with waste being treated rather than being re-injected.

There are four stages associated with hazardous waste management: collection, storage, treatment and final disposal. Drilling waste from the offshore industry is often collected at bases around the coast prior to being shipped to special treatment plants. Where the waste cannot be treated or recycled then it is delivered to a disposal facility. Each of the storage and treatment facilities are governed by a county governor’s office whereas the Norwegian Environment Agency treatment and disposal facilities. Scale from the offshore oil industry is regulated by the NRPA.

A Pollution Control Act came into force in Norway in 1983. The act covers all industrial activities including hazardous waste disposal and treatment sites. The overall objective of the Act is to prevent and reduce pollution and the generation of waste. It is stated that no person can possess, do or initiate anything that may entail a risk of pollution. Exceptions are made through the issuing of permits. Sanctions may be carried out as necessary to enforce the Act.

A second law for protection of the environment is the Nature Diversity Act, which complements the Pollution Act. The Nature Diversity Act requires the sustainable use, and protection of, the natural environment and requires measures to be taken to prevent threats to the environment. There are three principles to the act:

- Decisions affecting natural diversity are to be based on scientific knowledge;
- A precautionary approach is to be applied (lack of knowledge is not an acceptable argument for making decisions); and
- Decisions should be based on cumulative environmental effects.

The European Water Framework Directive has been implemented in Norway through water regulations and effects in the environment are monitored. The Industry Emissions Directive has also been implemented which also aims to protect the environment. Integrated permits are required from the authorities that take into account whole industry impacts, considering best available technique (BAT) and BAT reference documents (BREF) are being produced. Waste regulations are in place for landfills that allow for the disposal of radioactive waste.

Under the Pollution Control Act, the Norwegian Environment Agency may issue permits to industry that include a description of the authorised activities and stipulate limits on production or treatment. The permits also restrict the volumes of wastes that can build up. Emission limits to air and water, noise generation and odour limits are also stipulated. All enterprises are required under their permits to measure and report annually on their emissions. There are three special requirements for the treatment of hazardous wastes. Firstly, financial security is required to ensure that the costs of dealing with hazardous wastes at a facility are secured should financial problems be encountered. There is also strict requirements for the control of waste storage requiring risk evaluation and ensuring spills are avoided. Companies are also required to have suitably qualified personnel and be able to demonstrate appropriate knowledge and training. Permit requirements are followed up by the Norwegian Environment Agency through regular inspections and audits. Furthermore, companies are required to provide annual reports detailing production volumes, energy use, discharges to air and water and waste production volume. The volume of waste sent to other facilities or stored on site must also be reported.

Two enterprises have failed to comply with their authorisation with one being issued with a fine due to long-lasting issues and the other closed as a result of illegal waste management activities. This has had the effect of improving performance of other enterprises. The Pollution Control Act allows for fines to be levied upon operators failing to comply with authorisations or to impose temporary or permanent closure orders for facilities.

A waste declaration procedure was introduced in 1993 for hazardous waste and in 2012 for radioactive waste. The system is currently paper based but an electronic form is in the process of being implemented. The electronic system will provide additional data and improve data quality. It will also make reporting easier for operators and provide a consistent and parallel reporting system for hazardous and radioactive wastes. The launch of the electronic form is planned for spring 2015.

The regulation of enterprises in Norway has therefore become increasingly strict, requiring enterprises to have financial security for the volume of waste stored at any time and being subject to regular audits and inspections. The Pollution Control Act is considered to be a powerful tool for preventing, reducing and disposing of pollution and wastes.

Discussion

Different industries have individual permits with limits set on a case by case basis. Efforts are made however to ensure that there consistency is maintained. The principles of ALARP (as low as reasonably possible) and BAT are applied, taking into account associated costs. All anthropogenic sources impacting upon an area are considered when setting limits for individual permits.

Permits are granted for emission to air and discharge to water. All discharges to water regulated in permits are either to coastal water, river basin or in-land water, and in this regard, no permits are granted for discharge to groundwater. However, there have been some releases to groundwater associated with the de-icing of planes at airports, but this is not a regulated occurrence.

There are several hazardous waste landfill in Norway to which the European Landfill Regulations are applied, which stipulates the thickness required for barriers. In terms of prevention of groundwater pollution, leachate is collected, monitored and treated. Collection and monitoring will continue after the operational period for 30 years. Leachate in the post-operational period is considered when receiving waste for disposal. A risk management process has placed restrictions on the use of the site after closure to mitigate against risks from future activities. As such, no construction would be permitted and use would be restricted to recreation. Following the operational phase, the facility will be capped to minimise water ingress. Operators would be required to present a case to the authority for the period that barriers would be maintained.

2.4 RADIOACTIVE WASTE MANAGEMENT: A NORWEGIAN REGULATORY PERSPECTIVE

Jelena Mrdakovic Popic (NRPA) presented.

The Norwegian Pollution Control Act requires waste production to be reduced and justifiable waste management processes to be in place for both hazardous and radioactive wastes. The producers of radioactive waste in Norway are the oil and gas industry, the medical sector, research institutes, NORM industries including phosphate production and ore mining and two nuclear research reactors (Halden and Kjeller). There is no nuclear power production in Norway.

In Norway, the Ministry of Climate and Environment, Norwegian Environment Agency and NRPA are authorities responsible for implementing the Pollution Control Act. Dialogue between these authorities, but also between authorities and industries on the different waste questions allows for the sharing of knowledge of best practice and aids in ensuring a harmonised approach to waste management.

The NRPA, established in 1993, is the competent authority for radiation protection and nuclear safety. The roles of the NRPA include overseeing the use of radioactive substances, monitoring natural and artificial radioactivity in the environment and cooperation on national and international radioactive waste and nuclear safety issues. The authority is responsible for issuing permits under the Pollution Control Act in relation to radioactive waste release and/or pollution.

In 2011, revised Norwegian regulations for radiation protection came into force, following detailed discussions at the national and international level to develop the regulations. Prior to this, there were separate regulations for radiation protection and for the use of radiation. The introduction of the revised

Pollution Control Act means for regulatory practice use of holistic approach to protection of the human health and environment. All radioactive waste is now regulated alongside hazardous wastes in an ecosystem based approach; radioactivity is one characteristic of waste and the other characteristics of those wastes are also taken into account. There are difficulties however in assessment of a variety of complex wastes as this requires all potential stressors to be evaluated and the ecosystem to be considered as a whole. Regulators and operators therefore often require knowledge on individual and multiple stressors, as well as various principles such as ALARA, the precautionary principle and BAT. All regulatory decisions are made in light of knowledge of the ecosystem through complimentary assessments.

In the new legislation, a tiered, prescriptive approach has been adopted for regulation of radioactive waste in Norway. A set of radionuclides activity levels is defined in the regulation for when material is considered radioactive waste and requires a permit (e.g., 1 Bq/g of Ra-226 in case of NORM waste), and for when radioactive waste is subject to obligatory final disposal (e.g., 10 Bq/g of Ra-226 in case of NORM waste). According to newly introduced requirements, all the activities which lead or may lead to radioactive pollution or produce radioactive waste must have a permit issued by NRPA. Handling of radioactive material must be proper and practices that generate waste have a duty to deliver radioactive waste to authorised companies at least once per year. The radioactive waste must be declared in defined way. The same declaration form is used for radioactive and hazardous wastes. This form includes the European waste list for hazardous waste and a Norwegian waste category number which makes it possible to specify whether waste is hazardous and radioactive, only radioactive or only hazardous. This simplifies the process for operators and gives a better overview to competent authorities. An online reporting system (E-declaration system) is going to be implemented in spring 2015. Furthermore, quantities, activities of waste handled and the management options chosen must be reported annually to the authorities.

In terms of sites for the management and disposal of radioactive wastes in Norway, Senja Avfall IKS holds a permit for the incineration of certain radioactive wastes. Repository for low and intermediate level radioactive waste, run by Institute for Energy Technology in Himdalen, may accept radioactive waste from research, industry, medicinal industry and nuclear industry. The NOAH disposal site receives mixed radioactive and hazardous inorganic wastes, while Wergeland Halsvik AS may receive NORM from oil and gas industry, but also NORM waste from other activities.

Positive feedback has been received from industry on the holistic regulatory approach. Good communication between the regulatory bodies is key to ensuring this. Since 2011, 165 permits have been issued to 70 companies. The largest fraction of radioactive waste is masses from excavating the radioactive bedrock, accounting for 31,500 tonnes of a total of 31,600 tonnes of radioactive waste in 2013.

The whole of Scandinavia has alum shale in bedrock with variable U-238 concentrations. Regulation of alum shale is not easy with potential hazards being posed from the shale due to construction activities such as roads. Alum shale masses sometimes have U-238 levels so high that these have to be treated as radioactive waste, while sometimes the levels can be low, but the potential for acidic leaching and consequently radioactive pollution can still be significant. In Norway, several aspects of management of alum shale wastes have been considered intensively recently. All construction companies are required to screen U-238 activity concentrations in rocks to determine whether there will be waste quantities generated that may be of concern. Where this is the case, companies are required to obtain a permit from the NRPA that will stipulate safe handling and disposal requirements and require annual declarations on wastes to be made. Furthermore, the current challenge for regulatory body, operators and industry is that the quantities of excavated alum shale in different projects are large and there is not sufficient space in disposal sites for these generated wastes.

The shale is not just an issue in terms of radioactivity however. Heavy metals and other potential pollutants are present and intensive collaboration between the NRPA and Norwegian Environment Agency is ongoing to agree an approach to the characterisation of shale; to find a solution for the historical problem; and to facilitate the construction of shale disposal sites, which is a national priority. The volume of shale production is expected to increase in the future so has the potential to become a large problem.

In terms of regulatory challenges, a key challenge with the introduction of the Pollution Control Act was the increase in requests from industry for permits following communication between authorities and industry. Continued communication is an ongoing challenge, but the largest challenge at the moment relates to the need for more disposal sites. Further improvement of the interfaces between procedures for hazardous and radioactive wastes is ongoing.

Discussion

Mixed hazardous and radioactive wastes falling in between the first and second assessment tier (e.g., 1 and 10 Bq/g of Ra-226 in NORM waste) can be sent to a disposal site that has a permit issued by either the Norwegian Environment Agency or the NRPA whereas operators generating the wastes must possess a permit from both authorities. When a license is granted by one organisation, handling requirements will be stipulated that ensure safety in relation to both radioactive and chemical hazards. It is important to note that no permits given by the Norwegian Environment Agency or the County Governor include any specific requirements to ensure safety to radioactive hazard. However, it can be understood that all industries are required to perform risk assessment of all waste they handle, and thus are required to ensure safety in relation to both radioactive and chemical hazard. Not many disposal sites have come forward however to take radioactive wastes, but where revised categorisation of wastes now means that wastes previously accepted by hazardous waste disposal sites are now categorised as radioactive, those wastes continue to be accepted for disposal. The Himdalen disposal facility has a permit that allows radioactive waste to be disposed, but cannot accept hazardous waste whereas the NOAH facility has permits for both waste types. The incinerator for radioactive wastes is regulated to ensure that ash generated remains below the limit for classification as radioactive waste and ash can therefore be disposed to standard landfill.

2.5 REGULATING THE RADIOACTIVE AND NON-RADIOACTIVE COMPONENTS OF RADIOACTIVE WASTE FOR DISPOSAL IN ENGLAND

Candida Lean of the Environment Agency for England presented.

Within the UK there is a devolved regulatory system so different environment agencies are in operation in each country. Slightly different environmental regulations are therefore in place.

For radioactive waste disposal, facilities are required to meet 5 principles and 14 requirements set out in the UK environment agencies' Guidance on Requirements for Authorisation (GRA) for disposal facilities on land for solid radioactive waste. There are two GRA documents; one for near-surface facilities, including landfills that are permitted to receive low activity radioactive waste (which is authored by the environment agencies of England, Wales, Scotland and Northern Ireland) (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296507/geho0209bpjl-e-e.pdf), and one for geological facilities (which is authored by the environment agencies of England, Wales and Northern Ireland) (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296504/geho0209bpjm-e-e.pdf).

In terms of safety requirements for disposal facilities for radioactive waste, the GRA defines dose guidance levels of 0.3 mSv/y from a single source from which radioactive discharges are made and 0.5 mSv/y from the discharges from a single site while a permit is in place. Following surrender of a permit a risk guidance level of 10^{-6}/y is applied. Human intrusion requirements are in place for the period following surrender of a permit with a dose guidance level range of between 3 and 20 mSv/y. Values towards the lower end of this range are applicable to intrusion events of a longer term nature such as residential scenarios whilst values towards the higher end of this range are applicable to short term intrusion events such as borehole drilling. For deep geological disposal facilities, the likelihood of human intrusion is low and no constraint is applied. However, operators will be required to demonstrate that precautions are in place to prevent intrusion events. The exposure of wildlife is taken into account under the GRA's, but no specific criteria are stipulated. Rather, operators are expected to apply the most up-to-date framework in place at the time of assessment. There is also a need to demonstrate that the protection afforded from hazardous substances and non-hazardous pollutants present in the wastes is no less stringent than if national standards for disposing of non-radioactive waste were applied. Whilst radiological impacts are required to be as low as reasonably achievable (ALARA principle), this principle is not extended to the non-radioactive components of the wastes.

To take into account the introduction of the European Groundwater Daughter Directive, which includes a prevent requirement for hazardous substances reaching groundwater, the Environment Agency issued supplementary guidance to the near-surface and geological GRAs (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296508/LIT_8036_58590a.pdf and https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296505/LIT_8033_9dc673.pdf). The supplementary guidance document stipulates that radioactive doses to members of the public through the groundwater pathway should be consistent with, or less than, a dose of 20 µSv/y during the period of authorisation and a risk of 10^{-6}/y after the period of authorisation.

Permit applications for radioactive waste disposal sites are required to be accompanied by an environmental safety case (ESC) that demonstrates that GRA criteria have been met and that people and the environment will be afforded protection now and in the future. The ESC should be a living document that is subject to formal updates that are specified in the permit conditions.

In England, the 2010 Environmental Permitting Regulations (EPR10) seek to deliver the protection of groundwater. These regulations state that the Environment Agency must take all necessary measures to prevent the input of hazardous substances, and limit the input of non-hazardous pollutants to groundwater to ensure inputs do not cause pollution of groundwaters. Hazardous substances are defined as those substances that may be toxic, persistent and liable to bioaccumulate (or give rise to an equivalent level of concern). Whilst radionuclides are technically included in the category of hazardous substances they are assessed separately in accordance with ICRP guidance. Non-hazardous substances are defined as a pollutant other than a hazardous substance. A list of hazardous and non-hazardous substances is maintained by an expert committee (JAGDAG[d]) using the most up to date toxicological information. The GRA guidance for non-radiological contaminants within the radioactive waste stream, in relation to the requirements stipulated in the Groundwater Daughter Directive, require that control measures are no less stringent than for non-radiological landfill requirements, which effectively means that the radioactive waste disposal facility should seek to meet the groundwater protection provisions groundwater protection provisions stipulated in EPR10 must be complied with. These provisions stipulate that non-radiological hazard provisions should be proportionate to the non-radiological hazard presented by the waste. Permit applicants are also required to have regard to the Agency's guidance on hydrogeological risk assessments for landfills and the derivation of groundwater control levels and compliance limits.

There is a lot of debate within the UK as to how to demonstrate that the 'prevent' requirement for groundwater has been met. Prevention may be demonstrated if there is no discernible concentration of a substance in the discharge from a site or immediately downstream of the discharge. Alternatively an operator should demonstrate that a future discharge will not result in actual pollution or present a significant risk of pollution in the future and that all reasonable measures have been taken to prevent the input of substances to groundwater.

A consultation has been planned for May 2015 led by the UK environment agencies with regard to determination of hazardous substances in groundwater, defining regulatory standards for hazardous substances and addressing the issue of compliance points. Guidance may therefore be subject to change as a result of this consultation. A further development may arise from the implementation of a European Directive on radioactive substances in drinking water that was issued in 2013 (EU Directive 2013/51/EURATOM). Member States are required to bring into force the provisions necessary to comply with this Directive by the end of 2015. The Directive sets out a range of concentrations for natural and anthropogenic radionuclides in groundwater. If these concentrations are exceeded in groundwater used for drinking water then there is a requirement to assess and mitigate. The standards for total alpha and beta are consistent with the WHO drinking water standards.

There are notable challenges for radioactive waste disposal facilities in ensuring an appropriate level of environmental protection is achieved for both the radiological and non-radiological components of the waste. Different performance criteria are focussed upon for the different waste types with the focus for non-radioactive materials being concentrations in groundwater whereas for radioactivity the focus is on human health. Synergistic effects may also need to be evaluated. The timescales of the assessments may also vary, with radiological assessments often being assessed over longer timescales to take account of the long-lived nature of some radionuclides. Key differences in the assessment approaches include that for a conventional landfill there will be a declining source term as a result of leaching and biodegradation whereas leaching potential for a radioactive waste disposal site may be lower where the waste is conditioned. The conditioning of wastes with grouts and cementitious materials may also give rise to additional materials in the disposal facility that may themselves need to be assessed.

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[d] Joint Agencies Groundwater Directive Advisory Group

Operators of disposal facilities are required to demonstrate an acceptable risk over the lifetime of the facility, to identify those materials of concern and to develop waste acceptance criteria for each (if required). In the UK there is an objective to divert waste away from the Low Level Waste Repository (LLWR) where possible in order to maintain disposal capacity. A policy is therefore in place by which conventional landfill sites can apply for a permit to allow for the disposal of low activity low level waste (LA-LLW) and three sites in England currently hold such permits. One such site is a hazardous waste landfill. The others are for non-hazardous wastes. Hydrogeological assessments have been undertaken for the non-radioactive waste categories permitted for disposal of the site and these cover the non-radioactive properties of LA-LLW.

