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Radioecology as a Support to Regulatory Decision making on NORM and other Legacies, Related Waste Management and Disposal

Report of an International Workshop, Berlin, 3 September 2017

Reference:
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[1]Norwegian Radiation Protection Authority (NRPA), [2]Belgian Nuclear Research Centre (SCK·CEN)
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Key words:
Regulatory decision making, legacy sites, radioecology, NORM, radioactive waste

Abstract:
This report describes given presentations and main conclusions from an International Workshop on supportive role of radioecology in regulatory decision-making processes. The overall objective of the workshop was to evaluate progress and enable further linking of radioecology with regulatory needs in case of NORM and other legacies, and their waste. Workshop aimed to provide a general forum for discussion and understanding between scientists and regulators concerning various NORM legacy issues and to consider how radioecology can ensure input to a more comprehensive approach to deal with legacy issues.

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Resymé:
Denne rapporten beskriver presentasjoner og diskusjoner fra en internasjonal workshop om støtterolle av radioøkologi i forskjellige regulering og forvaltning prosesser. Målet med seminaret var å dele erfaringer og å videre utvikle knytting av radioøkologi og annen forskning med praktiskbehov i regulering av et bredt spekter av NORM arv, radioaktivt avfall og deponier.

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Approved:

Per Strand, director, Department of Nuclear Safety and Environmental Radioactivity

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Workshop Coordinators:

Malgorzata K Sneve (NRPA)

Hildegarde Vandenhove (SCK•CEN)

SCK•CEN	Statens strålevern
Belgian Nuclear Research Centre	Norwegian Radiation Protection Authority
Mol, 2018	Østerås, 2018

Preface

An international workshop **'Radioecology as a Support to Regulatory Decision Making at NORM and other Legacies, Related Waste Management and Disposal'** was co-organized by the Norwegian Radiation Protection Authority (NRPA) and the Belgian Nuclear Research Centre (SCK•CEN). The event resulted from the joint vision on the necessity to share views, challenges and experiences of the importance of scientific support in regulatory decision-making processes related to NORM and other legacies and related to waste management and disposal.

This report describes workshop presentations and discussions. The workshop was organized as a one day pre-event (3 September 2017) of the 4th International Conference on Radioecology and Environmental Radioactivity (ICRER, 2017), Berlin, Germany. Contributions and support were provided by a wide range of organisations via presentations and discussions, as described in the report.

The report is presented as working materials for general information; however, the content may not be taken to represent the official position of the organisations involved.

This workshop report is edited by:

Malgorzata K. Sneve (NRPA)

Hildegarde Vandenhove (SCK•CEN)

Jelena Mrdakovic Popic (NRPA)

Executive Summary

The role of science, and particularly radioecology, in regulatory decision-making has been demonstrated via various examples of international activities and national case studies. Several aspects of interface between radioecology and regulatory decision-making have been evaluated and challenges discussed.

A first step in dealing with legacy sites is to characterise the situation. Once characterisation has been completed, it is possible to assess transfer and dispersion of radionuclides and resulting exposure to man and environment. The dose criterion, together with other criteria to be considered, should allow to indicate whether it would be appropriate or not to undertake remediation. Where remediation is appropriate, the remediation options should be optimised. For legacy sites, reference levels should be set relative to the specific situation, i.e. on a case-by-case basis. Remediation options should then aim to provide a solution that results in the selected reference level being met thereby still considering other criteria. Throughout the process, it is important to draw together the people with appropriate skills that can assess the situation, identify what is important, and what should be done.

Decision making at most legacy sites requires integrated and comprehensive assessments of the risks associated with both radionuclides and chemicals that are present together. Whilst approaches for impact assessment have been established both for radionuclides and for chemicals, these are not necessarily consistent. Whether a fully integrated assessment approach could be developed that is balanced and proportionate to risk from radionuclides and chemicals both on people and the environment, or whether a separate risk assessment approach should be preferred and results discussed complementarily where possible. Development of integrated approach will require further thought and discussion at an international level, involving both decision makers and scientists. Ideally, it should take account of impacts on both humans and non-human biota and both chemicals and radionuclides.

Further development of specific areas of impact assessments in terms of environmental impact assessment (EIA) and environmental risk assessment (ERA) are also needed (for example, further dynamic based model development, improved parameterisation of key transfer processes, updating of existing databases etc.) to help determine ecological consequences under realistic circumstances.

It is recognised that the evolution of a site over time is an important factor to take into account in assessments and decision- making, and also in post-remediation assessment. Furthermore, land use and restrictions all have to be tied back to pathways and exposures. Radioecology has a central and essential role to play in answering these site-specific questions. It can help identify what is relevant to a site, provide guidance on aspects from monitoring approaches and frequency to assessing the implications of the movement of contamination from one area to another, and in identifying and evaluating exposure pathways, amongst others.

Communication of uncertainty, risk and dose are particularly important aspects of legacy site management, particularly when technical people are required to communicate technically complex or potentially contentious issues to a broad stakeholder group. Regulators need to show compliance against dose limits, but presenting and demonstrating compliance can be difficult. Even if results of dose assessments are well below dose limits, there can still be a perceived risk as far as members of the public are concerned. For example, particular concerns may arise in relation to the persons' activities or of their children and regulators must be prepared to answer these questions

(there is no ‘average person’ or ‘average concern’). The needs of the people may not therefore be met by simply demonstrating that impacts will be below a limit. It is also important to recognise that the public does not always understand limits and communication therefore should be targeted at an appropriate level.

Experience has shown that the early engagement of stakeholders and maintaining that engagement throughout the different regulatory processes is beneficial. Engaging with the public contributes to transparency, helps reduce controversy and builds public acceptance; whilst people may not want the responsibility for decision-making, they do want to have their voices heard.

Radioecology has an important role to play in NORM and legacy site management, from characterising the situation, through identifying and assessing transfer and exposure pathways and calculating doses, to supporting decision making and communicating with stakeholders during all phases of a regulatory process. A consensus has been seen that radioecologists can contribute to discussions and to the overall decision building process. Key to addressing the need for holistic and integrated assessments of the risks associated with legacy sites is ensuring that there is coordination and consistency in international activities and the guidance they produce.

Contents

1 Introduction

The Norwegian Radiation Protection Authority (NRPA) and the Belgian Nuclear Research Centre (SCK•CEN) organized jointly the International Workshop 'Radioecology as a Support to Regulatory Decision Making at NORM and other Legacies, Related Waste Management and Disposal'. The workshop was held as a one-day (3 September) pre-conference event of the 4th International Conference of Radioecology and Environmental Radioactivity (ICRER) in Berlin, 3-8 September 2017.

1.1 Background

The practical role of radioecology, in support of the regulatory decision-making processes, is to develop and provide the science base, methods and tools necessary for underpinning the guidelines, for assessments prior to regulatory (remediation) actions, but also for post-remediation monitoring and compliance checking. Basically, radioecology provides answers to important questions and issues from regulatory bodies and operators. However, independent development of the scientific disciplines, regulations and regulatory mechanisms, as well as waste management and disposal strategies linked with site and environmental remediation, has been internationally highlighted as not being optimal for overall efficiency, integration and harmonization.

To help resolve this and to facilitate and provide the basis for integration and harmonisation, NRPA has now organized the third international workshop (after two successful events organised in Bergen, 2008 and Barcelona, 2014) to promote cooperation between scientific and regulatory bodies and the application of good science, especially radioecology within the regulatory process for nuclear and radiation legacy sites.

1.2 Objective and scope

The overall objective of the workshop was to evaluate progress and enable further linking of radioecology with regulatory needs in case of NORM and other legacies and their remediation. We aimed at providing a general forum for discussion and understanding between scientists and regulators concerning various NORM legacy issues and to consider how radioecology can ensure input to a more comprehensive approach to deal with legacy issues.

1.3 Participation and programme of the workshop

The workshop was attended by 37 participants from 19 countries, illustrating the international interest in the subject of how radioecology can support the management of NORM and other legacy sites and associated waste management and disposal.