The 2011 ESC for the LLWR presented the first fully integrated environmental impact assessment whereby both radiological and non-radiological risk assessments were undertaken. Lack of source term information and inventory information led to conservative assumptions associated with form of contaminants and leachability. The ESC considered the groundwater and gas pathways, human intrusion and coastal erosion with results being used to derive waste acceptance criteria for some of the key hazardous and non-hazardous substances. The Environment Agency review of the assessment was challenging; the assessment was based on a radiological risk assessment model, which differs from conventional landfill assessment. Due to the nature of the waste and containment materials and the long-term containment afforded by the LLWR, some groundwater protection criteria for non-hazardous pollutants were not met in the long-term; the LLWR being optimised to ensure radiological impacts are ALARA. Discussions were therefore needed to consider whether the terms of the Groundwater Daughter Directive had been met. Given that any breaches that might occur would do so hundreds of years into the future and were on a localised scale with no impacts on a groundwater-body scale, the Environment Agency concluded that all necessary and reasonable measures had been taken to prevent the input of any hazardous substances to groundwater and limit the input of non-hazardous substances to ensure such inputs will not cause pollution of groundwater (i.e. by presenting an optimised facility design that is consistent with recognised good practice for near-surface disposal facilities for solid radioactive waste). The conservatisms in the assessment were also taken into account, the fact that monitoring indicates no significant current impacts and the fact that there would be time to address any issues if future assessments identify risks with continued waste disposal. LLW Repository Ltd is required to submit an updated hydrogeological risk assessment by 2017 There was also concern relating to asbestos on the local beach following coastal erosion, but risks were analogous to other landfill sites that are similarly at risk of erosion.

Radioactive Waste Management Limited (RWM) prepared a generic safety case in 2010 for disposal of higher activity radioactive wastes to a future geological disposal facility, which was assessed by the Environment Agency. The Environment Agency noted that the non-radiological assessment was not fully integrated into the generic safety case and identified some additional work areas in relation to hazardous substances, including considering synergistic effects of hazardous and radioactive substances. A regulatory observation has been issued to RWM for further work to be undertaken in this area. In order to ensure that RWM is able to apply for a future permit, a common understanding on regulatory expectations relating to the treatment and assessment of the non-radiological hazardous component of the radioactive waste is to be developed with the Agency. RWM is also required to ensure that there are appropriate packaging requirements for wastes containing hazardous substances to minimise the likelihood for repackaging in the future and to develop waste acceptance criteria to protect against the non-radiological hazards of the wastes.

The assessment approach for hazardous materials in radioactive waste is currently in its infancy so both the operator and regulator are learning. There is a wish to improve the reporting of hazardous substances and non-hazardous pollutants future versions of the United Kingdom Radioactive Waste Inventory.

Finally, issues around an update to the Paris-Brussels Convention were raised. The Convention sets liability limits for nuclear incidents and requires sites to have liability insurance. Amendments to the Convention have been agreed, including a significant increase in the nuclear third party liability limit. The amendments have not yet been ratified by signatories and, in the UK, national legislation will need to be revised to implement the changes. It is the view in the UK that disposal sites that are permitted to receive LA-LLW should not fall within the remit; to do so would require around £70 million liability insurance, which is considered disproportionate to the risks. Agreement is therefore being sought from the NEA Steering Committee for such sites to be omitted from the need to have the liability insurance. Unanimous agreement from all contracting parties will be required for agreement to be met. A decision is expected within the next year.

Discussion

Synergisms were briefly discussed at the London BIOPROTA meeting in 2014, but it is not thought that much research has taken place in this field.

Optimisation of design to limit radionuclide release is likely to prevent the release of other hazardous materials, but there is no specific optimisation requirement for non-radioactive hazards although BAT should be applied. There is some inconsistency between landfill assessments, in which it is assumed that biodegradation and leaching will take place over time, and the LLWR, given that it is engineered to keep the waste dry and isolated for as long as possible and thus prevent release of contaminants over longer timescales. It was noted that for some non-radioactive substances, for example heavy metals, retention over long timescales is more likely, potentially longer than radionuclides for which radioactive decay occurs.

For the Groundwater Daughter Directive there has been a lot of debate around the translation of the ‘prevent’ requirement across Europe. In Belgium there has been efforts taken to address this requirement whereby receptors are identified and concentrations of contaminants calculated. The approach for radionuclides in Belgium is to isolate and contain whereas for non-radionuclides, barriers allow for the slow release of materials, but the rate of release is low enough that pollution issues do not arise. In France and the Netherlands the draft Directive wording of ‘aim to prevent’ is still used. In the UK, radionuclides are included in the definition of hazardous substances, but this is not consistent throughout Europe. In the original Groundwater Directive radionuclides were specifically excluded, but this exclusion was removed from the Groundwater Daughter Directive and the UK interpreted this as meaning that radionuclides should be incorporated.

The interpretation of the prevent requirement may be critical for the UK LLWR; for example, lead is used as a shielding material and could be categorised as hazardous in the UK in the future.

2.6 COMPARISON OF CRITERIA FOR PROTECTING HUMAN HEALTH FROM RADIATION AND CHEMICAL HAZARDS IN THE UK

Kelly Jones from Public Health England (PHE) presented.

There are both similarities and differences in the approaches for deriving human protection criteria for radiation and chemical hazards. A report was published in 2007 by the UK Health Protection Agency (now PHE) that looked at the derivation of exposure criteria for ionising radiation and chemicals. Whilst it had been intended for further work to be done in this field, no progress has been made to date, but it could be timely for this work to now progress.

Protection criteria are set at exposure levels intended to prevent adverse effects (threshold effects) or limit their likelihood to acceptable levels (non-threshold effects). Judgement is required as to what constitutes an adverse health effect.

There are differences in approach in relation to the derivation of criteria and their application. For radionuclides the typical background radiation is one input to the development of protection criteria whereas for chemicals the criteria tend to be set in relation to total exposure levels. As such, a distinction is made between exposures that are amendable to control for radiation whereas for chemicals no distinction tends to be made between contributions to exposure from natural and artificial sources. There also tends to be considerably more information relating to the effects of radiation on humans than there is for chemicals with the latter placing more reliance on a rather limited set of animal effects data.

In terms of effects, both threshold and non-threshold effects are associated with ionising radiation whereas for chemicals there is a tendency for more non-threshold effects to be considered unless there is evidence of a threshold effect. For chemicals with non-threshold effects the primary health effects of concern are cancer and hereditary disease and a different approach is followed for chemicals than for ionising radiation. Both approaches follow an overall risk management policy to reduce exposures as much as reasonably practicable, but for chemicals the lack of data on human effects drives differences in approach. There is extensive data for the effects on humans and induction of cancer as a result of radiation exposure and a linear no threshold relationship is assumed, allowing the extrapolation of risk at low exposure levels. Since there is no level of exposure that is associated in no risk, the ALARA principle is applied. The approach allows doses to be summed from all sources to an individual for all intakes and external exposure. Comparison can also be made against natural background exposure.

In the case of chemicals, a margin of exposure term is often applied in line with recommendations from a committee on the carcinogenicity of chemicals (COC). The margin of exposure describes the magnitude of risk, but does not quantify this risk. Points of departure may be allowed where there is confidence in effects data. The approach involves dividing a measure of effect by the exposure to obtain the margin of exposure. If the margin of exposure is over 1 million then it is highly unlikely to be of concern. At the banding below this (a margin of error above 10,000) then it is unlikely to be of concern, but the principle of ALARP should be applied. Margins of exposure below 10,000 may be of concern. In other countries, notably the USA, mathematical models are used to extrapolate from high dose animal effects data to low dose risks to people, but the COC considered this approach to give an impression of precision that doesn't exist with the few data points available for many chemicals.

Where low exposure levels are likely, minimum risk levels (MRL) may be derived, which represent a negligible carcinogenic risk level. The MRLs are derived taking into account all available animal data.

A level without discernible effects is identified and expert judgement is then applied to derive an appropriate margin of error.

There are three compounds for sufficient human data have been available to allow air quality standards to be derived, rather than relying on animal exposure studies: benzene; 1,3-butadiene and polycyclic aromatic hydrocarbons (PAH). In the case of benzene and 1,3-butadiene, sufficient and good quality epidemiological data were available from occupational exposures to allow the identification of an exposure level associated with no increase in tumour development. Safety factors were applied to this value. A factor of 10 was applied to take account of the difference between full lifetime exposure and exposure at work. A further factor of 10 was applied to take account of the variability in the general population. However, for 1,3-butadiene, the derived standard was higher than ambient air concentrations. To ensure ALARP, a value lower than the ambient air concentration was therefore selected. For PAH, it was not possible to identify a no observable effects level and so an additional safety factor of 10 was applied.

Similar principles are therefore applied for radionuclides and hazardous materials with non-threshold effects with the principles of ALARA and ALARP being applied, respectively. However, a lack of human data drives differences in approach to avoid extrapolation from high dose animal bioassays to low dose human exposures.

For hazardous materials with threshold effects the objective is to select levels that would not be expected to produce adverse health effects. Exposure limits for different organs have been derived for radionuclides to prevent the occurrence of threshold effects, with criteria being determined on the basis of expert judgement following a review of the scientific evidence. For chemicals this approach is not so feasible since toxicological data are usually only available from animal studies and a range of uncertainty factors are therefore applied to take account of the large uncertainty in extrapolating from the available data to human effects. The starting point is to select the pivotal study and critical effect (Figure 1). Consideration is then given as to how close the test species is to humans or the severity of the observed effect. A no observed adverse effect level (NOAEL) is then derived by choice, but other effects levels may be derived depending upon data availability. Uncertainty factors are then applied to the derived effect level to take into account interspecies variability (a factor of 10 is often applied to be cautious), human variability (a further factor of 10). The overall uncertainty factor may be further increased where data are limited or of a poor quality or where severe and irreversible effects are observed. If human data are available then uncertainty factors may be reduced.

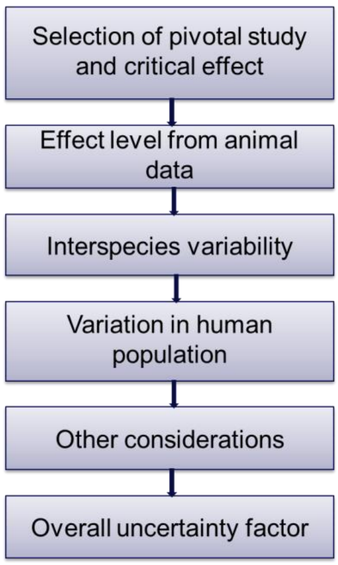


Figure 1. Approach to deriving uncertainty factors for hazardous materials with threshold effects.

It is recognised that the 'factor of 100' approach is not the most scientifically based system and alternatives are being considered although approaches such as linear fit are limited by the availability of relevant data. Acceptable daily intake or tolerable daily intake approaches are being considered which represent a value that can be ingested over a lifetime by humans without appreciable health risks. An alternative approach is to estimate exposure and use alongside a NOAEL to derive a margin of safety or exposure. Values of 100 or more are typically considered as being of 'no concern', but uncertainties must be taken into account.

In conclusion, differences in approaches for setting criteria for radiation and hazardous substances largely stem from differences in the availability of human effects data upon with criteria can be derived. For radiation international advice tends to be incorporated into EC directives and then nationally whereas for chemicals, international advice is just one input. Independent expert groups tend to be used in the development of criteria for both radionuclides and hazardous substances. It is important to remember however that there are a vast number of chemicals; in the last EC survey of chemicals in 1981, over 100,000 chemicals were identified. Overall, a similar approach to assessments is applied by preference, but a fundamental lack of human data on effects results in differences in approach being applied.

Discussion

For chemicals, an effect is defined as an observable change, but judgement is often required, particularly for threshold effects. Where there are classes of chemicals that act in the same way it is normal to consider the additive effect, but antagonistic and synergistic effects tend not to be considered to the same extent although awareness of the 'cocktail effect' is growing.

The principle of justification tends to be applied in relation to radioactivity, but less so for chemicals. However, for new chemicals there tends to be more of a requirement to justify production over certain quantities prior to being placed on the market.

2.7 ADDRESSING CHEMICAL TOXICITY IN RADIOACTIVE WASTE

Koenraad Mannaerts from the Belgian Federal Agency for Nuclear Control (FANC) presented.

FANC defines waste as material of any form for which no further use is foreseen now or in the future. For radioactive waste, the waste contains one or more radionuclides with an activity or activity concentration not negligible from a radiation protection point of view and thus requiring specific management. Hazardous waste is defined as waste with constituents having characteristics of corrosivity, ignitability, reactivity and/or toxicity that pose substantial or potential hazard to human health and the environment.

The Swiss-German alchemist Paracelsus (1493-1541) was the father of chemotoxicity. He realised that there was a direct relationship between dose and the degree of poisoning and was the first to undertake studies on mining disease.

Toxic materials can present both health and environmental hazards, where health hazards relate to lethality to the entire body or specific organs or may cause damage or induce cancer and environmental hazards tend to be focussed on aspects such as degradability, bioaccumulation and aquatic toxicity. Aquatic toxicity is particularly important for hazardous materials since the aquatic environment is often the final receiving media. Toxicity itself is dependent upon the degree to which a substance interferes with biological processes. Various models of toxicity can occur such as radiotoxicity, biological (e.g. viruses) or physical (e.g. asbestos) toxicity or chemical toxicity.

There are various factors to consider in addressing the chemical toxicity of a substance, including the chemicals state (solid, liquid, gas), nature (organic or inorganic) and physical and biological behaviour and how this is influenced by environmental factors such as pH and redox conditions. Acute exposure tends to be the focus for chemical assessments whereas for radionuclides both acute and chronic exposures are considered. There are also differences with the ease to which toxicity is evaluated; for radionuclides it is dose that is determined whereas for chemicals exposures there are a greater range of endpoints (e.g. mg/kg, mg/l, reference dose, LD_{50}, LC_{50} etc.). Exposures are therefore more difficult to interpret for chemicals than for radionuclides.

Historically, the chemical toxicity of materials in radioactive waste has not been widely addressed. Rather the focus has been to isolate and contain radioactivity from the biosphere to allow for decay and hence hazard reduction over time. However, the main bulk of radioactive waste is comprised of non-radioactive constituents, some of which may be hazardous and this hazard may persist over time. It is therefore considered that the nature and chemical form of chemotoxic substances should be taken into account when assessing the performance of the waste for disposal and transfer and exposure pathways evaluated. This is particularly important for near-surface facilities that tend to have less durable engineered barriers as compared with geological disposal facilities. Some countries have already started to consider the physical and chemical components of wastes with waste acceptance criteria being developed to address the chemical toxicity in the radioactive waste.

Post closure assessments for geological disposal facilities have traditionally focussed on the consequences of radionuclide release, but some studies have looked at non-radionuclide components. There are no guideline values that allow a holistic interpretation in terms of human health and environmental impacts. Since 2000, however, increasing national and international legislation, such as the European groundwater Directive, has called for chemotoxicity to be addressed and there is an increasing trend therefore for radioactive and non-radioactive components of radioactive waste under one single regulation. This is the case in Norway, UK and USA and the NEA-OECD includes chemotoxicity in their FEP database, in terms of affecting release and migration.

The central concept for both radiotoxicity and chemotoxicity is dose or exposure, but more research is required on target tissues for chemicals. There may be useful parallels between the ways that chemically hazardous and radiotoxic substances are managed and regulated however and learning from understanding commonalities and differences in assessment approaches.

Most approaches are solubility based by which a downward flux of water ultimately leads to the release of material to the biosphere. Different degrees of solubility may be considered and sorption assumptions varied in different assessment scenarios. For chemicals however there tends to be less consideration given to exposure pathways, rather concentrations in the environment are commonly compared against criteria to ascertain what human impact might be.

In Belgium there are separate legislative arrangements for the different wastes. Radioactive waste regulation is a federal matter whereas non-radioactive waste regulations are regional, which leads to variation in concentration limits and approaches between the three regions. Both waste types require an EIA.

In Flanders, the non-radioactive hazardous waste policy has changed to allow underground disposal, with the approach and method being similar to that required for an EIA for radioactive waste disposal sites although barriers are not considered; it is to be assumed that there is no containment from the saturated zone. This is a different approach from that taken for landfill sites.

An application for a LLW near-surface disposal facility began in 2013, but is still ongoing. One single EIA has been submitted, but this has to be evaluated by the two regulators (federal and regional). The non-radioactive aspect of the EIA has been accepted, but there remain some problems with regard to nuclear licensing.

Both qualitative and quantitative approaches were taken in the assessment to identify those materials in wastes that posed a chemotoxic risk. The quantitative approaches included comparing solubility limits water quality standards, calculation of the concentrations of substances in groundwater for comparison against those standards and comparing chemical toxicity and radiotoxicity. Qualitative screening criteria included consideration of the natural presence of substances in groundwater at high concentrations and other qualitative criteria such as water colour. One single scenario was considered. Out of an initial 36 inorganic substances, six elements (B, Cd, Mo, Pb, Sb and Zn) were identified as having the potential for chemotoxic impacts. A more detailed assessment was then undertaken for these elements with the result that no impact was to be expected in the long-term as a result of water buffering and dilution.

In conclusion, the chemotoxic constituents within radioactive waste and their behaviour should be considered and regulations continue to be developed with a greater move toward developing single national regulations to manage radioactive and non-radioactive components of wastes. There are commonalities in approaches to assessing chemical and radiological risks. For example, both focus on the protection of human health and the environment and the overall concept of toxicity is similar. A similar approach to safety assessments can therefore be carried out to address both the radiological and chemotoxic constituents within radioactive waste. There are however notable differences. The long-term behaviour of chemicals is not always considered in evaluating human health impacts and more acute uptake is generally considered as compared with the long-term effects of low dose exposures for radiation, which can make a direct comparison of chemotoxicity and radiotoxicity difficult. The ability to address additive effects for chemicals can also be difficult and greater understanding of synergistic effects of all potential hazards is required. There are also fundamental differences in the design of disposal facilities with radioactive waste facilities focussing on containment and hazardous waste facilities aiming for slow release and dispersion to avoid measurable impacts on groundwater and other receptors. A further key difference is the public perception of hazardous versus radioactive waste.

A consistent and balanced decision making process is required to implement feasible, consistent, long-lasting, balanced and sustainable solutions to the disposal of radioactive and hazardous wastes.

3. ASSESSMENTS AND SCIENTIFIC SUPPORT

The second session of the workshop focussed on assessments and the science behind the assessments. Participant presentations and points raised in associated discussions are summarised below.

3.1 NORM MANAGEMENT IN CONVENTIONAL HAZARDOUS WASTE DISPOSALS

Danyl Perez-Sanchez (Ciemat) presented.

There is a large NORM industry in Spain leading to tonnes of waste being generated.

Regulations in Spain require that industrial wastes must be characterised in terms of the physical and chemical properties of solid materials and that wastes should be minimised by recycling or incineration. The quantity of organic and inorganic toxic materials must also be evaluated. Industrial solid waste can be disposed of to two different types of landfill (hazardous and non-hazardous) according to the content of toxic materials. NORM wastes were not considered however when these categories were defined.

Regulations in Spain have been revised to include NORM wastes and it is now required that that waste categorisation include radioactivity. Below exemption levels, wastes should be minimised by recycling or reusing. Further categorisation of remaining wastes is then required according to whether they have toxic materials (organic or inorganic) and/or radioactivity present. There is a question however as to what level of radioactivity over the exemption level defines whether the waste is categorised as hazardous or not and what activity concentration wastes should wastes be defined as more than hazardous.

In the UK, no limits are placed on wastes falling below exemption levels. As such, any wastes with an activity below 5 Bq/g can be disposed of to landfill, up to a maximum of 50 GBq per year. Wastes with an activity between 5 and 10 Bq/g can be disposed of to a landfill authorised for VLLW disposal or to a waste permitted person. Wastes with a radioactive content above 10 Bq/g require specific permission for disposal. The exemption levels vary according to the radiotoxicity of the radionuclide. In Belgium, different categories are again applied to wastes according to activity concentrations. In Sweden there are specific regulations in place for NORM wastes with activity concentrations set for the different radionuclides associated with NORM wastes (10 kBq/kg for U, Th and the U-series radionuclides and 100 kBq/kg for K-40). It is specifically stated in the regulations that exemption levels have been increased to allow for a realistic solution to NORM waste management.

In Spain there are a series of decisions made according to the characteristics of the NORM waste (Figure 2). Where toxic materials are present and activity concentrations are at least 50 times lower than the exemption levels then disposal is to hazardous waste landfill. If no toxic materials are present then disposal can be to conventional landfill. For wastes with higher activity concentrations, disposal is required to be to either a radioactive waste or NORM waste disposal facility.

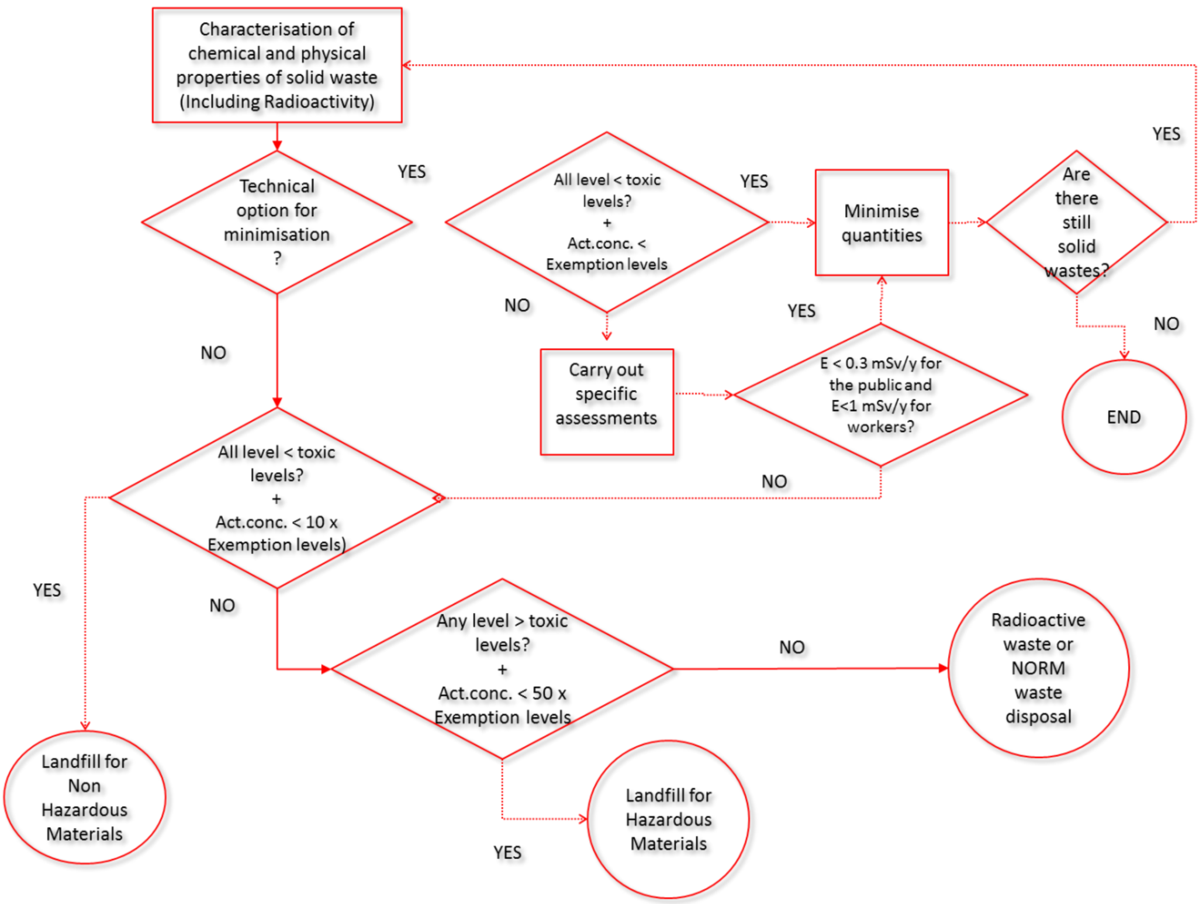


Figure 2. Decision framework for the disposal of NORM waste in Spain.

A generic study has been undertaken to determine the quantities of NORM wastes that could be managed in the different disposal facilities and resultant dose implications, based on the establishment of a limit with regard to the most enriched radioisotopes present in waste. The study took into account Spanish conditions in different areas, such as variations in precipitation, temperature, irrigation rate and different occupancy factors. No isotopic separation was assumed to have occurred as a result of the previous treatment of the NORM materials. The generic design of landfills in Spain is defined under regulations (Figure 3), but varies according to whether a landfill is intended for the disposal of hazardous or non-hazardous materials. These different features were taken into account in the assessment.

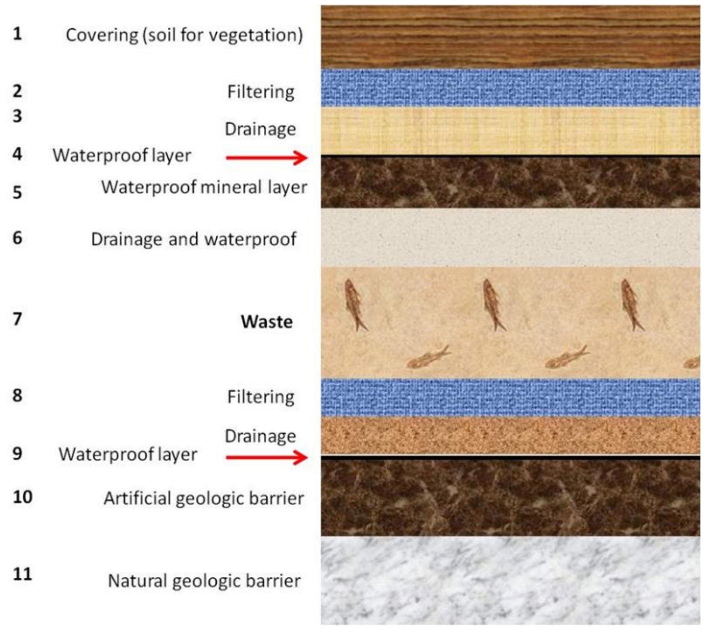


Figure 3. Generic Spanish landfill design.

The dose assessment focussed on workers within the landfill for a 60 year operational period. After closure of the facilities, residential use was assumed on the site for a time range from 1000 to 1500 years. The RESRAD (onsite) assessment code was applied. Dose constraints of 1 mSv for members of the public and 6 mSv for workers were considered. Radon emanation was excluded from the assessment. Parameters were varied according to the local conditions.

A mean effective worker dose of 0.7 mSv/y was calculated for a hazardous landfill disposing of NORM waste with an upper (95 percentile) effective dose of 1.4 mSv/y. Uncertainty analysis demonstrated that variations in parameters values had only a limited effect on dose calculations:

- A factor of 1.7 for worker dose from disposal of NORM to hazardous waste facilities
- A factor of 1.2 for public exposure resulting from the disposal of NORM to non-hazardous facilities

The assessment was most sensitive to variations in assumptions for mass loading for inhalation and cover depth for the workers scenario whereas density of cover material and density of the contaminated zone and erosion rate were the most important parameters for the public exposure scenario. The importance of erosion for public exposure is due to the timeframe of assessment.

From the output of the assessment, disposal volumes could be defined for disposal facilities according to the width of the facility and the permitted dose to workers for both hazardous and non-hazardous facilities. Site-specific studies would provide better estimates of disposal volumes and allow disposal quantities to be raised.

3.2 NORM WASTE MANAGEMENT IN NORWAY

Per Varskog (Zpire Ltd) presented.

Waste from the oil and gas industry comprises the majority of NORM waste in Norway; oil fields are present all along the Norwegian coastline. Supply bases are present at points along the coast that are used to transport material to and from the oil fields with NORM waste generated offshore being initially transferred to these bases for processing. The majority of wastes are brought ashore as either sludges or solid materials and are segregated into active and non-active fractions. Scale on the inner surfaces of process equipment is removed to allow steel to be recycled. This is primarily done by high pressure water jetting although one company in Norway uses chemical treatment, but this is a much more expensive treatment process. Water used in NORM decontamination processes is controlled prior to release.

Wastes with activity concentrations below 1 Bq/g are classified as non-radioactive. Where activity concentrations are in the range of 1 to 10 Bq/g, disposal can be to the NOAH Langoya hazardous waste disposal facility. Wastes with an activity concentration greater than 10 Bq/g are routed to the Stangeneset licensed site for the disposal of NORM wastes. The NOAH facility has limits in place for oil disposal and oil-containing wastes are therefore routed elsewhere. All waste in Norway is declared and, as such, each waste type is assigned a specific classification number.

There are a number of old oil installations that require decommissioning. These are brought into decommissioning facilities and large scissors are used to cut the steel apart and steel is then monitored for radioactivity. Non-contaminated steel is removed from the facility. NORM is collected and stored at the supply bases ready for disposal. Storage is mainly in drums within locked steel containers. All NORM stores are subject to the same regulations as for the storage of other radioactive material and require a permit from the NRPA.

Wastes are declared on specific declaration forms with different waste substance and category numbers assigned for the different types (e.g. sediment, scale, black dust etc.) and levels of radioactivity. Wastes not classified as radioactive are declared as oil containing wastes since they are generated by the oil industry. No free classification is permissible from this sector. The declaration form for each waste is initiated by the waste producer and is continually updated as the waste passes through the waste management and disposal chain. The assigned classification and category numbers define the final disposal option.

For the final disposal of NORM categorised wastes a multiple barrier repository is required. The barriers individually and collectively are required to protect against degradation occurring within the facility (e.g. from chemical erosion) and outwith (e.g. climate and erosion influences). The Stangeneset NORM disposal site (Figure 4) is located 80 km north of Bergen. The facility, which is located in shallow rock, opened in 2008 and has a current disposal capacity of 7,000 tonnes although there is the option for expansion through the construction of additional disposal tunnels. The maximum depth of disposal tunnels is 16 m.

The repository is constructed in an area with a high groundwater table. As such, the tunnel will be filled completely to address water ingress issues. NORM packed in drums are emplaced in the facility and the tunnels back filled with concrete at the time of disposals to force groundwater to flow around the disposal tunnel.

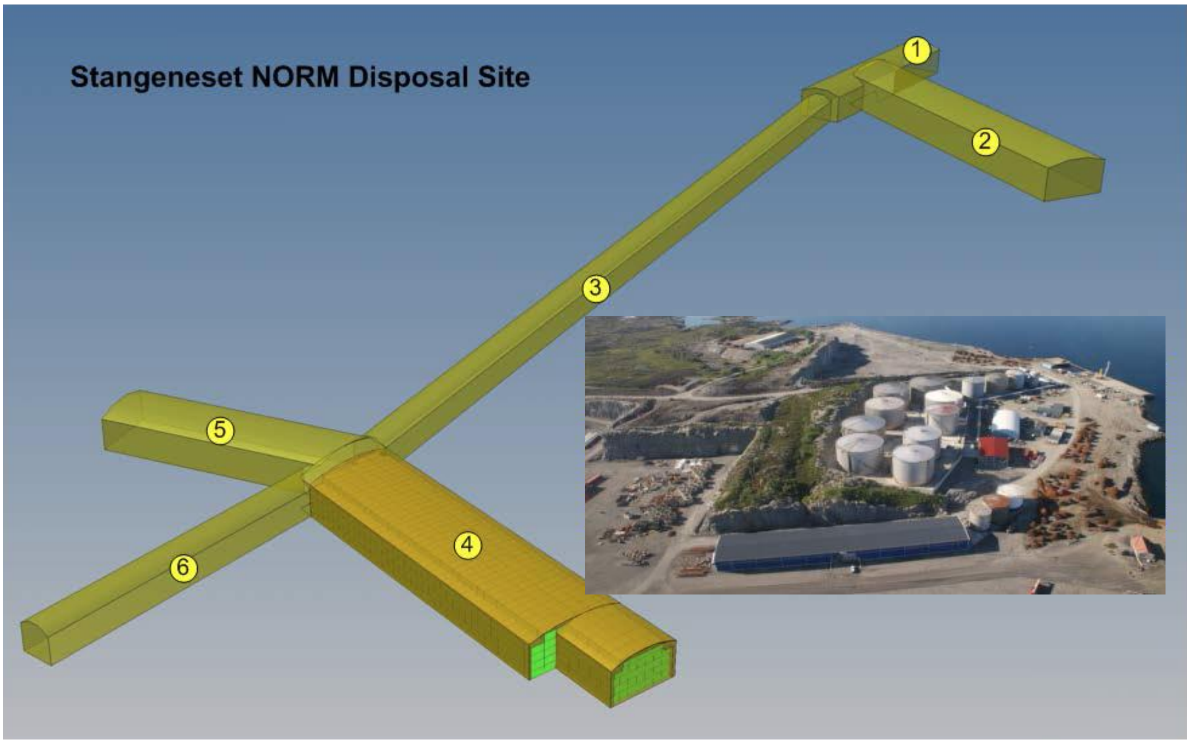


Figure 4. The Stangeneset NORM disposal site and facility design.

Acceptance criteria are as follows:

- Activity concentrations must be less than 300 Bq/g (set by the site to prevent the need for greater radiation protection measures)
- Heavy metals and oils can be disposed with the NORM waste
- Disposal of NORM from outwith Norway is also permitted, but must be legally imported

Different waste types are subject to different conditioning processes. Scales and sludges in drums are subject to water removal and sludges are additionally conditioned using an oil absorber. Following water removal, remaining space in drums is filled with gravel. Water removed from drums is treated prior to discharge. Black dust presents a particular challenge. It is a particularly nasty material that is typically collected in filters and gas refinery tubes. The dust self-ignites in air when dry due to a high component of FeS so must be placed immediately in water once removed from filters and tubes to prevent fire. The dust also contains significant amounts of mercury and other heavy metals in addition to radioactivity in the form of Pb-210. It is likely that black dust will be immobilised by a geopolymer within drums prior to disposal. Since mixed wastes are received by the facility, two permits are in operation, one from the Norwegian Environment Agency and one from the NRPA.

Radon can be an issue inside the disposal tunnels and a month-long survey was undertaken. The ventilation system was turned off during this time (although passive ventilation was still present) and radon monitored. A peak in radon was observed in relation to when drum lids were removed, but dropped again when lids were reinstated. Typical radon activity concentrations of 350 Bq/m^3 were recorded, most of which results from the rock in which the facility is constructed rather than the waste itself. With active ventilation the radon concentration is around 50 Bq/m^3, which is very low for Norway.

Monitoring programmes are in place for the facility. There are two ponds within the facility for the collection of drainage water and water is regularly tested for radioactivity to determine whether any leakage has occurred. The waters collected are released to surface water once monitoring has been conducted. An environmental monitoring programme is also undertaken. Fish, mussels and sea water from close to the facility, terrestrial soil and vegetation are monitored with sampling occurring every second year.

Closure of the facility will involve filling remaining areas of tunnels with stone dust from a nearby quarry. A concrete plate will then be used to seal the facility.