The workshop was structured around three topical sessions that included presentations and discussion on following themes:

- International initiatives concerning the need for closer collaboration among scientists, regulatory bodies and operators;
- Main challenges for regulators and operators in decision-making and management processes at legacy sites;
- Main radioecological uncertainties in state-of-the-art assessments - issues to be addressed in future collaborative work at international level;

A fourth session was dedicated to comprehensive discussion and drafting of workshop conclusions.

The workshop was opened by the hosts, Malgorzata Sneve (NRPA) and Hildegarde Vandenhove (SCK·CEN).

1.4 Report structure

This report was drafted by NRPA and reviewed by participants for correctness prior to publication. The following Sections summarize the presentations made in each of the topical areas listed above and the discussion in each area. Section 5 provides a summary of overall discussions and sets of conclusions and recommendations. The workshop participants' list and programme are given at the end of the report as Annexes, as well as Highlights and conclusions from previous related workshops organized by the NRPA (Bergen, 2008 and Barcelona, 2014).

2 Session 1: International initiatives concerning need on closer collaboration among scientists, regulatory bodies and operators

2.1 IAEA initiatives in support of remediation planning and implementation

Tamara Yankovich (IAEA) presented.

The IAEA is in the process of updating its safety guides on remediation and monitoring. There are also a number of initiatives whereby the IAEA is working with Member States to support regulatory programmes in the field of remediation.

The IAEA has a tiered hierarchy of documents. Safety Fundamentals are at the top of this hierarchy, the fundamental objectives of which are to protect people and the environment from the harmful effects of radiation through the provision of 10 safety principles:

1. Responsibility for safety
2. Role of government
3. Leadership and management for safety
4. Justification of facilities and activities
5. Optimization of protection
6. Limitation of risks to individuals
7. Protection of present and future generations
8. Prevention of accidents
9. Emergency preparedness and response
10. Protective actions to reduce existing or unregulated radiation risks

The Safety Fundamentals are supported by Safety Standards that set out how the ten safety principles can be achieved. The Safety Standards detail exposure groups (workers, patients and the general public), exposure situations (planned, emergency and existing) and three radiation protection principles (justification, limitation and optimisation).

Sites requiring remediation are existing exposure situations where a problem already exists and where a decision on the need for control needs to be taken. Such sites could relate to areas affected by high natural background radioactivity (e.g. radon), sites affected by residual radioactive material from past practices that were not subject to regulatory control (or to the current standards of regulatory control) or areas affected by emergency situations after the emergency has been declared to be over. For all of these situations, thought must be given as to how to integrate both social and technical science when setting remediation targets and developing remediation programmes. Guidance is being developed by the IAEA to provide a technical basis for managing these types of situation.

Existing exposure situations are very situation dependent and regulations and guidance, therefore, need to be adequately flexible to accommodate the range of existing situations that may need to be managed and the need for consideration of situation-specific conditions. As such, a range of dose reference levels within a range of 1 to 20 mSv/year are applied, with a reference level being set within this range according to the situation being addressed. The setting of a reference level for a given situation should take into account not only technical knowledge, experience and feasibility, but also people's concerns. Once a reference level has been set, the objective is that all reasonable steps be taken to prevent doses from remaining above that reference level. The reference level, therefore, provides the target for remediation.

Three questions arise in relation to reference levels and remediation:

- What is considered as 'reasonable'?
- What is considered as 'adequate'?
- What is considered as 'appropriate'?

The answers to these questions lie in the following three radiation protection principles and how they can be practically applied – remedial actions must be achievable:

- Justification. Actions should be commensurate with risk, and there should be adequate net benefit.
- Limitation. Establishment of hard "limits" (for planned exposure situations), or "targets" (for emergency and existing exposure situations), taking account of the situation (e.g., Reference Levels).
- Optimisation. Key impacts should be weighed out and balanced with consideration of relevant factors and in consultation with interested parties.

These principles are intended to be applied in the context of a graded approach with the stringency of regulatory oversight and remediation efforts being commensurate and proportionate to the level of risk. In this context, remediation is defined as "any measures that may be carried out to reduce the radiation exposure due to existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to people" [IAEA Safety Glossary, 2016]. It is important to recognise that remediation is intended to reduce radiation exposure due to existing contamination; the complete removal of contamination is not implied. It is also important to recognise that risk is not something that is just calculated, risk can also be perceived, varying with different people's opinions and perceptions. Engagement of interested parties is, therefore, an important factor in working toward an optimised approach with trust being built through communication and consultation throughout remediation process.

There has been significant discussion internationally on the need to develop practical guidance on the implementation of international recommendations and safety standards, such as how the radiological protection principles of justification and optimisation can be applied in the selection of remedial options and the establishment of reference levels. In response, the IAEA is revising its 2007 Safety Guide WS-G-3.1 on 'Remediation Process for Areas affected by Past Activities and Accidents'. The revision (DS468) will take account of more recent guidance and safety requirements relating to existing exposure situations and waste safety standards and aims to provide practical guidance on implementing the requirements on remediation of areas contaminated by residual radioactive material arising from past activities, areas affected by nuclear or radiological emergencies after the emergency is deemed to be over, and areas affected by incidents such as malicious acts involving the release of radioactive material. The guidance is intended to provide a framework for remediation that can be applied in a stepwise approach that will help to determine, on the basis of science and defensibility, whether remediation and post-remediation management are required.

The first stage in the stepwise approach is to undertake a preliminary evaluation. This involves characterising the situation to determine key exposure pathways and associated doses, and to decide on screening criteria that can be used to determine whether or not there may be an issue that requires further assessment and what the next steps should be. Where more detailed investigations are deemed necessary, a detailed site survey should be conducted that can be used to verify the situation and gain more detailed information to support the identification of priorities for remediation.

Key questions that should be considered when characterising the situation and making decisions around targets for remediation include:

- Which radionuclides are present and what are their characteristics and expected fate, including how levels of radioactivity are predicted to change over time and space?
- What is the distribution of radionuclides in the environment?
- How are people using the environment, how could their lifestyles result in radiological exposure and what are the key exposure pathways and their relative contributions to dose?
- What is the predicted influence of any remedial actions on exposure and dose compared to the present situation?

Where initial and more detailed investigations indicate the possible need for remediation, remediation plans will need to be drawn up and authorised. Remediation planning would require Reference Levels to be established and a decision made on whether or not remediation is justified. Where remediation is justified, options for remediation should be optimised prior to being authorised by the appropriate regulatory body. The guide DS468 will provide guidance on the steps associated with the selection of Reference Levels and their application within remediation programmes, including:

- Conducting radiological surveys of areas to be remediated;
- Conducting dose assessments and reviewing the outcomes;
- Identifying possible remedial options;
- Making decisions regarding end-state and end-use of land and determining whether remediation can be justified;
- Setting the Reference Level and measurable derived reference levels;
- Development of a plan to optimise protection; and
- Conducting monitoring to verify that doses and Derived Reference Levels fall within predicted and authorised levels.

Remediation generates wastes and a key aspect of remediation planning and implementation is therefore to take the necessary steps to minimise the generation of radioactive waste. However, to aid in the management of wastes, it is advised that the term 'radioactive waste' is only used when necessary/appropriate, with 'residual materials' being used as a comprehensive term to cover radioactive and conventional wastes, materials that can be reused and materials that can be recycled.

Once a remediation plan has been developed and authorised, it must be implemented. This involves conducting remediation in accordance with the authorised plan, assessing the effectiveness of the remedial actions, and determining whether or not restrictions may be needed to meet the Reference Levels set within the plan. Where restrictions are deemed necessary, it should be determined whether further remediation could be beneficial, with options being re-evaluated through further planning.

Once implementation has been completed and it has been determined that the Reference Level and other criteria have been met, the next step is to initiate post-remediation management. This would involve establishing institutional controls and long-term surveillance and monitoring programmes, as well as periodic review of these controls and monitoring programmes.

The draft Safety Guide DS468 has been sent to Member States and work is currently ongoing to address comments received, with a revised draft planned for submission to Member States in early 2018. Underlying technical guidance is also under development, on topics such as:

- Effectiveness of remedial options to address dominant exposure pathways;
- How to establish Reference Levels;
- Decision-aiding tools for remediation of existing exposure situations; and
- Optimisation of technical and social aspects in living in contaminated environments

Strong science is an important requirement in addressing legacy issues and radioecology has an important role to play in all stages of remediation planning and implementation, including in:

- Characterising the situation (initial situation, during remediation and post-remediation);
- Evaluating exposure pathways and associated doses;
- Providing sound science upon which screening criteria / reference levels can be appropriately selected;
- Supporting the evaluation of different remedial options and in their optimisation; and
- Supporting the characterisation of residual materials to inform on appropriate waste management.

2.2 Update on the progress of ICRP TG76 – NORM

Jean-Francois Lecomte (ICRP-C4) presented.

ICRP Task Group (TG) 76 on protection against NORM exposure to individuals or contamination of the environment was initially launched in 2007 and was re-launched in 2013. The TG aims to develop a report on substances with NORM that are used for other than their radioactive properties, in industrial processes that can significantly enhance the concentration of radionuclides in products, by-products, discharges, residues and waste. Other TGs are focussing on related aspects, such as contaminated sites (TG98). There is also a series of reports that focus on existing exposure situations, including NORM, that have been produced by ICRP Committee 4 (e.g. ICRP 111, 126 and 132).

NORM arises as a result of a diverse range of practices, including mining and extractive industries, the production of coal, oil and gas, production and use of metals (such as thorium, niobium etc.), the phosphate industry and water treatment, among others. The characteristics of NORM industries are that they are already on-going within a number of industrial sectors and tend to be large industries that are of economic importance. Furthermore, these industries tend to be subject to authorisation due to being associated with risks from multiple hazards, but for which the radiological risk is rarely dominant and, hence, authorisations tend not to relate to radiological protection and the radiological protection culture within these industries is often poor. Radiological doses are, however, often higher than those associated with the classic nuclear industry, but doses are capped; there is almost no real prospect of emergency exposure situations occurring. With the culture of risk management being largely focussed on non-radiological hazards, there is a need to introduce greater radiological protection to these industries, within an integrated and graded approach, ensuring that controls are commensurate with risk.

In many instances, NORM exposure falls within the category of existing exposure situations. However, the IAEA BSS (IAEA, 2014[1]) indicates that it should be considered as planned exposure in some circumstances. Notwithstanding, each workplace should be managed properly within a graded approach according to the dose level and the selection and implementation of protective actions.

Radiological risk at work should be integrated within a global risk management framework within industries. A Reference Level should be selected which, in most cases, will be less than 1 mSv/y. Higher Reference Levels may be appropriate (up to a few mSv/y) in some instances, but rarely would fall within the range of a few mSv/y to 20 mSv/y.

Two series of protective actions are proposed. The first relates to workplaces and working conditions and may involve characterising who is exposed and how and demarcating areas and putting in place engineering controls and working procedures that are adapted to the particular situation. The second is focussed on each worker individually and may involve informing, educating and training, health surveillance and the provision of personal protective equipment. The way to implement protective actions may be more or less thorough according to the situation.

For the protection of the public, the starting point is again characterisation in terms of who is exposed, when and where they are exposed and how they are exposed through exposure pathway analysis and dose assessment. Reference Levels should be set (below 1 mSv/y) and any required actions for public protection should be justified and optimised, with stakeholder engagement. Practically, the protection of the public is ensured through the controls of discharges and waste arising or the reuse of residues, notably in building materials. For building materials, the materials at stake should be listed, characterised and indexed with the strategy aimed at limiting the use of materials to those with an index of less than 1 mSv/y.

For protection of the environment it is recommended that radiological risk is included within environmental impact assessments. This would involve radiological characterisation and the analysis of exposure pathways and the transfer of radiological materials within the environment.

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[1] IAEA (2014). Radiation protection and safety of radiation sources: International basic safety standards. General Safety Requirements. International Atomic Energy Agency, Vienna.

Doses to non-human species should be calculated and potential effects evaluated against dosimetric criteria. Stakeholders should again be involved in the process.

A public consultation on the draft TG 76 report is due to take place mid-2018, with the final report being published by the end of 2018.

2.3 Ongoing NEA and ICRP legacy management activities (NEA Expert Group on Legacy Management and ICRP TG98) and links to radioecology

Ted Lazo (NEA) presented.

There is a need for practical international guidance on legacy management and the regulation of existing exposure situations: many countries with nuclear programmes are facing problems with legacy sites and objects and there are many examples of how different legacy problems and existing exposure situations are managed in different countries applying different approaches and standards. Both the Nuclear Energy Agency (NEA) and the ICRP have work programmes ongoing to address these issues. The NEA Expert Group on Legacy Management (EGLM) was created in 2016 with the objective of promoting practical regulatory guidance for legacy sites. Within ICRP Committee 4, a task group (TG98) was created, in 2015, with the objective of describing and clarifying the application of ICRP Recommendations to exposures resulting from sites contaminated by past industrial, military and nuclear activities. Both the EGLM and TG98 aim to coordinate their activities, which is assisted by a number of members common to both groups.

The mandates of each group are detailed in Table 1. The ultimate objective in managing a legacy is to consider the preferred end state and how that can be achieved. Stakeholder involvement is essential throughout the whole process. Both the EGLM and TG98 have defined the term 'legacy', with TG98 defining a legacy as a situation whose radiological nature is of concern to regulatory authorities and may not be well characterised, whose management may not meet current radiological protection expectations, and whose operational responsibility may be unknown. The EGLM defines a legacy as a site that has not completed remediation, and that has radioactivity that is of concern to the regulator. A wide range of different situations fall within these definitions, including NORM processing sites, poorly stored radioactive wastes and spent fuel, and uranium mining sites, among others (Figure 1).

Table 1. Mandates of the NEA EGLM and ICRP TG98

EGLM	TG98
Assist in deriving practical interpretation and application of generic radiation protection guidance to nuclear legacy site management.	Address exposures resulting from sites contaminated due to past industrial, military and nuclear activities.
Enhance safety and security culture as it applies to legacy sites.	Sites never subject to regulatory control or subject to regulatory control not in accordance with current Recommendations (not post-accident).
Address specific situations at real sites within NEA member countries.	Characterisation of sources, exposure pathways, dose distribution, occupational and public exposure, protection of the environment, reference levels, sustainable protection strategies.

EGLM	TG98
Support a holistic approach to all the risks. Develop better regulatory understanding of diverse radiation risk to diverse groups on diverse temporal and spatial scales.	Stakeholder involvement in all steps of the process will be considered.

FIGURE 1. EXAMPLES OF DIFFERENT LEGACY SITES.

Within the report being prepared by the EGLM, a chapter will focus on challenges and uncertainties with legacy sites, covering aspects such as the regulatory framework, characterisation of the prevailing circumstances societal aspects, how to define and choose end-states, optimisation and long-term protection values. The management of legacy sites must be planned and holistic as well as integrated and innovative if it is to be successful.

One of the key challenges in the management of legacy sites is to achieve a reasonable balance between competing objectives, for which stakeholder involvement is key. For example, where a forest is contaminated, the societal value placed on the continued presence and recreational use of that forest may be of greater importance than the benefits in terms of dose reduction that could be achieved through the remediation of that forest.

The EGLM report will also include future recommendations relating to the key challenges and uncertainties.