Discussion

The application process for the NORM disposal facility did not require long-term effects assessments to be undertaken although a thorough EIA was required that took into account leaching in the event of all barriers failing. Groundwater velocity in the area is so low however that all radon would have decayed before groundwater reached the repository and no long-term assessment was therefore deemed necessary. Non-radioactive components of the waste were not specifically considered in the assessment. However, the repository was intended for the disposal of mixed wastes and the facility designed in response to this. The facility is privately owned and disposal costs are therefore negotiated with the oil and gas industry.

The black dust conditioning process using a geopolymer is to be tested in a research programme to ensure it presents sufficient stabilisation of the dust and also immobilised mercury to ensure the safety of workers. Black dust will be treated external to the facility to protect against fire risks.

3.3 POST-DISPOSAL ASSESSMENT OF DECOMMISSIONING WASTES

Graham Smith presented on behalf of Ulrik Kautsky (SKB).

The points raised in the presentation were the personal viewpoints of Ulrik Kausky rather than being an organisational view.

The major source of radioactive waste in Sweden is the nuclear power industry. There is already a repository for LLW and an application for a repository for high level waste (HLW) has been made. A repository for long-lived ILW is also planned to address waste generated during decommissioning activities and is likely to include hazardous materials generated during decommissioning works. There is also historic ILW that was originally designed to be dumped in the Baltic Sea, but legislation preventing this practice was brought in. Currently this ILW is therefore stored until a facility is available to allow disposal. The hazardous material content of stored wastes is largely unknown since this was not a requirement prior to storage.

The other part of the ILW is from decommissioning activities.

A single endpoint (dose) is used for evaluating risk from radionuclides with dose being calculated according to the physical energy of the radionuclide and its transfer in the environment. There are a whole range of considerations for hazardous materials however, including eutrophication status, habitat destruction etc. Whilst there is a long list of radionuclides that may be present in wastes, the list of other pollutants is vast; not all substances are yet known and for many substances the health and environmental effects are unknown. The endpoint for chemicals is largely concentrations in the environment.

The risk limit set by the Swedish nuclear regulator (SSM) is lower than natural background and the calculated risk for the planned facility for HLW is three orders of magnitude lower than natural background. The risk level for other pollutants is much greater than for radionuclides with risk evaluated over a much smaller timescale (risk from radioactivity was evaluated over a 1 million year post-closure period). The timescales required for evaluating risks from radiation require that potentially dangerous scenarios must be considered such as the effect of future glaciations on the repository with potential releases being considered in terms of their effect on the biosphere. An ecosystem model has been developed to this end and the behaviour of radionuclides mapped across ecosystems as a means of evaluating risk. Understanding the ecosystem is key to evaluating radionuclide behaviour and, as such, a large scale site characterisation programme was undertaken by SKB to obtain the required knowledge. The radiation assessment approach could be applied to other pollutants and a similar site characterisation programme undertaken, but information on effects for pollutants other than radiation is often lacking. The SKB approach to site characterisation included detailed element analysis of materials sampled in the biosphere and materials have also been stored to allow for future analysis using new techniques or to address new questions. Sites analogous to future conditions at the disposal site such as climate changes have also been studied in detail.

Radionuclides are measurable down to almost the atom level and are therefore measurable at levels well below those that would be associated with a risk of harm. They are not expected to be released from the repository as the facility design is required to prevent release. Conversely, the measurement of other pollutants tends to be difficult and expensive and many pollutants may be unknown in the heterogeneous wastes. Impact can be easier to measure than for radionuclides where cocktails of pollutants give rise to changes in an ecosystem, but it can be difficult to assign blame to a particular chemical. The release of chemicals from a disposal site for non-radioactive waste is largely accepted, which is contrary to the need to retain radioactive materials to allow for radioactive decay. The responsibility for treatment and disposal of wastes also seems to vary considerably. For radioactive waste it is the responsibility of the waste generator with funding commitments required for decommissioning, waste storage, infrastructure, research and disposal being taken from the income generated by the nuclear power industry. For other pollutants however it is largely the public that pay with few funds being earmarked to allow for the treatment, storage and disposal of wastes. Very little research is funded to specifically address issues associated with non-radioactive waste management and disposal.

There are two separate authorities in Sweden for radioactive and other pollutants. The Radiation Safety Authority (SSM) is responsible for radiation safety and permitting. The responsibility for other pollutants falls to the Swedish Environment Protection Agency (EPA). If radionuclides are present then the legislation requires that the matter should be handled by SSM, irrespective of whether the risk of harm associated with the radionuclides is greater than that for other pollutants. SSM is not however familiar with non-radiological impacts and there does not appear to be a fluent communication between the two authorities. Furthermore, it is difficult for the public to understand why there are separate frameworks and authorities to treat apparently similar questions.

Environmental protection legislation in Sweden has historically been good. However, since joining the EU, the dependence on EU legislation has increased and this has resulted in protection standards being reduced. There is a fear that there would be increasing issues if the frameworks for radiation protection and that for hazardous materials were to be mixed at the level of the EU. The two frameworks can be managed separately, but greater communication between authorities is required.

For the LLW repository, other toxic materials are present in the waste, but regulation is focussed on the radioactive component. Higher standards are applied to nuclear waste repositories than for toxic waste repositories and this may not be commensurate the level of risk.

Discussion

With authorities having worked separately and undertaking separate research for decades, combining the different disciplines is seen as difficult. However, it should still be possible to evaluate and regulate consistently. Whilst the level of protection afforded as a result of the stringent protection criteria placed on radioactive waste facilities may also provide protection from the hazards posed by other materials in the wastes, this cannot be confirmed due to a lack of knowledge of effects from other hazardous materials.

3.4 SCOPING STUDY OF POST-CLOSURE IMPLICATIONS OF HAZARDOUS SUBSTANCES PRESENT IN A UK GEOLOGICAL DISPOSAL FACILITY

Helen Kendall from Radioactive Waste Management Ltd presented.

It is UK Government policy that higher activity radioactive waste be disposed of to a geological disposal facility, but no site has been selected as yet. A White Paper, *Implementing Geological Disposal*, was published in July 2014that defined the process for site selection, updating a previous 2008 White Paper. Volunteerism is the basis for site selection and in an initial phase RWM is currently preparing for this process and will consult on a process for national geological screening. A period of engagement with communities is expected to follow this initial stage, lasting about 15 to 20 years and may include some initial site investigations.

In the UK, geological disposal is defined as between 200 and 1,000 m depth with no intention for waste retrieval. Waste should be isolated and contained in a suitable rock formation using multiple barriers, both natural and man-made. With no site having yet been selected, preparatory work is being undertaken for when a site is available in addition to preparing for community consultation. Information is also being provided to waste producers on waste conditioning and packaging requirements to ensure that waste packages can be accepted for disposal once a facility is available.

Work has been done in the past on the assessment of chemotoxics in higher activity wastes. In 2010 a generic disposal system safety case was published, aimed at demonstrating capability in undertaking a safety case and underpinning the engagement process with stakeholders. Within this generic safety case, a biosphere status report was produced which included five chemotoxic substances (beryllium, cadmium, chromium, lead and uranium) that had been identified in a previous study to be the priority toxic substances with regard to human health. The assessment of these substances considered two groundwater pathway scenarios (a well scenario and the natural groundwater pathway) and took account of ingestion and inhalation as the key exposure pathways. A tiered assessment approach was employed with each successive tier including a lower degree of conservatism through the inclusion of geo-mechanical processes that reduce or retard the release of contaminants to the biosphere. In all tiers it was assumed that waste containers had failed. The first case assumed an unlimited release with no sorption in the near-field and was intended to screen out those contaminants of low risk. The second case then considered a solubility limited scenario where cellulose degradation products were considered with regard to effects on element migration. Sorption in the near-field was again excluded. The third tier then considered a solubility limited scenario with sorption in the near-field. A worst case scenario of a fractured host rock was assumed in all cases and limits for concentrations in the environment were derived from the WHO, where available. Exceedances were calculated with respect to chromium, lead and uranium.

More recently, further investigations have been undertaken, particularly for lead which may be used in packaging materials, using drinking water standards as compliance values. Again a conservative assessment approach was employed, resulting in the exceedance of drinking water standards. However, it is thought that continued work to reduce conservatisms will demonstrate that groundwater limits can be met.

In 2010 the Environmental Permitting (England and Wales) Regulations (EPR10) came into force, which transpose the requirements of the European Groundwater Daughter Directive into national legislation. These regulations were not taken into account in the generic disposal system safety case as they were not in force at the time of the safety case development.

The regulations stipulate that the relevant environment agency must, when determining an application for a permit, "*take all necessary measures:*

a) *to **prevent** the input of any <u>hazardous substance</u> to groundwater; and*

b) *to **limit** the input of <u>non-hazardous pollutants</u> to groundwater so as to ensure that such inputs do not cause pollution of groundwater*."

RWM would be required by the Environment Agency within a permit to use "*all necessary technical precautions*" to achieve these objectives.

Hazardous substances are defined as "*any substance or group of substances that are toxic, persistent and liable to bioaccumulate"*. In the UK, the responsibility for identifying hazardous substances falls to the UK environment agencies' Joint Agencies Groundwater Directive Advisory Group (JAGDAG) and the list of hazardous substances is changing continually. Lead is not currently classified as hazardous, but this may be revised in the future.

Non-hazardous pollutants are defined as "*any pollutant that is not a hazardous substance*" where pollutant is defined as "*any substance liable to cause pollution*", which is itself defined as "*the direct or indirect introduction, as a result of human activity, of substances or heat… which may:*

a. be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems,
b. result in material damage to material property, or
c. impair or interfere with amenities or other legitimate uses of the environment".

Lead currently falls within the category of non-hazardous pollutants for which input to groundwater must be limited to avoid causing pollution.

RWM commissioned work to look at the implications of these requirements on planning for a geological disposal facility. The key conclusions of this work are that compliance points at which concentrations in groundwater are evaluated may need to change to reflect the requirements of the Groundwater Directive. The compliance points used in previous assessments could however be easily changed to accommodate these requirements. The need for waste acceptance criteria to be developed for non-radioactive substances has also been noted following a regulatory observation issued by the Environment Agency. A strategy detailing how these regulatory changes will be addressed by RWM is currently being prepared. Within this, it will be necessary to identify which substances (both hazardous and non-hazardous) are present in the UK waste inventory as this information is not currently reported. Further work on the post-closure assessment of hazardous substances is also planned.

In current work being undertaken by RWM, the prevention requirement is being interpreted as no discernible concentration of a hazardous substance in the discharge with a worst case assumption that this relates to a compliance point of the groundwater immediately surrounding the engineered barriers of the facility. With information lacking on the non-radioactive inventory, RWM is working with the national radioactive waste inventory team and LLWR to obtain more detailed information on the substances that may be present and their potential quantities. Until further information is available, minimum reporting values (MRV) of non-radioactive materials are being applied, but these are only available for some of the hazardous substances defined by JAGDAG. Consideration is therefore being given to the development of alternative compliance points such as limits of detection. Materials throughout the facility are being considered, including those associated with engineered barriers and movement of materials through those barriers is also being evaluated. As the assessment is generic, a bounding geological location is being used to evaluate compliance. The amount of each hazardous substance present in the entire facility that would give rise to an exceedance of the MRV at a compliance point immediately outside the outer limit of the engineered facility is being calculated. Work is due to be completed by the end of March 2015. The work will be used to consider requirements for packaging of wastes that could be placed on operators that would help in future disposal.

The next steps would be to develop and agree with the Environment Agency a strategy for addressing the regulatory requirements of EPR10 and to continue discussions to develop an understanding of how the regulations apply to a geological disposal facility. An update to the generic Environmental Safety Case is also planned to take account of information arising from the most recent work on post-closure assessment of hazardous substances using an MRV approach. Discussions are also continuing with the national radioactive waste inventory team and LLWR on hazardous and non-hazardous pollutants present in the wastes.

3.5 AN ECOSYSTEM APPROACH TO INTEGRATING RADIATION PROTECTION WITH ENVIRONMENTAL PROTECTION

François Bréchignac from the International Union of Radioecology (IUR) presented.

Within the IUR, work is progressing on the integration of radiation protection with environmental protection. A first task group promoting brain storming on the issue resulted in the publication of IUR Report-7 '*Towards an ecosystem approach for environmental protection with emphasis on radiological hazards*' (2012). A follow up task group, including specialists from the chemicals risk management field, took place in 2013 to promote cross communication between the different assessment groups and to consider concepts that could be taken forward.

The ICRP framework on reference plants and animals was prompted nearly two decades ago by an IUR task group that challenged the paradigm the human protection ensures environmental protection; there are situations where this is not true and the assumption was not based on scientific findings. The original approach was very anthropocentric, focussing only on human health impacts. People were considered to be outside of the environment with animals and plants only considered in terms of agriculture and its implications for human uptake of radionuclides. The ICRP took the issue forward and developed a specific system meant to achieve demonstration of protection of the environment from radiation. The approach, based on the use of reference organisms, resulted in a move from an anthropocentric to a more biocentric view that addresses wildlife as a means of demonstrating environmental protection. The approach parallels the reference man approach for human radiological protection.

The reference organism approach necessarily includes a number of assumptions and extrapolations. A small set of organismal entities are used as the basis for comparison to evaluate potential effects that assessors can use as the basis for determining environmental risk. This is a large simplification considering the biodiversity of an ecosystem; the ICRP has developed 12 reference animals and plants (RAPs) in total across all ecosystems, which is not sufficient to represent biodiversity adequately.

Although recognised not to be fully appropriate, the chemical approach to environmental toxicity has for a long time also been based on some reference species such as *Daphnia* so there are parallels. Both approaches use effects at an individual organism level. However, unlike human radiation protection, the focus is also recognised not to be individuals, but rather populations or ecosystems that are the object of protection for the environment. This drives for differences in the way in that environmental protection should be evaluated.

The current approach uses modelled or monitored concentration in environmental media and the application of concentration ratio and Kd to estimate uptake into a RAP and exposure of that RAP to radiation from internal and external radiation. The degree of effect at an individual organism level is then considered for a given dose rate. The ICRP has analysed available effects information for the different RAPs for mutation, morbidity, mortality and reproductive success endpoints and, from this information, derived consideration reference levels (DCRLs) have been developed. The DCRLs are illustrated in Figure 5. This approach was taken since literature data is largely based on individual effects, which is the most traditional toxicity approach. However, it is difficult to demonstrate protection at the level of the population using individual effects data. The information could be applied to demonstrate protection of endangered species where the individual would be an appropriate focus, but when looking at the general environment, protection standards could allow for the loss of a proportion of individuals so long as the population is maintained in the long term. Indirect effects arising from inter-species relationships, a widespread mechanism of ecological effects at an ecosystem level, remain out of grasps from an exclusive consideration of individual organisms. There is therefore a mismatch between protection objectives for the environment, where the structure and function of ecosystems is of key importance, and assessment criteria that have been proposed. The IUR therefore proposes that an additional ecosystem approach be used where population or community level endpoints are the focus.

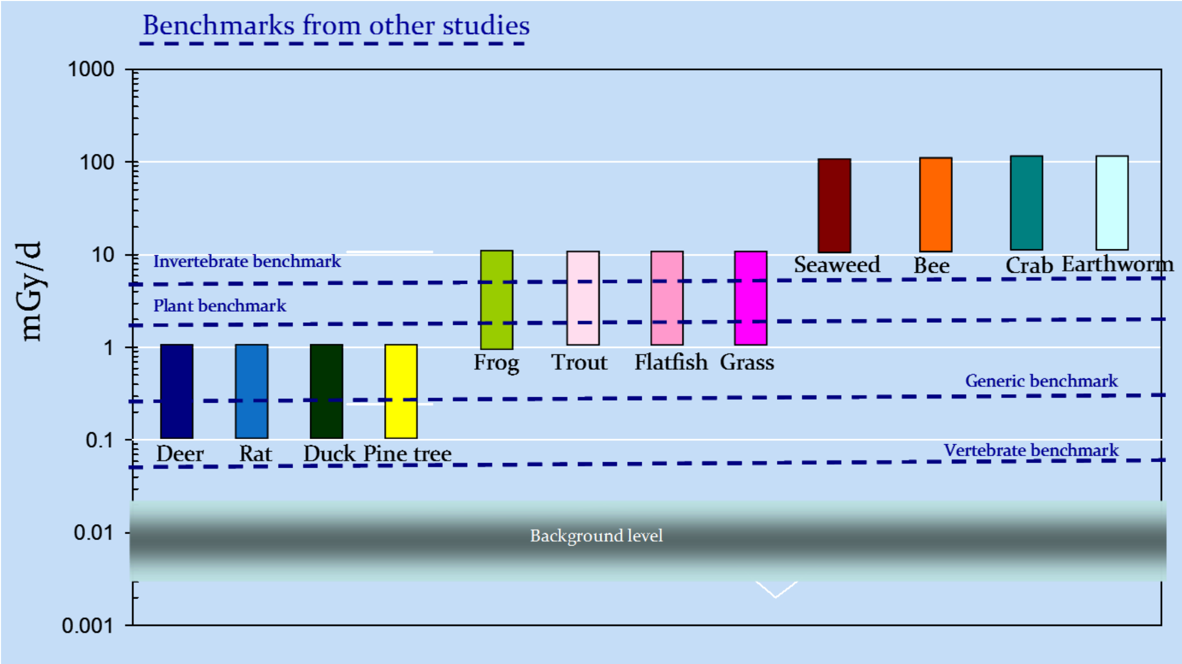


Figure 5. DCRLs for the ICRP reference animals and plants and illustration of their relationship to benchmarks proposed in the European Commission PROTECT project.

The basic conceptual unit in the proposed approach should be the ecosystem, as a structural and functional entity, as all organisms only exist in the context of ecosystems. The survival of all organisms results from interactions between species. For example, plants produce oxygen and remove carbon dioxide from the atmosphere, microbes decompose waste etc. No individual species can survive in isolation (except very primitive ones). This therefore drives for an ecosystem approach to environmental protection, as already adopted by the International Convention on Biological Diversity.

The interactions between populations and the abiotic environment are paramount and there are various properties that need to be considered. As an example, CO_2 enrichment in the atmosphere does not lead to any direct toxic effects, but does indirectly cause an increase in global temperature that is detrimental to the environment. Similarly, CFCs in the atmosphere are inert in terms of life processes, but they affect the ozone layer, leading to greater solar radiation reaching the surface environment that does cause an impact via increased UV irradiation. It is clear therefore that a protection approach exclusively based on individuals is not appropriate for demonstrating environmental protection; individual effects are not readily extrapolated to ecosystem effects and overall impacts may be over or under estimated as a result.

Field studies have provided data on the effects of radiation in an ecosystem setting. Use of high level gamma sources in forests have shown that a direct radiation effect on trees can lead to a cascade of other indirect impacts on other populations. Impacts on trees can lease to changes in the soil microclimate that in turn affects soil microorganisms leading to changes in ecosystem functioning.

The ecosystem approach is intended to be based in science and requires further brainstorming to better define and develop the approach. A conceptual approach is presented in IUR Report 7 that can be taken forward however. The proposed approach is ecocentric whereby the ecosystem is defined as a combination of a biotope and a biocenose such that both biotic and abiotic components are considered with humans included rather than being considered as a separate entity. Producers, consumers and decomposers should all be considered (Figure 6). The producers (photosynthetic species such as plants and algae) produce organic matter from light energy and mineral matter and are the food source for consumers. Consumers embrace all animal life sustained by mitochondrial respiration from ingested carbohydrates, including the *Homo sapiens* species Decomposers then convert dead organic matter back to mineral matter. Within this turn-over of matter and energy, each of these families interacts symbiotically with the others determining ecosystem services and life support. It is these services or interactions that should be protected if ecosystem function is to be preserved.

An ecosystem approach is already recommended for use in some environmental protection domains such as fisheries and within some international agreements and conventions such as the European Water Framework Directive and the International Convention on Biological Diversity. The need for an ecosystem approach is demonstrated in the following example.

UV irradiation of an isolated population of diatoms leads to a reduction in population density. Similarly, irradiation of an isolated chironomids population causes a reduction in the population. However, when irradiated as a duel interacting system, as within a real ecosystem (chironomids feeding upon diatoms), the chironomid population first crashes because chironomids are more sensitive to radiation than diatoms, which in turn causes an overall increase (not a decrease) in the diatom population as a result of the release from the predation pressure it was submitted to being larger than the UV toxic effect. Such very common interactions would not be predicted from the individual effects. The approach therefore takes into account interactions between populations through considering food sources and predators. For example, a fox population will have an indirect effect on grass populations through their predation on rabbits.

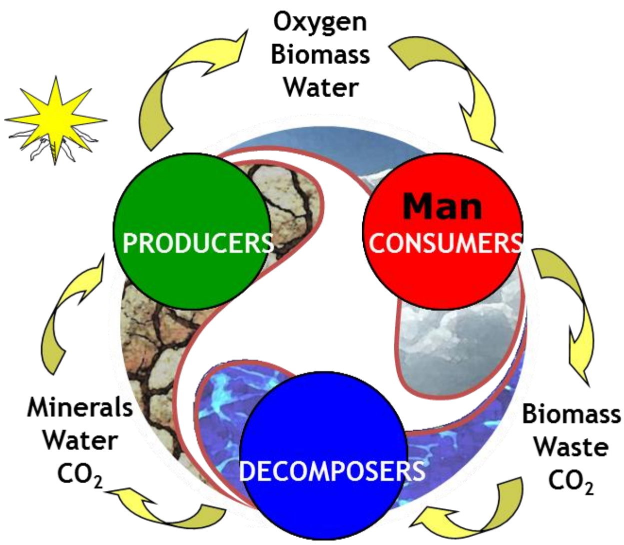


Figure 6. The Ecosystem approach: key components and interactions.

Ecosystems belong to complex systems and can vary in their resilience to change, as induced by a toxicant for example. All ecosystems will have a tipping point at which the equilibrium of the system can shift rapidly, for example, eutrophication of lakes as a result of nutrient input. Resilient ecosystems have some capacity to resist stress whereas poorly resilient ecosystems have a low capacity and can be readily pushed away from one state to another by stressors. Current protection criteria such as the ICRP DCRLs that are based on individual effects do not take account of these differences in ecosystem resilience.

In practical terms, there is a need to define more ecosystem relevant endpoints that relate to ecosystem structure (e.g. trophic structure, biodiversity) and/or ecosystem functioning (e.g. rate of primary productivity or nutrient cycling). The approach is not intended to replace the reference organism approach, but rather to be complimentary, compensating for shortcomings. The approach sets the grounds for the integration of human and environmental protection on a sound and robust conceptual vision.

Discussion

An ecosystem approach has not yet been adopted with regard to chemicals, but it has been considered for some time and significant progress has been achieved. As such, the IUR task group engaged with SETAC which deals with risk assessment for chemicals.

Nature is complex and this complexity must be considered. If excluded from consideration, the ability to protect a system may be limited as important interactions may be missed. A cautious approach to regulation is encouraged to mitigate against potential interaction effects.

3.6 HOW TO ASSESS CONSISTENTLY (AND COMPARE) CHEMOTOXICITY AND RADIOTOXICITY FOR WILDLIFE UNDER CHRONIC EXPOSURE SITUATIONS

Karine Beaugelin-Seiller (IRSN) presented.

Discharges from nuclear facilities can present a double toxicity hazard due to both radiotoxicity and chemical toxicity. The corresponding Ecological Risk Assessment (ERA) is based on the estimation of the probability and magnitude of the adverse effects that are likely to occur in an ecosystem (or some of its sub-organisational levels), together with identification of uncertainties, due to these releases. The approach is generally considered as independent of the individual stressor and so it is largely admitted that it can be applied to both radionuclides and other chemicals.

There are four phases to the ERA approach: problem formulation (release scenario, target ecosystem, object of protection); exposure analysis (pathways, transfers, dosimetry); effect analysis (dose-effect relationships); and risk characterisation. The simplest way to deal with this last phase is to calculate a risk quotient. For radionuclides, a predicted exposure dose rate (PEDR) is calculated and compared against a predicted no effect dose rate (PNEDR) to derive the risk quotient. A similar approach is used for chemicals whereby a predicted exposure concentration (PEC) is compared against a predicted no-effect concentration (PNEC).

An ERA is normally undertaken in an iterative manner. An initial screening approach helps screen out situations that are not of concern. More refined assessment approaches are subsequently applied, ultimately leading to a detailed site-specific assessment where necessary (Figure 7). The four assessment phases are applied in each tier of assessment

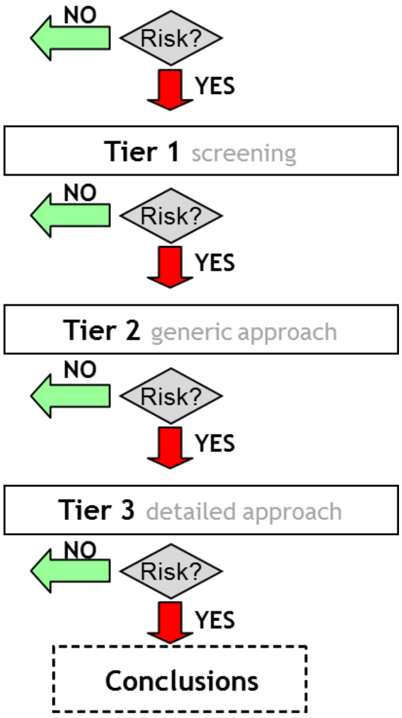


Figure 7. Overview of the tiered ERA approach

Such an approach can be applied to both radionuclides and chemicals, taking into account some differences. For example, for chemicals each substance causing an effect is individually considered whereas for radionuclides, considering their effect as additive, all radioisotopes and their decay products should be considered simultaneously. Exposure considerations also differ with chemicals focussing on internalisation and contact whereas exposure at a distance is also considered for radionuclides, but for both chemicals and radioactivity there is a need for environmental benchmarks to be defined on the basis of environmental concentration/dose-response relationships.

Since the EC ERICA project, a consistent basis for the derivation of benchmarks is available for radionuclides and non-radionuclides. A species sensitivity distribution (SSD) was applied in ERICA to derive a benchmark that is assumed to be safe on the basis of exposure-response information. This is consistent with the approach for chemicals for which an adequate ecotoxicity knowledge is available. The SSD approach is indeed a statistical extrapolation model that is used to address variation between species in their sensitivity to a stressor, requiring a minimal amount of data. The objective is usually to aim to protect 95% of species of a given ecosystem, based on available effects data (Figure 8). Two hypotheses are required in undertaking a SSD analysis of effects data:

- H1: species for which results are known are representative, in terms of sensitivity, of the totality of the species in the ecosystem
- H2: effect endpoints measured on individuals in laboratory tests are indicative of effects on populations in the field

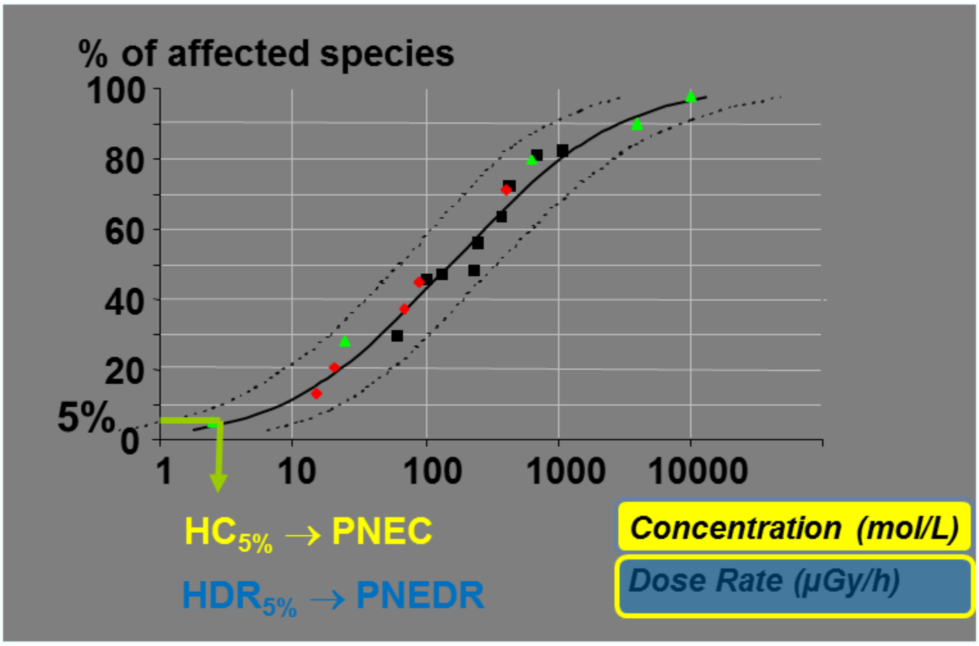


Figure 9. SSD approach to the derivation of environmental benchmarks, protective of 95% of species, for chemicals and radionuclides ($HC_{5\%}$/$HDR_{5\%}$: concentration or dose rate hazardous for 5% of species).

The ability to apply a consistent ERA approach to chemical and radiological risks was evaluated at a former uranium mining site in the centre of France (Limousin area). Uranium poses both chemical and radiological risks with radioactive decay leading to other radionuclides of concern such as Pb-210 and Po-210.

During the problem formulation stage, the protection goal was defined as the ecosystem structure and functioning of a freshwater ecosystem, with the assessment focussing a single watershed and a temporal scale ranging from 1993 to 2006. Since uranium is naturally occurring, the added risk was of interest and, as such, background sites were identified to allow additive impacts to be evaluated. Protection criteria were obtained using the SSD method, giving rise to a PNEC for uranium in freshwater of 3 µg/L and a PNEDR of 10 µGy/h (from the derivation performed within the ERICA programme). For the exposure analysis, annual maximum concentrations in water were initially applied, assuming secular equilibrium in the first tier of assessment. Degassing was excluded to be conservative and biota concentrations were calculated assuming a steady-state equilibrium approach. Calculated risk quotients were greater than 1 for both chemical toxicity and radiotoxicity and the assessment therefore progressed to a second tier, which used a probabilistic approach focussing on dissolved elements. Best estimate dose rates and concentrations for chemicals were calculated, in association with their statistical distribution. No overlap between the selected percentiles of the exposure and effect data distributions was observed in terms of radiotoxicity risk, but there was an overlap in chemical toxicity risk, triggering a third tier of assessment for this last aspect only.

The speciation of uranium in water is complex and influences the metal toxicity. As such, the third tier of assessment used different hypotheses as to which forms of uranium were associated with toxicity and on the concentration of each with the maximum concentration during the exposure period and the geometric mean being evaluated. However, even when refining the assessment to take account of speciation it was not possible to screen out a chemical toxicity risk. The chemotoxicity risk associated with uranium was therefore greater than the radiological risk.

From the study, a list of recommendations for operators and regulators was developed. The first was to develop an exhaustive inventory of stressors (chemical versus radiological) for all substances and to consider the different exposure media and pathways. Further data acquisition was also proposed to better characterise the background situation, to characterise the local ecosystems and the equilibrium state of decay chains. The lack of ecosystem characterisation was identified as a factor leading to generic conservative assumptions being applied in the assessments. Research to better characterise uranium in terms of the relationship between labile uranium and its toxicity was also recommended.

In a second study undertaken by IRSN, and unbiased common evaluation of ecological risks associated with radionuclides and non-radionuclides simultaneously released was attempted. To evaluate risk a unique risk indicator was required. The risk indicator selected (effect factor, EF) was inspired by life cycle assessment approaches. The effect factor is defined as the change of the potentially affected fraction (PAF) of species in an ecosystem due to the change in the exposure concentration for each considered stressor or for a mixture. In other words, the EF gives a level of risk per unit environmental concentration. For substances for which a SSD is available, the hazardous concentration for 50% (HC_{50}) of species (i.e. a PAF of 0.5) can be derived and used to calculate the EF. The index can then be summed to allow effects from mixtures of chemicals and radionuclides to be available.

The EF approach was applied to liquid releases from nuclear power plants that contained a mixture of chemicals and radionuclides. For chemicals, HC_{50} was obtained from an assessment of the mean impact (AMI) database whereas for radionuclides the HDR_{50} was calculated on the basis of effects data within the FREDERICA database and converted to a HC_{50} using a dosimetric and conceptual transfer model. Results indicate that radiotoxicity is of greater concern then chemical toxicity, based solely on the calculated effect factors (Figure 10).

The effect factors were applied to a Rhone River test case. The river receives liquid effluent releases from four nuclear power plants. The annual release from all sites for radionuclides and non-radionuclides was used as a starting point to the assessment and used in combination with the effect factors to calculate total impact of each category of substances. The level of impact from radionuclides in discharges was calculated to be around 6 orders of magnitude lower than for chemicals released from the power plants. This type of analysis also allows the most contributing chemicals to impact to be identified. In this case, C-14 was the key contributor to radiotoxicity whereas copper was the key contributor to chemical toxicity.

The EF approach was considered to be a powerful technique for comparing the relative impact of radionuclides and non-radionuclides and can be used to identify the main affecting components and to rank substances according to environmental risks. The approach could be used to help select management options, both for existing and planned facilities.

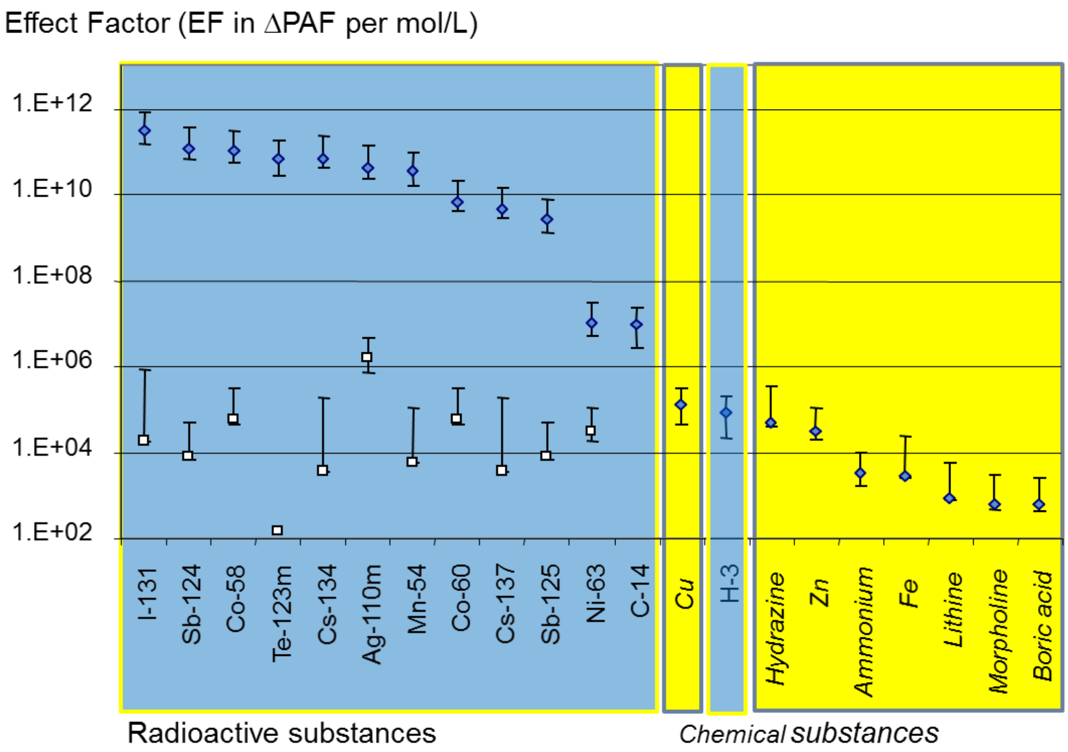


Figure 10. Calculated effect factors for radioactive and chemical substances. Total EF is represented by blue symbols, white symbols indicate the chemical EF for radionuclides.