The output will be based on case studies that detail the challenges faced, actions taken and lessons learned. A number of sites have been identified as potential case studies for inclusion, including:

- Fukushima (Japan)
- Stráž Pod Ralskem/Rožna (Czech Republic)
- Capriano del Colle (Italy)
- Little Forest (Australia)
- Søve (Norway)
- Sellafield and Low Level Waste Repository (UK)
- Andreeva Bay, Techa River (Russia)
- Shiprock and West Valley (USA)

In May 2017, a site visit was arranged to Sellafield in the UK to look at legacy facilities at the site, many of which are part of ongoing operations and, as such, must be managed in light of ongoing activities. The objective of the visit was to develop an understanding of the challenges associated with the management and regulation of the legacy facilities present, including the recovery and interim storage of waste from old stores, long-term planning, optimisation in practice and how engagement with stakeholders is done in practice.

The TG98 report will also be based on practical case studies. The report will cover general consideration, such as describing the situation and who is exposed and addressing the dynamics of the exposure situations, and implementation of the system of radiation protection to the management of exposure from contaminated legacy sites, including identification of options and decision making and implementation. In terms of workers, the report will recommend that, where a source is known and well characterised, worker exposure can be controlled and approached in terms of a planned exposure situation.

There are a number of links between science and values, in relation to protection objectives (for which it should be recognised that members of the public may have very different focus areas), setting standards equal to objectives, demonstrating compliance with standards, optimisation of proposal and implementation of strategies. Science and radioecology can help at all stages with radioecology providing important support in the development of practical solutions. For example, radiological assessments support the process of defining and achieving effective solutions that are practical and address the often-contradictory stakeholder needs and policy objectives. Radioecology is an important aspect of assessments, providing source-pathway-receptor linkages and providing the basis by which radionuclide transfer can be evaluated and impacts on receptors (humans and biota) can be evaluated. It should be noted, however, that there can be challenges in identifying sources, pathways and receptors. For example, groundwater can be a source, a pathway and also a receptor, which is a challenge faced not only in relation to legacy site management, but also in relation to solid waste disposal post-closure safety. The sharing of knowledge and experience from the different assessment communities can help in addressing challenges, including those working in the field of non-radioactive hazard assessment and management.

The TG98 draft report will be submitted for review by ICRP Committee 4 in October 2017. The NEA EGLM final draft report is due to be submitted for review in April 2018. The EGLM may also hold a workshop in late 2017/early 2018 on national approaches to legacy management.

2.4 A European perspective of the radioecology research needs in context of NORM legacy management

Hildegarde Vandenhove (SCK•CEN) presented.

There is no dedicated NORM research and development programme within the EC, however there are research programmes that take account of NORM. For example, within the radiation protection and nuclear safety unit of the DG-ENER (Directorate-General for Energy), a working party has been created on natural radiation sources that is working on the requirements on natural radiation sources (including NORM) in the new Basic Safety Standards. There are also a number of European NORM related networks, including:

- The European Radon Association (ERA) that aims to serve the interests of the European radon community and assist in reducing the health burden of Radon Exposure in Europe;
- The European ALARA Network for Naturally Occurring Radioactive Materials (EAN_{NORM}) that connects experts from NORM industries (operators, industry associations), regulators, laboratories and consultants and provides a platform for the exchange of experience for the implementation of the as low as reasonably achievable (ALARA) optimisation principle, operational radiation protection and remediation; and
- EU-NORM (www.eu-norm.org) that organises symposia in order to bring together experts and other interested persons in the field of NORM.

The EAN_{NORM} and EU-NORM have complimentary aspects and will soon join to form a European NORM Association (ENA) that is due to be established in October 2017. The objectives of ENA will be:

- to promote and advance radiation protection in the context of exposure to NORM by operating as a European platform for discussion, dissemination and exchange of information, training and education and by supporting scientific knowledge and new directions of research related to NORM issues; and,
- ensure that NORM is managed in compliance with European standards and Member State legislation and according to best practice so that legal and regulatory uncertainty is minimised, and humans and the environment are protected in an optimised way that is acceptable to society.

It is intended that a research agenda will be established within the ENA, following its establishment in October 2017.

The European Radioecology Alliance was founded in 2009 to develop a vision on long-term research needs in radioecology, foster cooperation and assure sustainability. When initially founded there were 8 members. By June 2017 the membership had increased to 27 members from 14 countries. An important aspect of the work undertaken by the Alliance was the development of a Strategic Research Agenda (SRA). The SRA was developed in consideration of discrete challenges associated with different exposure situations. Three key challenges were identified for which a number of priorities were detailed, as follows:

- Challenge 1 - Predict human and wildlife exposure in a robust way by quantifying key processes that influence radionuclide transfers and exposure.

    - Identify and mathematically represent key processes that make significant contributions to the environmental transfers of radionuclides and resultant exposures of humans and wildlife.
    - Acquire data necessary to parameterise key processes that control radionuclide transfer.
    - Develop transfer and exposure models that incorporate physical, chemical and biological interactions, and enable predictions to be made in a spatial and time dependent manner.
    - Represent radionuclide transfer and exposure at a landscape or global environmental level with an indication of the associated uncertainty.
- Challenge 2 - Determine ecological consequences under realistic exposure conditions.
    - Establish processes to link radiation induced effects in wildlife from molecular to individual levels of biological complexity.
    - Understand what causes intra- and inter-species differences in radiosensitivity.
    - Identify mechanisms underlying multigenerational responses to long-term ecologically relevant exposures.
    - Understand the interactions between ionising radiation effects and other co-stressors.
    - Understand how radiation effects combine at higher levels of biological organisation.
- Challenge 3 - Improve human and environmental protection by integrating radioecology.
    - Integrate uncertainty and variability from transfer modelling, exposure assessment, and effects characterisation into risk characterisation.
    - Integrate human and environmental protection frameworks.
    - Integrate risk assessment frameworks for ionising radiation and chemicals (which is particularly important for NORM).
    - Provide a multi-criteria perspective in support of optimised decision making.
    - Integrate ecosystem approaches, such as ecosystem services and ecological economics, within radioecology.
    - Integrate decision support systems.

Roadmap working groups have been established to address key issues, one of which is a NORM roadmap working group that has members from across Europe. The main tasks in the NORM roadmap involve developing process understanding and identifying what processes matter through data generation that, together support transport modelling that underpins the development of a remediation strategy (Figure 2).

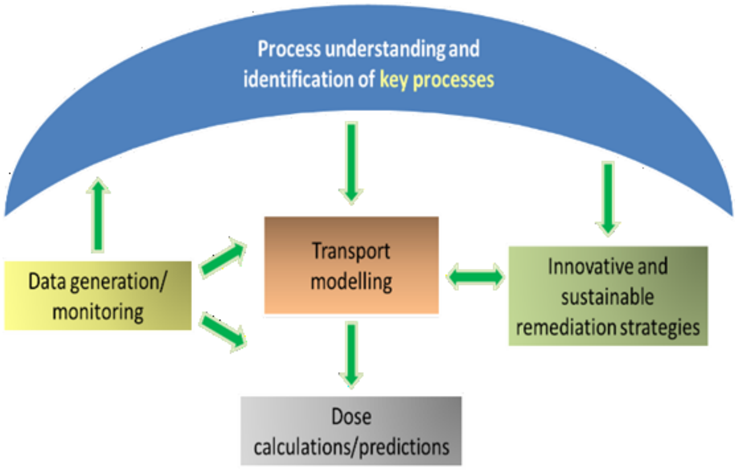

FIGURE 2. MAIN TASKS IN THE ALLIANCE NORM ROADMAP.

The overall objectives are to improve risk assessments for existing and future NORM sites, extend transport modelling of radionuclides to other risks, such as hazardous chemicals, and develop a mechanistic understanding of the biological and chemical processes that can be translated into robust models that support new strategies for sustainable remediation of NORM sites. These objectives can be achieved through the identification of key processes relevant for the environmental transfer of NORM and resultant exposure of humans and wildlife, including acquiring data that are necessary for the parameterisation of those processes, and improving assessment models that link accumulation, mobility and transfer with environmental parameters and processes that will allow predictions of spatial and temporal patterns of NORM in the environment.