Both of the studies presented have been published in the following journal articles:

- MATHEWS T, BEAUGELIN-SEILLER K, GARNIER-LAPLACE J, GILBIN R, ADAM C and DELLA-VEDOVA C (2009). A Probabilistic Assessment of the Chemical and Radiological Risks of Chronic Exposure to Uranium in Freshwater Ecosystems. Environ.Sci.Technol.43(17): 6684-6690.

- BEAUGELIN-SEILLER K, GARNIER-LAPLACE J, GILBIN R and ADAM C (2009). A common ecological risk assessment on freshwaters for chemical and radiological ecotoxicity: the uranium case. Radioecology 2008, Bergen (Norvège), 16-21 juin 2008. *Radioprotection*, vol. 44, n◦ 5 913–918. http://www.radioprotection.org/articles/radiopro/pdf/2009/05/radiopro44163.pdf

- GARNIER-LAPLACE J, BEAUGELIN-SEILLER K, GILBIN R, DELLA-VEDOVA C, JOLLIET O and PAYET J (2009). A Screening Level Ecological Risk Assessment and ranking method for liquid radioactive and chemical mixtures released by nuclear facilities under normal operating conditions. Radioecology 2008, Bergen (Norvège), 16-21 juin 2008. *Radioprotection*, vol. 44, n◦ 5 903–908. http://www.radioprotection.org/articles/radiopro/pdf/2009/05/radiopro44161.pdf

3.7 APPROACH TO ASSESSING THE IMPACT OF NON-RADIOLOGICAL CONTAMINANTS AT THE UK'S LOW LEVEL WASTE REPOSITORY

Presented by Andy Baker (Eden Nuclear and Environment) on behalf of Low Level Waste Repository Ltd (LLWR).

The LLWR is the UK's near surface disposal facility for low level waste (LLW) and is comprised of two units. From 1959, LLW was tipped into a series of trenches that have now been covered by an interim cap. Leachate is collected from the trenches, but there is some discharge to groundwater. More recently, waste has been disposed of to a series of vaults. The disposal concept is therefore different from the original approach with waste being disposed of in steel containers with a cementitious grout. The containment means that there is no significant release to the environment, but degradation of containers over time is likely to lead to discharges in the future. The site is located only a few hundred metres from the west Cumbrian coastline.

In 2011, LLWR submitted an Environmental Safety Case to the Environment Agency in support of a licence application for continued disposal at the facility. The ESC was intended to demonstrate optimisation of the facility and that appropriate management practices were in place. Impacts relative to regulatory criteria were also evaluated. The environmental impacts were evaluated both for radionuclides and toxic materials, based on a groundwater release scenario. The ESC is subject to ongoing review by the Environment Agency. Nonetheless, as a result of initial feedback, LLWR has submitted a permit application.

With the repository being located close to the coast, coastal erosion is a key consideration. The coastline is comprised of soft sediment and is subject to erosion that, over time, will affect the site. The question was raised with the Environment Agency as to whether a case could be made for a site where it was known that future erosion would occur. The response was that yes, a case could be made, so long as dose, risk and other relevant criteria would not be breached.

The repository is not a landfill and is not therefore subject to landfill siting and design requirements and regulations even though these may be pertinent. Guidance has been provided however that the level of protection afforded by a near-surface repository against non-nuclear hazards should be no less stringent than would be provided if standards for disposing of hazardous waste were applied. The guidance is not descriptive and is therefore open to interpretation. A further regulatory complexity arises with regard to groundwater regulations and these have proved to be a key issue for the site.

In terms of quantitative criteria, LLWR adopted the following with regard to radionuclides and non-radiological contaminants.

- During the period of authorisation, doses to people from exposure to radionuclides associated with the repository should not exceed 20 µSv/y. After the period of authorisation risks must remain below a guidance level of 10^{-6}/y. Where these conditions are met, the site could be deemed to be in compliance.

- For hazardous non-radiological contaminants, groundwater entry must not be at discernible concentrations and, for non-hazardous pollutants, concentrations should be less than the appropriate standard at the site boundary.

Groundwater releases from the trenches are occurring at the present time. As such, monitoring activities can be undertaken to determine compliance with the above criteria. The site regularly collects water from the trenches for analysis. No localisation of pollution is observed at the site, with leachate concentrations of key contaminants largely being similar to or lower than those in groundwater. It has therefore been inferred that any pollutants in the groundwater at the site at the current time do not result from the site leachate but are rather from sources such as agriculture.

A large uncertainty with the site relates to what has historically been disposed in the trenches. The data obtained from leachate monitoring is therefore useful in determining what may be present. In the vaults however, there is no means of collecting leachate so analysis is not feasible and a modelling approach was therefore required. The approach employed to evaluate risks from non-radionuclides was similar as that used for radioactivity for the purpose of consistency and assessments were performed over a similar timescale and using similar assumptions where practicable, including in relation to chemistry in the near-field and contaminant transfer in groundwater. The key difference between the assessments for radioactivity and non-radioactive substances was in the way impacts to people and the environment were assessed. The alternative approach would have been to follow a landfill assessment approach, but there were issues in the application in that the available assessment software is quite restrictive in not considering the range of release pathways required for the LLWR and the approach would not support calculation of disposal limits for different chemicals.

The model used in the assessment was GoldSim. A simple source term was defined, based on solubility limitation and sorption. Release of metals would not be instantaneous as corrosion processes are slow, hence it was ensured that the release of copper, lead and iron was governed by an understanding of corrosion rates relative to the conditions in the facility. The GoldSim model was used to evaluate concentrations of substances on initial entry to groundwater and in groundwater downstream of the repository. Modelled concentrations were then compared against available drinking water and environmental quality standards. Saturation of the facility over time was considered, assuming gradual degradation of the facility cap over time such that water ingress increased throughout the assessment.

The quality of an assessment is governed by the quality of the information on the waste inventory. For some materials, such as steel and lead, there are good estimates. However, for trace metals the inventory is more uncertain. Work is therefore ongoing by the LLWR with other UK organisations to try to improve the inventory. This includes working with waste consigners to obtain a better understanding of the wastes received to provide a better basis for future assessments.

The impacts from some non-radioactive materials were identified as being more significant issues than those arising from radionuclide. Based on the results of the assessment a list of substances to be controlled has been generated and limits derived based on the capacity of the repository. These limits are being used to derive waste acceptance criteria for future disposals.

The LLWR safety case tried to build a range of safety arguments with underpinning information. The design of the facility is believed to be more effective than a typical landfill for containing wastes and the ESC demonstrated that impacts are acceptable relative to regulatory guidance. Future work is nonetheless planned. The chemistry of lead in the assessment model is being reviewed to ensure this is appropriate as lead was identified as an element of issue. A comprehensive review of trace metals that are present in typical LLW is also going to be undertaken and used as a basis for identifying sensible strategies for control where practicable. The monitoring programme will also continue to be reviewed and updated to ensure that contaminants of interest are included.

Key difficulties that have been identified in terms of future permitting of the site relate to the categorisation of certain pollutants. For example, lead is currently classed as non-hazardous, but this may change in the future to hazardous, which would potentially cause issues for the site in terms of groundwater regulations. A further difficulty relates to demonstrating the prevention of persistent materials such as heavy metals from entering groundwater over long timeframes as barriers degrade. It is not possible to state indefinitely that prevention will be achieved. International perspectives on the 'prevent' requirement of the Groundwater Daughter Directive are therefore of great interest to LLWR.

3.8 REMEDIATION OF TENORM RESIDUES: AN INTERDISCIPLINARY STUDY ON A CASE IN HANOVER

Graham Smith presented on behalf of Claudia Koenig (University of Hanover).

It has been recognised that TENORM (technically enhanced naturally occurring radioactive material) is an issue in Hanover and that there is a need for remediation activities. This is in part motivated by an observed gap between the expert assessment and public perception of risk to radiation.

In Germany, NORM and TENORM are regulated under the Radiation and Protection Ordinance, which covers fossil fuel production (the oil and gas industry), processing or ores and the processing of phosphate. A survey of NORM industries in Germany has been undertaken to identify current and future sources of TENORM, in accordance with European legislation.

An urban area of Hanover, the capital of the federal state Lower Saxony have been contaminated with TENORM. The polluted area lies in the centre of the city in a popular residential area. Contamination resulted from past use of the area by a chemical plant that, in the second half of the 19th century, processed uranium and thorium amongst other materials. A survey in 2008 identified elevated levels of ambient gamma dose rates in the now residential area as well as in a community allotment area that had previously been used as a disposal site. Residues of uranium and thorium and their decay products have also been found in local soils. Ambient gamma dose rates in the area were around 1 µSv/h, compared against a regional background of 0.08 µSv/h. Uranium residues in one area however resulted in considerable emanation of Rn-222 that permeated into two properties. Whilst uranium and thorium (and their decay products) were elevated, the main health risks in the area resulted from chemical pollutants such as arsenic, mercury, lead and cyanide that were also measured in the local environment.

Concentrations of arsenic, antimony and lead in soils exceeded soil protection criteria for residential areas and the need for remediation was therefore identified and a remediation plan was drawn up by the authorities. The total cost of the remediation was around 2.3 million Euros.

Following remediation, a number of interviews were held with local residents (11 individuals) and experts (11 individuals, five from the remediation case and six from a uranium mining remediation programme elsewhere). Two journalists and at least two local people from the contaminated allotment area were also interviewed. The interview responses have been analysed.

Communication problems with regard to risk communication and risk management were identified. The issue largely stemmed from the challenge of communicating highly complex topics to non-scientists and the mismatch in understanding residents' values. A regulatory gap between radiation protection and soil protection with regard to TENORM legacies in Germany was also identified: Since the German Radiation Protection Ordinance excludes contamination resulting from old, non-nuclear practices, the remediation of the radioactive and chemical contamination had to be carried out according to Germany's Soil Protection Ordinance.

According to the Soil Protection Ordinance, the health risk assessment is a multistage process. The first stage involves measuring the level of different contaminants. Where these exceed regulatory guideline values, the mobility and bioavailability is investigated as a second stage. If regulatory guideline values for detailed investigations are exceeded, remediation activities are recommended. However, guidance values for radioactive contaminants are not presented in the Soil Protection Ordinance and therefore had to be derived for the purposes of the assessment. Both residents and experts pointed to the difficulties associated with communicating the factual information relating to radiation with experts noting the challenge associated with modifying radiologically related information for those without a technical background.

Residents identified a number of areas that they considered threatened their physical or intangible values. In particular, health risks to children were highlighted, even by those individuals without children. Injustice due to material aspects such as risk to property value was also identified along with the need to pay to the remediation of damage caused by a third party from a hundred years prior. The lack of information provided about the site at the point at which properties were purchased was also an area where injustice was felt.

The NEA-OECD has previously noted the existence of multiple values and perceptions around individual risk and need for these to be respected and addressed in risk communication. Where people's concerns are not addressed, risk communication will be less effective. The use of a mediator in the Hanover case was seen as a positive measure both by experts and residents, providing a point of contact for residents with questions and communicating in a way that did not dismiss the views and feelings of residents. The mediator was also able to communicate the real issues of concerns to the specialists.

Overall, a key issue in addressing the situation arose from the lack of legal standards for radionuclides, consistent with other soil contaminants.

3.9 WHY INTERIM STORAGE FACILITIES IN JAPAN ARE STILL SUSPENDED: A REVIEW

Graham Smith presented on behalf of Keiko Tagami (NIRS).

Following the Fukushima incident, a large volume of material has been contaminated and remediation activities are giving rise to materials that require treatment and/or storage. The management strategies for different wastes are shown in Figure 11.

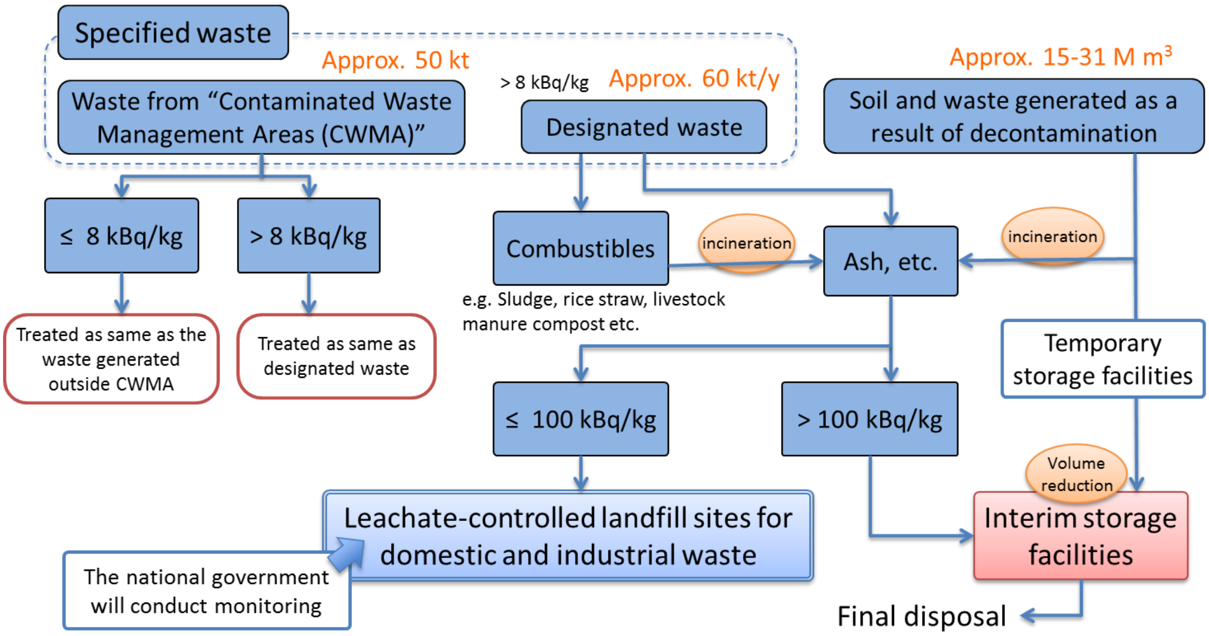


Figure 11. Waste management strategy for the wastes arising in the Fukushima Prefecture.

By November 2014, areas for interim storage facilities were due to have been selected and facility design finalised. The process has been delayed however. The delay has arisen for a number of reasons. The Japanese government proposed to inspect potential storage sites, before residents had agreed and the areas selected coincided with good agricultural land areas for rice growing. Residents had concerns therefore that their lands would be taken and contaminated forever. Concerns grew as a result of scientists warning of the potential for radiocaesium to leak from the facilities whilst others were stating that the facilities were well designed.

However, in the four years since the accident, residents have gained a lot more knowledge on radiation effects and related regulation and are now beginning to understand the need to interim storage areas. With this understanding, residents have agreed for projects to proceed.

In moving forward, consideration is being given to the effects of disturbance on storage facilities to avoid any additional contamination in the future that might result from human errors or unexpected weather conditions. Such events are inevitable and countermeasures are therefore being considered.

A greater issue is faced with regard to the final disposal of waste in the prefectures outside of Fukushima. Designated wastes have to date been stored temporarily in individual incineration facilities and these must be disposed of. It is intended that one disposal facility will be constructed in each prefecture on national land. However, the Japanese government did not consult with regard to site selection and candidate sites were just announced to the public, resulting in ferocious opposition from residents. As a result, stakeholder consultation has begun, but residents in selected areas are still not happy with the site selection and construction has not yet commenced.

The management of wastes outwith the Fukushima prefecture differs with wastes with contamination levels greater than 100 kBq/kg being sent to isolated-type landfill sites for hazardous industrial waste for disposal. However, within the Fukushima prefecture, wastes with this level of contamination are sent for interim storage.

From the experience gained following the Fukushima accident, the importance of transparency in the decision making process and good communication is evident. The use of reliable scientific knowledge is also paramount to avoid confusion and distrust. It is also imperative that consideration and understanding for the local communities potentially affected by planned activities is given.

3.10 MULTIPLE STRESSORS – SCIENTIFIC CHALLENGES

Presented by Brit Salbu (CERAD-NMBU).

CERAD is the Centre for Environmental Radioactivity in Norway that has a vision to provide new scientific knowledge and tools for better protection of people and the environment from the harmful effects of radiation. The aim is to reduce the overall uncertainties in impact and risk assessments associated with radiation (including UV), individually and in combination with other stressors, focussing on sources, transfer, effects and risks. CERAD has been funded by the Norwegian Research Council for a period of 10 years, from 2013-2022.

The scientific concept behind CERAD is the development of an ecosystem based scientific approach to the protection of people and the environment, which requires a programme of targeted and focussed long term research. As such, CERAD collaborates internationally with relevant organisations and consortia and works to provide education in the field of radioecology, providing the only MSc in radioecology in Europe and providing a PhD research school.