It is important to recognise that, whilst simplistic approaches to modelling radionuclide transport are commonly applied, such as the use of partition coefficients (Kd) and transfer factors, an understanding is required on the environmental conditions affecting those parameters. For example, Kd is largely reported in terms of soil texture, but this is not a dominant factor for some radionuclides; sorption can be affected by a range of different parameters, including soil pH, organic matter content and redox conditions among others.

To address some of these issues, NORM observatory sites have been established that serve as valuable test areas that could be used in the verification of models and/or to test concepts developed by the radioecology community. The observatory sites include a phosphate industry legacy site in Belgium and a natural site in Poland that is contaminated by the release of liquid NORM wastes as a result of coal mining.

A further European programme related to NORM research is TERRITORIES (To Enhance uncertainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations). TERRITORIES began in January 2017 and will run for three years. The project includes six legacy sites, three of which are NORM sites. The overall objectives are to reduce uncertainties to a fit for purpose level within a graded approach, to bridge the gap between monitoring and modelling, humans versus wildlife populations, experts versus decision makers versus the public in the management of legacy sites, and to provide guidance on monitoring, modelling, dose assessment and decision making, accounting for social and ethical aspects.

Models used in environmental impact assessments are necessarily simplified and are usually considered to be conservative (Figure 3). However, such models can be overly conservative and associated with large uncertainties, which can prevent an optimised outcome being achieved. Improving model parameterisation can help reduce uncertainties and this can be achieved through site characterisation that helps identify the factors that are important at a site that should be taken into account if a situation is to be reliably modelled. For example, if modelling the release of uranium from a tails pile, site characterisation can provide information on factors that are important in governing the transport and fate of uranium in soils, such as pH variation across the site. The spatial contamination across a site cannot be realistically modelled using simple models with generic parameter values; process and mechanistic understanding are required if the output from models is to be relied upon. With the correct basis, assessments and associated remediation options will be more robust.

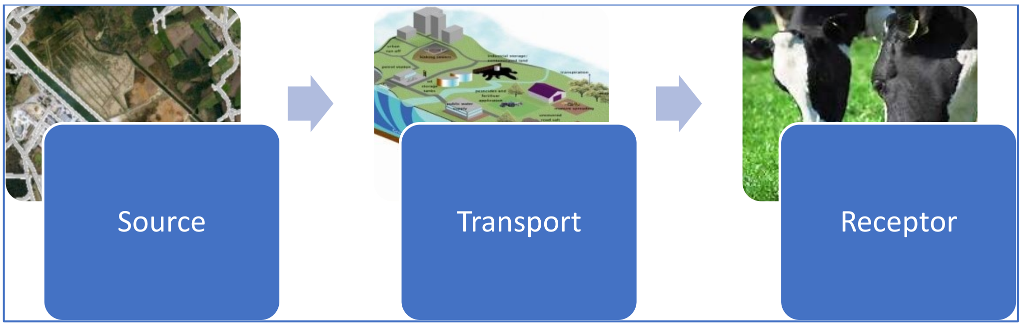

FIGURE 3. ENVIRONMENTAL IMPACT MODELS, STRONGLY SIMPLIFIED (TOO CONSERVATIVE, LARGE UNCERTAINTY).

2.5 Coordinating radioecology input to safety assessments for NORM, legacy and waste disposal sites – role of IUR and IUR Forum

Per Strand (IUR – NRPA/CERAD) presented.

From a regulatory perspective, uncertainties and knowledge gaps are key parts of assessments that need further improvement. Therefore, interaction and close collaboration between scientists and regulators as well operators is important as good science can greatly assist in decision making and management processes.

The International Union of Radioecology (IUR) is an independent, non-political, non-profit society that is dedicated to the worldwide development of radioecology. The role of the IUR is to maintain a network of scientists and professionals to foster communication between researchers from different fields and geographical regions to aid consensus building and to publish and circulate technical papers and organise conferences and training courses. The IUR currently has around 1,000 registered members from 58 countries. There have been various task groups set up over the years within the IUR, including task groups on non-lethal methods in radioecology; radioecology in a multiple stressor environment; protection of the environment; radioecology and waste; and, speciation.

The IUR has an objective to achieve worldwide harmonisation of research and development programmes in radioecology through:

– Identifying key research priorities and gaps;
– Promoting efficient use of existing infrastructures and resources;
– Supporting harmonised and coherent regulatory developments;

– Developing well-informed and balanced consensus on scientific conclusions; and,

– Meeting the specificities of problem oriented or regional objectives.

The IUR can help achieve these objectives through the integration of different disciplines and helping to optimise collaborative working between different communities. This may involve promoting discussion within the scientific community to identify common bases and differences, for example through the organisation of conferences and workshops. Regional differences do exist and bringing together people for discussion helps in the move toward harmonisation.

To further promote harmonisation, the IUR created the IUR FORUM in 2014. A founding workshop was held in Aix-en-Provence in June 2014 at which 15 international networks and organisations were represented. These networks and organisations came from a variety of different disciplines, including emergency preparedness and response, routine releases and waste disposal, but also non-radiological fields. Participants ranged from scientists, regulators, academic institutions and technical support organisations. The position of the FORUM amongst other organisations and networks is illustrated in Figure 4.

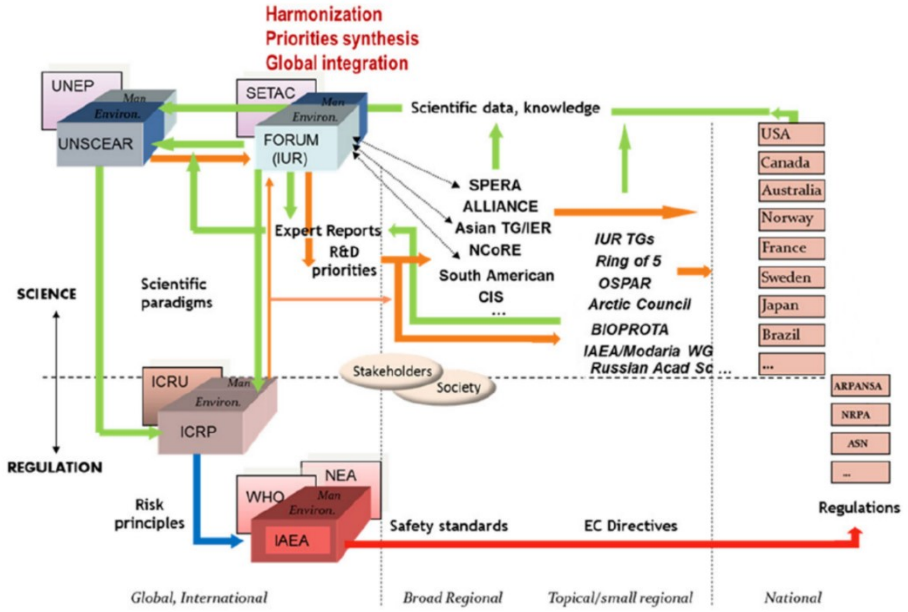

FIGURE 4. THE IUR FORUM'S ROLE WITHIN THE INTERNATIONAL RADIATION PROTECTION FRAMEWORK (FROM BRECHIGNAC ET AL, 2016).

During the founding workshop, the following priority research issues were identified:

– Improving dynamic modelling for simulation of radionuclide migration;

– Multidisciplinary analysis in processes affecting contaminant migration at the geosphere–biosphere interface;

– Fundamental research for assessment approaches for management of NORM, nuclear legacies and uranium mining;

– Radiation effects at low doses radiation, dose rates on the ecosystem level; and

– Monitoring techniques - support to emergency preparedness and response, confidence in arrangements for radioactive waste containment and the routine release of radionuclides.

Future challenges in radioecology were also identified during the workshop that fell into the categories of external and internal challenges. External challenges included aspects such as climate change, nuclear security and terrorism, and non-nuclear radiological issues. NORM is also a considerable challenge, spanning across a range of different industries and with different radioactive waste issues. Internal challenges include uncertainties in parameters such as Kds, concentration ratios etc., the implications of multiple stressors in the environment, and understanding radiological effects evidenced in individuals of non-human species and the implications of those on populations.