Eight umbrella focus areas have been identified:

- UMB1: Particle sources and effects
- UMB2: Dynamic transfer (i.e. the development of ERICA to allow for dynamic assessments)
- UMB3: Radiosensitivity (why do species react differently to exposure)
- UMB4: Combined Toxicity and Cumulative Risk
    - Further development of prediction models for combined toxicity and cumulative risk assessment of multiple stressors and implementation in experimental design.
    - Laboratory experiments to obtain information on interactions between relevant stressors affecting uptake and responses in selected test organisms.
    - Utilise experimental data in cumulative hazard and risk assessment to improve prospective and national and international regulatory practice.
- UMB5: Trans-generational effects- reproduction and epigenetics
- UMB6: Ecosystem approach (a joint working group with the IUR)
- UMB7: UV-/ionising radiation and dosimetry

- UMB8: Case: Potential nuclear accidents and deposition in Norway
    - Sources in UK
    - Russian sunken submarines

It is not appropriate to look solely at stressors, consideration needs to be given also to terms of defence to those stressors and what this means for effects. Multiple stressors can be a particular issue. For example, mercury, PCB's and HCH (Hexachlorocyclohexane) have all been measured in polar bears and can cause effects, but it is difficult to determine what is the cause of any observed impact and whether there are interactions from the different substances.

We have always been exposed to naturally occurring metals, organics and radionuclides in the environment, but over the last 50 years there has been vast growth in industries producing metals and synthetic organic compounds. The nuclear industry has also grown during this time. It is also recognised that there can be diffuse sources of contaminants arising from pesticide and nutrient use in agriculture and from the remobilisation of contaminated soils and sediments. It is also recognised that the environment has a limited capacity for receiving anthropogenic material before effects are observed and that speciation of chemicals in the environment is also key to understanding interactions, transfer, uptake and effects rather than total concentrations. Furthermore, chemicals are seldom found in isolation in the environment (Table 1) and interactions in terms of uptake and effects are known to occur.

Table 1. Percent occurrence of the top five contaminant groups occurring in association with radioactive contamination

Contaminant Group	**Metals**	**VOC**	**Inorganic**	**PAH**	**Pesticides**
Percent occurrence with radioactive contamination	**99%**	**77%**	**73%**	**67%**	**54%**

The predictive power of assessment models is limited by uncertainties relating to the source term, ecosystem transport, uptake and effects. There can be considerable uncertainties in an assessment as a result of conservative assumptions at different stages of assessment and an assessor needs to consider the degree of uncertainty and what this means with regard to interpreting the output of the assessment. To reduce overall uncertainties, knowledge is required in relation to the speciation of materials, how materials interact and are affected by different processes (including the kinetics of interactions and processes). Uncertainties can also be reduced with improved site understanding through characterisation activities.

Stressors such as heavy metals, radiation and organic materials can all induce free radicals in organisms with individual stressors having the potential to affect multiple targets and potentially multiple stressors affecting the same target. Cells exposed to such stressors can respond in different ways. Cells may die, be repaired or be wrongly repaired, which could result in mutations etc. Where multiple stressors are present, it is difficult to predict how these will interact in terms of biological effects.

Stressors may interact to give additive (level of effect can be summed), synergistic (the effect is greater than additive) or antagonistic (the overall effect is less than additive) effects.

A series of experiments are being undertaken on salmon to look at the interactive effects of exposure to metals (uranium and cadmium) and gamma irradiation using a range of different endpoints. Uranium can form colloids in a pH range of 6-7 and this can reduce uptake of cadmium via gills. In undertaking multi-stressor assessments it is therefore important to consider which interactions are to be compared as these can be highly varied and result in potentiation or repressive effects.

It is also important to consider the basis by which assessment criteria have been derived. For example, environmental quality standards are routinely used in risk assessments as benchmark concentrations which, if exceeded, may result in harm to the environment. These benchmark concentrations are therefore used by regulators in authorising industrial discharges. The standards have however been based on single stressor assessments with a number of extrapolations being applied to derive values. This can include extrapolating from one organism to the range of organisms that may be present in an environment, from acute to chronic effects, from laboratory to field conditions of from isolated single species test systems to complex systems. To address these key uncertainties, scientific judgement has been applied to derive a set of standard safety factors to apply to effects data, depending upon the quality of that data. For example, safety factors of 100, 10 and 1 may be applied depending upon data quality and extrapolations required.

There is interest in developing a consistent mechanism by which risks can be evaluated in terms of risk quotients that would allow the summation of risks from both radionuclides and chemicals. Information on measured or estimated concentrations for a range of chemicals and radionuclides associated with the decommissioning of oil platforms and other installations in Norway has been used to evaluate risk quotients for the different stressors. Predicted environmental concentrations were calculated and compared against available environmental quality standards, where available, to allow relative risks of the different stressors to be evaluated. Results indicated that chemicals rather than radionuclides were largely associated with the greatest risk, with iron having by far the greatest risk quotient (Figure 12).

This approach is seen as a useful way for risks to be placed in perspective. However, risk factors may vary among species and data may not be available for all stressors and species.

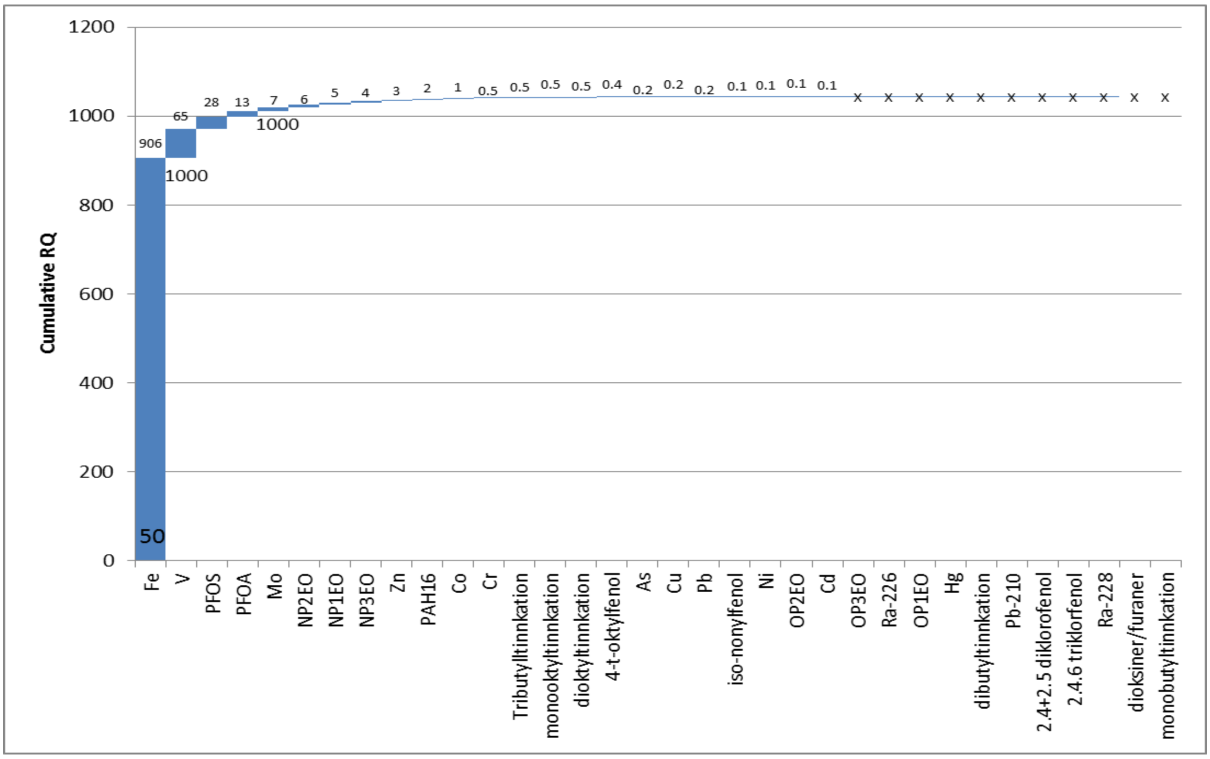


Figure 12. Cumulative risk quotients for multiple stressors associated with the decommissioning of oil platforms in Norway.

CERAD is currently working on implementing models that will allow interactions between different stressors to be evaluated such as the blockage of cadmium uptake across salmon gills by uranium. Consideration is also being given as to how approaches to risk assessments can be harmonised. There remain a lot of challenges however. For example, many aspects of stressor effects are unknown, such as the responses of organisms exposed at different life stages and the effect of ecosystem conditions on the transfer of pollutants and how the presence of some stressors influence the behaviour and uptake of others. There are also issues around the use of published effects data since experimental design and methods for evaluating exposures and effects can vary drastically such that collation and comparison of results can be difficult. A prognosis is only relevant within the bounds of the uncertainties and experimental approaches must therefore be transparent and well recorded. Experiments should also be designed in discussion with modellers to ensure the output is of relevance to the improvement of assessments by providing much needed data and knowledge.

Discussion

Analysis procedures are required to allow parameters or factors contributing most to the outcome of an assessment that may inform on the design of a facility or the planning process to be identified. Such procedures also allow those parameters and factors that do not affect results to a great extent to be identified and potentially excluded with justification. The approach therefore helps with prioritisation of resources to address key issues. Approaches to assessment should therefore begin complex and be simplified as parameters and processes are justifiably excluded from assessments.

3.11 COMPARISON OF RISK ASSESSMENT FRAMEWORKS FOR RADIOACTIVITY AND CHEMICALS

Deborah Oughton (CERAD) presented.

Radiation is complex in that it both causes cancer and is used in the treatment of cancer. The system for radiological protection has been developed separately from chemical risk assessment and management with the ICRP being the main driving force behind the current assessment approach for radiation. The ICRP is an independent organisation that has been in existence since 1927. With radiation being used in medicine, the protection framework initially focussed on deterministic risks arising from high exposures. Over the years however, the framework for protection has evolved to take account of the increasing areas where ionising radiation has been used and to take account of scientific developments, experience and ethical values. This has included recognitio0.n of health effects from radiation exposure such as leukaemia following exposure to radium paints and the exposure of populations as a result of weapons test fall out. Societal attitudes have also changed over time.

There is a three stage philosophy for radiological protection, set out in ICRP 103:

- The Principle of Justification: Any decision that alters the radiation exposure situation should do more good than harm.
- The Principle of Optimisation of Protection: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable (ALARA), taking into account economic and societal factors.
- The Principle of Application of Dose Limits: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission.

Different criteria are in place depending upon whether the receptor is a worker (20 mSv per year over a 5 year period), a member of the public (1 mSv per year over a 5 year period from all nuclear practice sources) or a pregnant worker (1 mSv to the foetus). These criteria have been developed from a vast amount of data derived from epidemiological studies. The fundamental unit is a risk of detriment of 0.057 per Sv.

There are challenges in communicating risk and people's perception of risk, particularly for radiation. For example, following the Fukushima accident the focus has primarily been on the nuclear incident, rather than the earthquake and resultant tsunami that killed tens of thousands and left nearly half a million people homeless. In addressing communication issues, risks can be placed in context using information on natural and medical exposures (e.g. Figure 13), but this does not necessarily help. There may however be opportunities to learn from the experience of the chemicals industry in addressing and communicating risks.

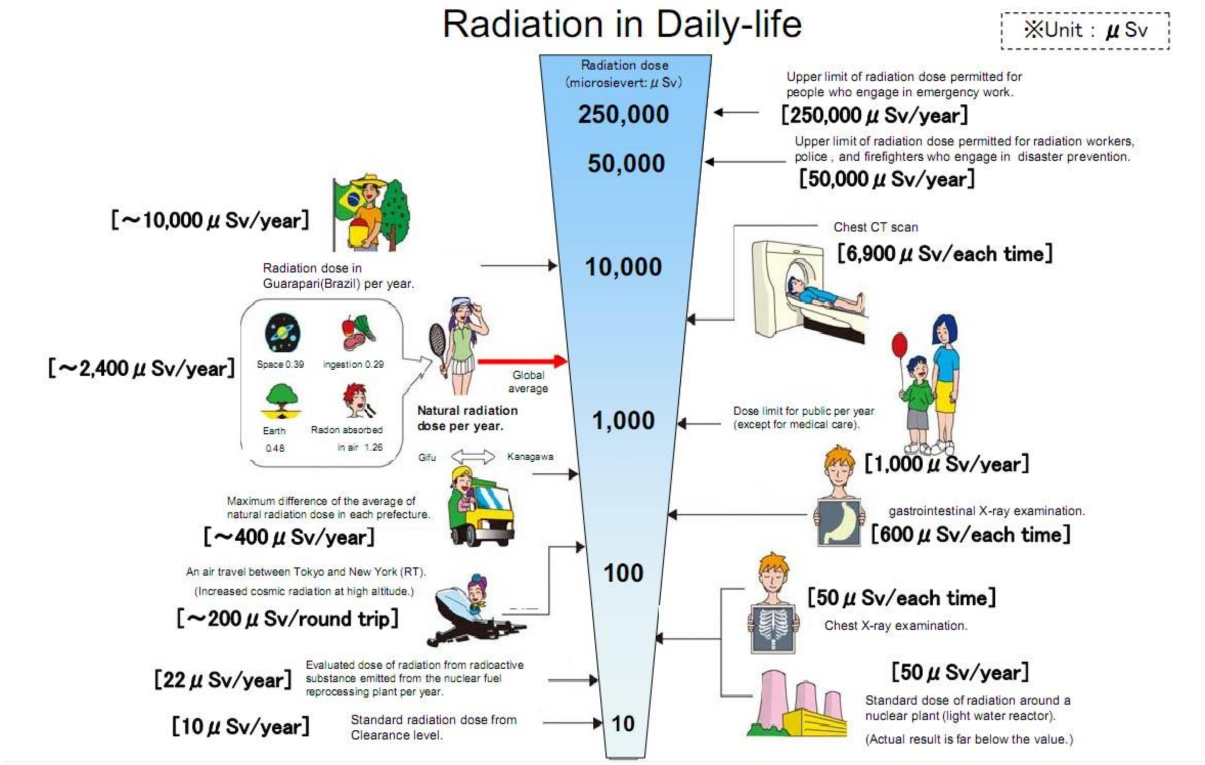


Figure 13. An example of radiation risks in the context of natural and medical exposures.

Risks from low dose levels are a particular issue with regard to communication. There are large uncertainties around effects at low dose levels and this can be interpreted as 'anything could happen'. Following the Fukushima accident, UNSCEAR tried to communicate risks from low doses in in terms of cancer incidents not being discernible, but this did not help and there are some indications that people may be becoming more adverse to medical radiation exposures. The way in which information communicated may be interpreted therefore needs to be considered to ensure that low risks are not seen as alarming.

The protection concept has changed over recent years, moving away from a human centred approach whereby it was considered that if people were protected then the environment would also be afforded protection. There has been an emerging consensus however that radiation protection needs to address the effects of ionising radiation on non-human species and for environmental protection to be demonstrated in its own right. Two principal assessment approaches have been developed as a result of this change: the ICRP reference animals and plants approach, and the EC ERICA assessment tool. This latter assessment approach is considered a good example of trying to take the chemicals environmental risk assessment (ERA) approach and apply to radiation. The basis of the chemicals ERA framework was investigated and the same framework applied in ERICA, including the calculation of risk quotients that have the potential to allow the summation of risks from different hazards. An overview of the ERA framework is provided in Figure 14.

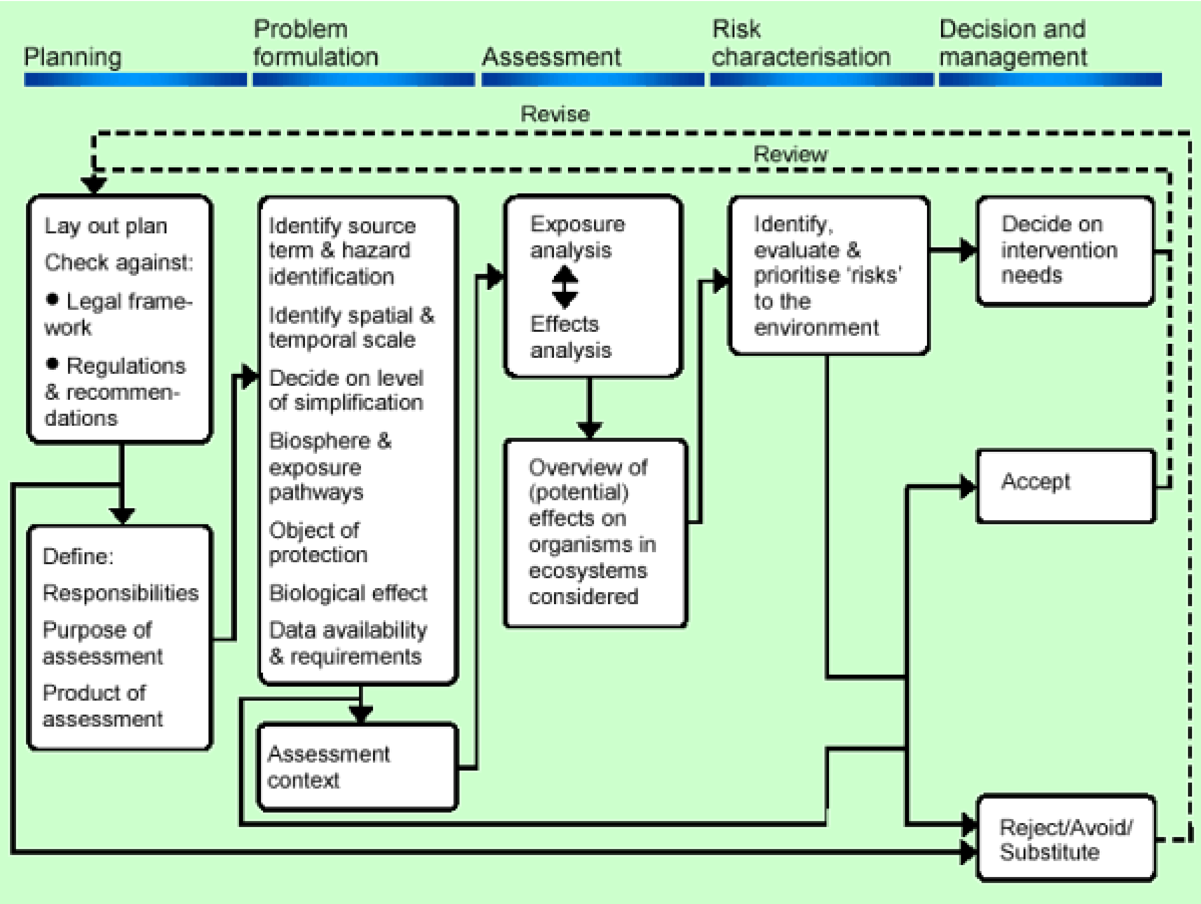


Figure 14. The ERA framework

The chemicals SSD approach was applied in ERICA to provide a means by which risk could be evaluated through the generation of a generic screening value. Whilst this approach is derived from the chemicals assessment approach, it is not routinely applied due to a lack of effects data for individual chemicals. The alternative approach is to use safety factors in combination with effects data. A no observable effects concentration (NOEC) or lowest observable effects concentration (LOEC) is derived from the effects data and a safety factor between 10 and 1000 applied to account for uncertainties in the data and its extrapolation from one species to another or from laboratory to field conditions etc. Safety factors are also applied in the SSD approach, but are lower, ranging from 1 to 5.