The FORUM is intended to provide a mechanism by which interaction between scientists and regulators can be facilitated and can support the resolution of identified challenges, including supporting the application of radioecology to regulatory decision making at NORM and other legacy and waste disposal sites.

2.6 Discussion relating to international initiatives

Radiological assessments are just one aspect in the management of NORM contaminated sites; environmental and chemical aspects must also be considered, particularly since chemical risks tend to dominate over radiological risks. Risk assessments should be consistent and harmonised, irrespective of the hazard to support decision making and stakeholder engagement (having conflicting risk assessment methods is not helpful when engaging with the public and other stakeholders). As such, thought should be given as to how interactions should be managed between the different risk assessment fields and guidance provided on how a harmonised approach can be achieved. This could be a simple as ‘this is what is done for chemicals and this is what extra is needed for other risks’. Irrespective of the approach taken, a holistic view of all risks and issues faced at a site must be taken to support decision making.

The need to link radiological risk assessment to other contaminant assessments is extremely important and has been recognised for some time, both from an assessment viewpoint and a regulatory viewpoint. In Norway, the Pollution Act is used to regulate technically-enhanced NORM (TENORM) activities generating wastes that include both chemicals and radionuclides. Using the Act as the basis for a system for radioactive waste management was successful. In Canada, the nuclear regulatory body is responsible for the management of all stressors associated with nuclear facilities, including chemicals. The regulatory body is responsible for coordinating impact assessments and evaluating the criteria that assessments should be compared against in order to identify and rank hazards. Where a risk ratio is in excess of 1, further site assessment may be required. Whilst these provide examples of successful harmonisation of regulatory frameworks for managing risks from different hazards, it is recognised that national regulatory frameworks can be an issue to the introduction of harmonised approaches. In some countries, there are different regulatory bodies responsible for nuclear and other hazards. Clear roles and responsibilities are required for different authorities and good communication between different authorities is vital.

A further issue that can be faced with regard to the regulatory management of legacy sites is that decision makers may not always have the required technical background and options appraisal may not be as balanced as it should. Regulatory frameworks are needed that allow the prevailing circumstances for a situation to drive the way forward.

From a radiation perspective, a first decision should be whether or not a NORM site requires regulating in terms of the radiation hazard. Decisions in terms of chemical and physical hazards are also required, irrespective of whether radiation hazards are also present. Whether or not a site should be exempt from regulation should be based on a dose assessment that identifies risk. If the decision is made that a site does need to be regulated then the level of regulation required should then be considered. This could be placing conditions on an operator, taking account of the different hazards and risks.

Whilst NORM is not considered in terms of emergency exposure situations, it should be recognised that non-radioactive emergency situations can arise that may pose radiological risks. For example, waste dumps could become unstable or storms may result in tailings being distributed over large areas. Whilst the radiological risks may not be considered an emergency, there can be large costs associated with undertaking required remedial action. Appropriate management of legacies is therefore important to prevent urgent situations from arising.

3 Session 2: Main challenges for regulators and operators in decision-making and management processes at legacy sites

3.1 Regulations and decision making in the management of Belgian NORM legacy sites

Geert Biermans (FANC) presented.

As a result of the geology, the south of Belgium has high levels natural uranium and thorium present. The average dose for a Belgian resulting from natural sources is 2.5 mSv/y. According to national regulations, if working with natural radiation sources, dose to workers and the public must be assessed to demonstrate that doses are below 1 mSv/y. If doses are above 1 mSv/y then corrective measures are imposed. Such corrective measures could be the use of personal protective equipment or limiting the exposure time of workers. However, if such measures fail to reduce doses to below 1 mSv/y then licensing will be imposed. There are a number of different work activities that fall within the category of NORM work, including the storage, handling and processing of phosphate ores, zircon and zirconia, groundwater treatment facilities, coal-fired power plants and oil refineries, production of non-ferrous metals and iron, extraction and transport of natural gas and shale-gas and the production, storage, use and handling of thorium-based materials.

The NORM sectors included under the European Directive 2013/59/EURATOM (the new Basic Safety Standards) have been primarily transposed into national legislation through FANC Decree 01/03/2012, although geothermal energy, which is an important sector in Belgium, was later transposed within FANC Decree 03/03/2016. Remaining activities will be included in regulations planned to be implemented in 2018.

For NORM residues, a different approach has been taken by FANC to the use of 1 Bq/g that is considered in the Basic Safety Standards. The approach of FANC has been to develop risk-based clearance levels for residue producers for each radionuclide, derived from RP 122, part II. If residues exceed these clearance levels then they are subject to notification and a dose impact study would be required. NORM residues have therefore been integrated into the existing radiological protection framework.

There is no direct obligation in the Basic Safety Standards to consider the impacts of radiation on non-human biota, but the position of FANC is that this doesn't mean that it shouldn't be evaluated and sometimes biota assessment is required through integrated environmental impact assessments for classified operators, such as the Belgian Low-Level Waste disposal facility. This integrated approach does not, however, apply to NORM at this moment. No legal requirements are in place that stipulate what models should be used to evaluate the impacts of radiation on non-human biota, but there is guidance available that promotes the use of probabilistic models within a tiered assessment framework.

The majority of NORM legacy sites in Belgium relate to the phosphate industry, with most being located in the north of the country. There is a formal obligation for these sites to be identified and characterised and for exposure assessments to be undertaken in order to determine whether measures are required to reduce risks. This obligation is being taken forward within a draft law regarding the remediation of contaminated soils. This law has been proposed by FANC, based on regional regulations regarding non-radioactive soil contamination.

There can be a lot of money involved in identifying and remediating legacy sites. Currently in Belgium there is an informal approach to dealing with sites that is parallel to classic soil legislation. Remediation projects are established following soil characterisation to consider whether remediation is required and, if so, what options are available. Consideration is also given as to the balance between options in terms of social and cost implications. FANC has a good relationship with regional authorities and interact, providing advice on radiological aspects, when radioactivity is identified as present at a site.

The main challenges for NORM legacy sites include demonstrating compliance against dose criteria, identifying the important processes at play that influence exposure, evaluating the amount of uncertainty and whether it matters, deciding on whether remediation is needed, and evaluating the impact of remediation options. Radioactivity is just one aspect of the problem.

One example of a legacy site in Belgium is the Winterbeek Case. This is a waste disposal site that has releases to two rivers, both of which have been contaminated. The river to the south of the site has been previously remediated.

Ra-226 was released to the river until 1990, along with heavy metals such as cadmium, zinc and arsenic. Dredging has been practised in those rivers and this has resulted in land areas next to the river becoming contaminated. Flood zones are also contaminated. Altogether there is over 700 hectares of land that has been contaminated. The river bed also remains contaminated. The area has been characterised. Radioactivity concentrations range from 8 to 8600 Bq/kg on the left river bank and 15-3700 Bq/kg on the right bank, with average values of 1330 Bq/kg and 810 Bq/kg, respectively. A dose assessment has been undertaken, considering different exposure pathways associated with current use of the area and resultant doses are less than 1 mSv/y. As such, no intervention would be required. However, a risk from indoor radon in the future has been identified and construction of buildings on the contaminated area should therefore be avoided. Monitoring of local workers through the use of dosimeters has also indicated that exposures are not of a level of concern.

As noted previously, however, radionuclides are just one aspect to consider and a risk evaluation for the other contaminants present indicated that cadmium levels were of concern. Interestingly, the contaminated zones are similar at this site for radioactive and non-radioactive contaminants and, as such, radioactivity could be used as a tracer for metals to help identify zones of highest metal contamination. Cadmium contamination in the area exceeded soil remediation levels. Non-negligible impacts on non-human biota were also possible. The chemical contamination at the site is such that remediation is required.

The motivation to remediate the site was therefore the presence of heavy metals and the responsibility for remediation therefore fell to the regional authorities. However, since radioactivity is present, remediation of the site will lead to radiological exposure of workers and the public (under a planned exposure situation). A solution for excavated material is also required.

In deciding on the remediation strategy, land use had to be considered and options weighed. One option is to do nothing, but continue monitoring, since remediation could have a large impact on nature. Decisions were therefore required on a micro-scale for each contaminated area. Protection measures for radioactivity and chemicals can be contradictory and good discussion is needed between chemicals and radioactivity regulators prior to any wider stakeholder engagement to derive a consolidated set of measures that could be employed.

For most NORM legacy sites radionuclides are not the main concern, but decisions on remediation can lead to them becoming of increased concern due to a move from an existing to a planned exposure situation. The example given illustrates the mixed hazards that can be present and some of the issues that can be encountered. NORM is always a mixed contamination and several legal frameworks may therefore apply. It is therefore important to ensure that assessments for radioactivity and chemicals are compatible, even though conclusions may conflict, as demonstrated in this case study. It should also be recognised that risk assessments are just one aspect to consider when deciding on remediation strategies and other aspects may dominate, such as cost relative to risks. It is also possible that sub-optimal options may actually be preferred as the most pragmatic solution.

3.2 Norwegian legacy sites – experiences and lessons learned

Jelena Mrdakovic Popic (NRPA) presented.

The NRPA is the main regulatory body for radiation protection and nuclear safety in Norway. The main roles and responsibilities include:

- Regulating and inspecting radioactive sources and fissile material;
- Regulating radioactive discharges in the environment and the disposal of radioactive waste;
- Leading the Norwegian Nuclear and Radiological Emergency Organisation;
- Monitoring doses to the public and to the environment; and,
- Maintaining an overview of the current knowledge regarding risks and radiation effects.

Basic information on the NORM legislative and regulatory framework in Norway was provided. The revised Pollution Control Act came into force in January 2011, resulting in radioactive waste being regulated alongside other types of pollutants, thus providing a holistic approach to the protection of human health and the environment. The approach to licensing requires facility operators with planned or existing discharges to the environment or disposals of wastes to submit an application that provides information on the company and the discharges or radioactive waste production, handling and disposal. The NRPA then considers that application and requests further information if necessary. A risk assessment is usually provided by operators and checked by the NRPA. This likely includes modelling to undertake a risk assessment, but also other considerations such as future land use, economic and social circumstances are taken into account. Based on this information, a decision is made as to whether the license will be granted or rejected. If granted, the license is formulated and any necessary requirements such as monitoring stipulated.

There are around 170 licenses in Norway for radioactive waste management and pollution, for which the majority (160) are related to non-nuclear related activities. There are five repositories for radioactive waste in Norway, four of which are for NORM and hazardous waste or acid forming rocks.

A case study was presented around the Taraldrud legacy alum shale disposal site in Ski Municipality. The site was operational between 1988 and 1992 and resulted in an area of 50,000 m^3 being filled with alum shales. Alum Shale is regulated by the NRPA according to the Pollution Control Act, but also by the Environment Agency since the shale is considered as contaminated soil/rock. At Taraldrud, acid leaching was officially noticed for the first time in 2006 and stream water analysis identified low pH and high concentrations of trace metals, including uranium. As such, the owner of the site was required to take measures to stop the release of contaminants to the stream, which flows to a river that is used for drinking water. There was therefore a public health risk associated with the site. Between 2008 and 2012, precipitation ponds were expanded and precipitated sludge masses were removed and the disposal site was limed to increase the pH. Whilst these actions improved the situation, problems are still evident at the site (Figure 5).

FIGURE 5. CURRENT POLLUTION STATE AT OLD ALUM SHALE DISPOSAL SITE.

One of the issues in regulatory decision making in this case has been around assigning responsibilities. Although current owner was aware that it would be necessary to clean up the area before future use, he is now neglecting full responsibility since the economic sources needed for resolving the situation are large and the site has become a legacy.

Another issue was technical problem with waste deposition due to waste characteristics. The NRPA was contacted in 2013 following the categorisation of two sludge masses as highly contaminated. The sludge had uranium concentrations up to 8000 Bq/kg, along with high concentrations of metals such as nickel, manganese, cadmium, iron and arsenic and high total organic carbon. Where to dispose of the sludge was therefore an issue due to the mixed contamination, with the disposal sites in Norway being unable to receive the waste. As such, where to dispose of the waste became a state-level issue. It is not permitted in Norway for wastes to be homogenised in order to reduce concentrations of contaminants to levels within permitted disposal limits (1,000 Bq/kg U), but in this case the contamination was very patchy and the decision was made therefore that if the waste was homogenised then it could be disposed of to a proper disposal site. This was implemented in 2014.

When the NRPA considered this case of radioactive contamination of the environment, it was known that redox reactions were ongoing at the site, which resulted in uranium becoming more mobile in the environment. Radioecology was used within a risk assessment to consider speciation of uranium and the spatial and temporal variations at the site. This gave an overview of the degree of contamination. However, with the site being subject to mixed contamination, a cumulative assessment of risk was required. As such, the NRPA and Environment Agency collaborated to apply a complimentary approach to risk assessment. Decisions on actions were still made separately, but the combined approach to assessment was useful in ensuring a coordinated approach.

The NRPA highlighted that there remained areas of uncertainty in risk assessments for areas with mixed contamination however. Tools and approaches for mixtures are required, and more information is needed to support the evaluation of possible synergistic or antagonistic effects from mixed contaminants.

A second case study was presented around the Søve legacy niobium mining site that was operational between 1953 and 1965. The mine is state owned, but the responsibility for cleaning up the site had not been decided until 2011 when the Ministry of Trade, Industry and Fisheries received the mandate to clean up the area. The area is NORM rich and the mining activities have resulted in radioactive waste in the form of rocks, slag and soil (Figure 6). There has been a lot of negative attention at the site with a lot of research being published, but where risk has not been properly communicated, resulting in fear within the local population.

FIGURE 6. FORMER NIOBIUM MINING SITE – LEGACY SITE IN NORWAY

Radioecology has been used at the site in characterising the contamination and undertaking risk assessments. Concentrations of thorium and uranium are high in the area with radioactive waste having NORM concentrations that exceed exemption levels. Outdoor gamma dose rates are also high (up to 20 µGy/h). Dose rates were calculated for non-human biota using the ERICA assessment approach. A high risk was calculated when using Tier 1 of the assessment tool, which was an issue. However, when site data were applied within Tier 2, a negligible risk was calculated, which illustrates the need to acknowledge and clearly explain uncertainties in assessments and to undertake site characterisation studies to underpin assessments. Whilst the risks were not as high as those perceived, NORM concentrations were in excess of 1 Bq/g and, therefore, in line with national legislative requirements, wastes were required to be disposed of to an NRPA licensed site.

Radioecology is the study of the behaviour and effects of radionuclides in the environment and is therefore vital in supporting regulatory decision making around sites affected by radioactivity. Wastes from legacy sites normally contain a range of contaminants, all of which need to be addressed properly. Tools are available to support risk assessment for contaminants, but these tend to include default parameters. For these models to be intelligently applied to a situation, intelligent users are required.

Radioecology provides information on the speciation of radionuclides, their bioavailability, particle speciation and weathering, all of which are important in characterising a site. Radioecologists can also be intelligent users of assessment models, understanding important aspects in models and key uncertainties. The transfer of scientific knowledge to support regulatory approaches is not trivial; decision making must be guided by sound scientific judgements. Science can help in the development of standards for protection of people and the environment and in the development of integrated approaches for different contaminants and endpoints, and also in addressing data and knowledge gaps. Science can also be used to support stakeholder communication.

3.3 The problems of implementation of the international safety criteria (BSS 2014) in modelling systems for public safety justification

Alexey Kiselev (IBRAE RAN) presented.

In order to justify population safety outside of a site for scenarios related to emissions of radioactive substances into the environment, modelling systems are largely used to evaluate the transfer from the source to the population, taking account of the dispersion of radionuclides in the environment. Calculated doses then need to be compared against appropriate criteria (national or international).