The Fukushima accident has provided an opportunity to explore the integration of human and environmental risk assessment. There have been substantial costs as a result of marine contamination by radioactivity following the accident. This includes loss of sales in seafood and reduced market value even when the seafood is not contaminated. The loss of livelihood for fishermen has had both social and demographic consequences. There have however been significant ecological benefits as a result of fishing bans.

The divergence between the approach to assessment of radiation risks and chemicals is partly due, therefore, to a historical separation, but the introduction of environmental risk assessments for radiation is providing an opportunity for greater interaction between the chemical and radiological disciplines. This may lead to improved comparison of radiation and other environmental hazards, which may help in the communication of risks from radiation to the public.

3.12 INFORMATION FROM OTHER INTERESTED AND RELEVANT ORGANISATIONS

Graham Smith presented on behalf of BIOPROTA sponsors unable to attend the workshop.

ENSI has since 2008 been looking at comparing waste management practices for radioactive and hazardous wastes. The objective of the programme is to undertaken a systematic and comparative analysis of the practices of both waste categories and to evaluate whether the principles and regulations of the Swiss Environmental Act are properly accounted for in the legislation for the management of radioactive waste. The programme involves members from all relevant ministries in Switzerland. The regulatory domains have been found to be largely consistent, but there have been notable inconsistencies in relation to permissible content of organic matter and underground disposal of metals. A report for the project is due to be published in April.

A presentation was made at the previous workshop in Ljubljana by Neale Hunt from NWMO (Canada). This demonstrated the NWMO assessment of the non-radiological hazard associated with a deep geologic repository in crystalline rock. NWMO is presenting an update of this assessment at the International High Level Radioactive Waste Management Conference taking place in Charleston, USA from 12 – 16 April 2015. NWMO maintain interest in the development of acceptance criteria for hazardous substances in radioactive waste repositories.

Work is ongoing on behalf of EPRI by Vanderbilt University in the USA on how to undertake a comprehensive radiological and chemical risk assessment for the nuclear fuel cycle, the objective being to overcome limitations in assessment approaches and provide a comprehensive baseline risk assessment for the US fuel cycle. Again, progress is due to be presented at the Charleston Conference.

Finally, it was noted that a deep geological disposal facility has been planned in Sweden for the disposal of mercury. The impact assessment for the facility is required to consider at least 1,000 years, which is inconsistent with requirements for radioactive waste disposal.

4. OVERVIEW OF THE NOAH FACILITY SITE VISIT

Marit Lægreid provided a presentation on the NOAH facility for the safe treatment and disposal of hazardous waste in Norway, prior to a tour of the disposal site.

The NOAH disposal site is located on Langøya Island, which is around 3.5 km long and 500 m wide. The Island has a history of industrial use, having previously been used for limestone quarrying and associated activities. Approximately 70% of the Island is associated with industrial activities with the remainder being a nature reserve due to its unique flora and fauna.

NOAH has two parallel tasks on the Island. One is to provide the relevant expertise and technology to treat hazardous waste and render it harmless. The other is to produce a basis for restoring the island to its original shape and returning to the community as a recreational area. Use is therefore being made of waste and contaminated soil for the benefit of society.

NOAH has a permit to dispose of 500,000 tonnes of inorganic hazardous waste and 500,000 tonnes of non-hazardous waste per year, including NORM waste from the oil and gas industry. In 2014, NORM waste accounted for around 1.4% to the total waste received to the island, of which 90% was Alum shale.

The core business for NOAH is the neutralisation of acid with alkali. Around 200,000 m3 of sulphuric acid containing waste is received at the facility per year and this is neutralised with fly ash from the combustion of household and industrial waste not only from Norway, but from Sweden, Denmark and other European countries. The calcium in the fly ash reacts with sulphate from the sulphuric acid to create a gypsum waste. This gypsum waste is used to fill the craters on the island created by past quarrying activities. Other waste fractions are incorporated and stabilised within this gypsum mix.

The majority of waste arrives to the island by boat and wastes are subject to regular random sampling and analysis. All waste water is collected in a water reservoir and analysed daily and subject to purification prior to discharge. External analysis is also performed twice weekly. A yearly monitoring programme is also performed by external organisations on the disposal site itself and the surrounding environs.

The treatment and disposal method for NORM wastes depends more on the characteristics of the waste than on its radioactivity content. Alum shale poses risks from weathering giving rise to acidic runoff containing heavy metals. The chemical conditions in the gypsum is ideal in mitigating against these risks, providing a high pH and low redox potential. The gypsum matrix contains surplus alkali which provides buffering capacity. Metals are stabilised and are therefore subject to low leaching potential. Reactive materials are also stabilised.

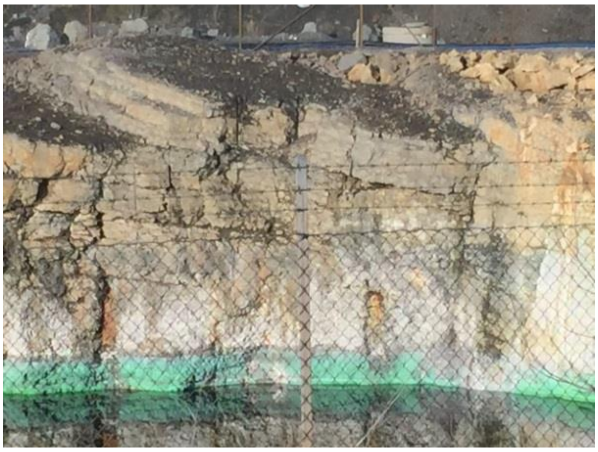
The craters that are filled with the gypsum are watertight due to physical barriers. There is a negative water gradient, preventing leakage below sea level and a drainage system is in place along the crater edge at sea level to avoid pressure build up.

The rehabilitation of the Island has already begun and the first area will be finished and covered by 2016. The main rehabilitation measures will take place from 2020 to 2026 once disposal operations have ceased. The Island will be required to be returned to a natural state with vegetation and ecology restored as far as it is practical and environmentally sound.

A range of site images is presented below, taken during the visit with the kind permission on the site operators.





5. DISCUSSION AND RECOMMENDATIONS

In this section, the key emerging issues arising from the presentations and discussions during the workshop are identified and conclusions presented. Ideas for what might be done practically to address the identified issues are also outlined.

5.1 KEY EMERGING ISSUES

It is clear from presentations that there has been a separate development of the science, management strategies and regulations for radioactive and hazardous materials. The idea that the non-radiological hazards associated with radioactive wastes need be considered is not a new concept, but the converse is relatively new (for example, radioactively contaminated asbestos).

Hazardous waste disposal appears to focus on controlled release of leachate from managed landfill to ensure that benchmarks are not exceeded. Hazardous waste landfills tend to have a membrane installed to prevent the release of hazardous material to groundwater and a cap designed to limit infiltration, but leachate occurs and is required to be managed. In the case of radioactive wastes, the focus tends to be on containment of wastes to allow for radioactive decay. The IAEA do however acknowledge that there may be some release from radioactive waste disposal facilities[e], but the intention should be to try to contain the wastes until radioactive decay has reduced the hazards to an acceptable level.

Assessments for radioactive waste disposal facilities typically extend into the future for at least 1,000 years. For hazardous wastes, assessments are usually for timeframes much less than 1,000 years. The timeframe associated with management of waste natural occurring radioactive materials (NORM) is more variable. Waste from the oil and gas industry is normally of small volume and may therefore be subject to containment in a disposal facility. However, other NORM wastes can be of very large volume and containment is unlikely. NORM is not classified as radioactive waste in all countries.

The period of active or passive institutional control at sites varies considerably. The period of institutional control for radioactive waste disposal sites is commonly around 300 years. For hazardous waste sites however, the period of institutional control will vary according to the hazards. For example, in the UK and Norway there is no institutional control concept, but the release of a site from a permit would only occur if it can be demonstrated that the site does not pose a risk to people or the environment and that leachate control measures are no longer required. The period of authorisation and active control have been aligned in the UK for radioactive waste facilities such that both are terminated at the same time. In some countries, a long-term stewardship approach is taken to NORM, which effectively imposes an indefinite management burden upon future generations. This is a very different policy compared with that taken for radioactive and hazardous wastes.

Methods are available that allow the release of chemicals from radioactive waste facilities to be assessed, but risk criteria are not always available and those that are available may not necessarily be consistent with the risk criteria for radionuclides. Comparison of risks can therefore be difficult.

[e] See the definition of containment in the IAEA Safety Glossary. Terminology Used in Nuclear Safety and Radiation Protection. 2007 Edition

Optimisation may also therefore be difficult, although it may not be necessary to optimise to protect against non-radioactive hazards.

The chemical impact of hazardous waste has the potential to be greater than that associated with radioactive waste. This is particularly the case for low-level and very low-level radioactive waste, in which there are comparatively low levels of radioactive constituents. It may also be the case for nuclear facility decommissioning wastes, in which the hazardous waste content can be comparatively high compared with operational radioactive wastes.

Safety indicators and criteria are not always consistent in terms of the concepts that they are based upon and the level of protection afforded. This may be appropriate in terms of concepts in many cases since there are different mechanisms of harm. Nevertheless, the level of protection afforded should be consistent.

The categorisation of hazardous wastes is changing all the time and is therefore difficult to match up with the international scheme for categorising radioactive waste. It is not just waste disposal where these irregularities have an impact. The issue also applies to legacy site management where disposal routes for wastes are required during clean-up operations or assessments required to support leaving materials in place.

The Groundwater Daughter Directive has been frequently referred to as a potential issue for waste disposal. England appears to be further ahead than others represented in the workshop in terms of considering the implications of the Directive requirements on radioactive waste disposal. A greater understanding of the approaches being taken in different countries to address the requirements of the Directive was identified as being beneficial.

5.2 CONCLUSIONS AND IDEAS FOR ADDRESSING KEY ISSUES

Ideally, radionuclides and hazardous materials should be assessed on a common risk management basis such that consistent assumptions are employed in assessments and consistent criteria used to evaluate risk. Some differences may be necessary, but there should at a minimum, be an understanding of the basis for the different approaches to allow differences to be understood and communicated. For example, differences in the approaches to dealing with NORM waste often arise as a direct result of the variation in waste volumes.

The basis for separation in approaches within a country may be regulatory or institutional. There is the potential for a mismatch in regulatory frameworks where different ministries or agencies are assigned to the management of radioactive and hazardous wastes. However, even where there is a single organisation responsible for both, it is often the case that there are different groups within that organisation specialising in the different areas. Improving communication between agencies and assessment groups would help drive toward consistency in assessment approaches and in the management of risks. The development of a common set of objectives and, hence, assessment endpoints and timeframes for the different waste types would be very beneficial. Such development would support coherent risk management and allow alternative options to be compared on an equal basis. This is particularly important when considering radioactive and non-radioactive hazards associated with the same facility. For example, environmental impact assessments for radioactive waste repositories tend to be undertaken separately from safety cases, which can give rise to differences and inconsistencies, even though the assessments are in support of the same facility.

Where possible, a pragmatic way of maintaining consistency should be identified and followed such that a holistic approach to disposal assessments for individual sites is achieved rather than hazardous materials being something of an afterthought to radioactivity, or vice versa. There may necessarily be differences in how assessments are made, but those differences should be transparent and the reasons for them should be clearly explained. A holistic approach to assessment would also support the proportionate application of resources to the different hazards presented by a waste.

Similarly, development of a common language to addressing issues would be very beneficial to avoid the use of different terms that could not only be confusing and lead to errors, but also lead to mistrust. Whether or not a common toxicity index for both radioactive and hazardous substances could be developed may warrant investigation, including presenting complementary considerations such as the reduction in toxicity as waste decays back to natural ore levels.

The development of international guidance on criteria for long-term chemical safety of the hazardous waste component of radioactive waste would also be useful, ensuring that the criteria are consistent with those for the radiological impact. This would help with addressing public perception toward radiation, by indicating that radiation is just another hazard associated with waste. Work may be ongoing at the UN level and this may warrant investigation. The development of such guidance would not only be beneficial to the radioactive waste disposal community, but would also support those working in NORM and hazardous waste management fields.

It was considered that NORM management may be a convenient place to start in addressing some of the issues raised. NORM management is a significant interest area for many countries and would also conveniently address many of the issues relating to regulation and hazards. It was also noted that different approaches to assessing impacts can be applied to long-term management of contaminated land at legacy sites and those applied to waste disposal. This can apply to both radiological and other hazards. There is nonetheless a need to consider waste management during legacy site management since wastes will be generated as a result of land remediation activities.

It was noted that the assessment community is not always able to undertake the quality of assessment necessary to support regulatory and other decisions, due to a lack of supporting information and science. Being able to reach out to the research community would help address these data and knowledge gaps. The Centre for Environmental Radioactivity (CERAD), a partnership of a range of Norwegian academic, technical and regulatory institutions, was noted as having a ten year programme to undertake radioecology and other research potentially relevant to the issues discussed above. The International Union of Radioecology (IUR) also provides an opportunity to further knowledge through research and networking. A FORUM network has been set up by the IUR to promote networking between networks working in the field of radioecology and ecotoxicology so that knowledge may be shared and developed and to promote consistency, integration and harmonisation in research and assessments. The IUR FORUM also provides a mechanism by which research needs can be communicated.

Various legislation exists specifically related to protection of groundwater, e.g. the European Commission's Groundwater Daughter Directive, which has implications for the disposal of radioactive and hazardous wastes. An international view of what is being done to address the requirements of the Directive and similar legislation outside the European Union, would be useful. A specific issue is the state of application of the 'prevent' requirement in the Directive both for the radioactive waste and hazardous waste disposal communities, including the regulatory authorities. Understanding the approaches that are being applied to address the issue would provide a basis for developing a consistent approach. The degree to which radionuclides are classed as 'hazardous' under the terms of the Groundwater Daughter Directive at an international level may also be worth further investigation.

APPENDIX A. LIST OF PARTICIPANTS AND TECHNICAL CONTRIBUTORS

The workshop participants and their affiliations are detailed in the following table.

Participant	Affiliation
Thibault Monaco-Back	Autorité de Sûreté Nucléaire (ASN), France
Danyl Perez-Sanchez	Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Spain
Andrew Baker	Eden Nuclear and Environment, attending on behalf of Low Level Waste Repository Ltd (LLWR), UK
Beatriz Lourino-Cabana	Electricité de France (EdF), France
Candida Lean	Environment Agency (EA), England
Koen Mannaerts	Federal Agency for Nuclear Control (FANC), Belgium
Graham Smith	GMS Abingdon Ltd (BIOPROTA Technical Secretariat), UK
Karine Beaugelin	Institut de Radioprotection et de Sûreté Nucléaire (IRSN), France
François Brechignac	International Union of Radioecology (IUR), France
Alessandro Proverbio	Low Level Waste Repository Ltd (LLWR), UK
Henrik Ness Mikkelsen	Norwegian Environment Agency (NEA), Norway
Isabelle Thelin	Norwegian Environment Agency (NEA), Norway
Norun Reppe Bell	Norwegian Environment Agency (NEA), Norway
Solveig Dysvik	Norwegian Radiation Protection Authority (NRPA), Norway
Kristin Elise Frogg	Norwegian Radiation Protection Authority (NRPA), Norway
Jelena Mrdakovic Popic	Norwegian Radiation Protection Authority (NRPA), Norway
Marte Holmstrand	Norwegian Radiation Protection Authority (NRPA), Norway
Brit Salbu	Norwegian University of Life Sciences (NUMB), Norway
Deborah Oughton	Norwegian University of Life Sciences (NUMB), Norway
Kirsi Riekki	Posiva Oy, Finland
Kelly Jones	Public Health England (PHE), UK
Karen Smith	RadEcol Consulting Ltd (BIOPROTA Technical Secretariat), UK
Helen Kendall	Radioactive Waste Management Ltd (RWM), UK
Matthew White	Radioactive Waste Management Ltd (RWM), UK
Per Varskog	Wergeland Halsvik, Norway

In addition to the participants listed above, the following individuals, unable to attend the workshop, kindly provided presentations to be presented on their behalf:

- Gloria Kwong (Nuclear Envergy Agency of the Organisation for Economic Cooperation and Development, NEA-OECD);
- Ulrik Kautsky (Swedish Nuclear Fuel and Waste Management Company, SKB);

- Claudia Koenig (University of Hanover, Germany); and,
- Keiko Tagami (National Institute of Radiological Science, NIRS, Japan).