There is a current task underway to improve existing models for the purpose of comprehensive safety justification, in line with international recommendations of the Basic Safety Standards. However, during the implementation of these standards, a number of problems have been identified. For example, different approaches to the application of generic safety criteria are used to solve the problem of safety justification. There is also the problem of aggregating data from different sources and address data gaps. This leads to a difference in the constant supply, which in turn leads to problems in communication between different groups and justification the constant provision in the supervisory bodies. Especially for the purpose of safety justification of nuclear-legacy facilities and radioactive waste disposal sites for accident scenarios related to atmospheric emissions of radionuclides it is necessary to take account of the specifics of the release source, yet the methodology of population safety justification needs to be universal and transparent.

Both internal and external events can lead to the release of radionuclides into the environment. External events include seismic impact, fires, loss of external power supply and extreme weather events. Internal events include violations during transportation and technological operations and fires. There can also be initial events beyond design basis accidents, such as explosions or aircraft crashes. In order to evaluate the potential impacts of such events, parameters around the source term are required, including radionuclide composition and release dynamics and the chemical form of radionuclides. Then, depending on the problem to be solved, a decision is required as to the radionuclide dispersion approach that will be applied – either probabilistic or deterministic. In order to then convert baseline values around the source to doses, a range of parameters are required, including data on exposure pathways, and the development of a “self-consistent” database of the required parameters can be a big challenge.

The process of compiling a constant set of data is complicated, largely due to the combination of different sources of data that are needed. Tables need to be compiled for different radionuclides that allow the integration of dose rates in organs for different periods separately for radiation with low and high LET. It is also necessary for some data to build algorithms to fill missing data, for example for some physicochemical forms of radionuclides. Specific parameters are also required to address the different events, such as coefficients for aerosols and dusts generated during fires or explosions etc. How appropriate these data are under different exposure situations, when no specific information on solubility of particulate aerosols, particle size distribution, chemical compounds, etc. is available, is questionable. Whether or not these coefficients can be considered as reference data is also questioned.

The Basic Safety Standards provide generic criteria for protective actions and other response actions in emergencies to reduce the risk of stochastic effects. The use of this data seems simple, but there are problems. For example, in different documents there are different approaches taken to dose assessment and endpoints differ (critical group, reference person, multiple reference age groups etc.) and the ambiguity in the choice of endpoint and baseline of codes used can lead to problems in aggregating calculation results from different expert groups working on the same project in different areas of safety justification , for example, groups working on assessments for normal operation, project accidents and beyond design accidents.

The Basic Safety Standards table of protection actions for acute dose criteria is even more complicated. For example, two criteria are given for red bone marrow for an acute internal exposure, depending on the atomic number of the radionuclide, and these differ considerably from the single criteria given for red bone marrow following acute external exposure. Whilst there is a clear scientific basis for this, it is difficult to implement within assessment codes, particularly when there is a mixture of radionuclides or long-term exposure via inhalation pathway.

Therefore, in order to develop and implement codes to demonstrate the safety of populations, taking into account international recommendations in the field of radiation safety, it is necessary to develop approaches to the use of common criteria for safety justification and develop self-consistent databases for use in modelling systems. Methods for the practical use of international intervention criteria and for justifying the safety of nuclear facilities are also required.

3.4 NORM and other radioactive legacies of a multi-faceted history

Rainer Gellermann (Nuclear Control and Consult) presented.

The definition of a legacy can vary according to the context. In terms of radioactive legacies, these can be considered as a heritage of burdens instead of benefits, and result from a shift of values in society. For example, uranium mining can provide societal benefits when mines are operational, but when mining activities are terminated, the mining sites no longer bring societal benefits and instead become burdens.

There are a number of challenges for radioecology in relation to radioactive legacies, including the estimation of existing exposures to members of the public, assessing and communicating results, justifying remediation measures, and optimising radiation protection in consideration alongside environmental effects and regional development.

In 1991, the German Commission on Radiological Protection (SSK) published recommendations on radiation protection regarding uranium mining. These recommendations were based on the ICRP recommendations for intervention and delivered a guidance for assessment and remediation of radioactive contaminated areas and mining heaps.

A particular situation regarding remediation of uranium mining legacies was the uranium mine Koenigstein. In this mine the uranium was extracted from a sandstone deposit by sulphuric acid leaching. For the leaching procedure certain segments of the rock were blasted in order to enable an effective access of the acid to the rock. Because several of such segments of rock had been prepared for leaching, the operator of the Koenigstein Mine, the Wismut GmbH had submitted an application for a limited production of uranium. On the other hand, the German government has decided to terminate the uranium production. Therefore, the question arose: must the uranium be extracted in order to prevent a strong mobilisation with potential groundwater contamination from uranium in the future or is this not necessary. In a study that analysed the scientific basis of the application, as well as the technical options for reduction of unwanted effects, the final conclusion was that a significant risk will remain that the uranium could mobilise in the future. In spite of this, the application of Wismut was denied.

However, more recently there have been a number of newspaper articles and other reports relating to uranium production in Germany. For example, an article in 2010 reported that a remediation company removed between 30 and 40 tonnes of uranium concentrate to a US company and in 2016 it was reported that, whilst uranium production is no longer allowed in Germany, the cleaning of mine water results in the extraction of uranium.

From a societal point of view, this recent burden can be considered as a legacy, but from a radiation protection point of view it can be considered as an unintended planned exposure situation.

A quite other type of legacies are related to former chemicals plants. As an example, a chemical plant that was operational from 1862 until 1902 in the village of List near Hanover can be considered. In 2008 radioactive contamination was discovered within a residential area and in an allotment area about 1km northward. The contamination spread out over public streets and squares as well as private properties. Investigations demonstrated that, besides radioactive contamination, the soils were polluted with chemical substances, particularly heavy metals.

The challenges for radioecology from this situation included estimating existing exposures, assessing and communicating the results and deriving proposals for remediation measures. There were also particular problems faced by authorities because there was no legislative framework in place for radiation protection from legacies, but only in relation to a Soil Protection Law. As such, initial risk assessments had to be derived on the basis of soil protection methods, with the risk of ingestion / inhalation of soil particles being used to develop a basic benchmark for radionuclides considered to be carcinogenic substances in soil. Despite soil protection scenarios being different from those that would be used for radioactively contaminated sites, the results obtained for a playground scenario have to be proven as applicable.

Experience gained from communicating the results to members of the public included that radioactivity is perceived as a very special treat and communicating facts around risks, whilst necessary, is not sufficient in itself; people need to be involved. In radioecology, we tend to communicate in terms of risk, whereas journalists work in terms of danger and the distinction can be difficult to communicate – there is a (chronic) risk, but no (acute) danger. Overall, communication around hazards needs both rational and emotional arguments.

A number of questions also arise from the experience gained. The first of such questions refers to radon and how radon from soil contamination should be integrated into dose estimates. Enhanced radon concentrations detected in several dwellings of the contaminated residential area can clearly be attributed to the radioactive contamination of the ground. If this radon is assessed with the same benchmarks as an existing situation, i.e. 300 Bq/m^3, a radon contamination with calculated doses that exceed the reference level of 1 mSv/y will be accepted in dwellings with enhanced radon concentrations below the reference value.

A second question refers to the fact that the contaminations as a result of the historic practices at the site were not only radiological and the issue of how to consider mixtures of substances remains unresolved up to now.

For communication with the public, a methodological basis for deriving dose values for most of the people in the contaminated area was missed. All radiological approaches tend to be conservative in estimates and, consequently, the public is informed about doses that exceed the realistic ones of the overwhelming number of people by orders of magnitude.

Furthermore, it has to be mentioned that the legacy contamination may result in cost implications for property owners, even where no remediation is required. As long as radioactively contaminated soil remained at a plot, any excavation work requires special management of the soil material and leads to additional costs to the owners. Consequently, the contamination also affects the value of properties. Even if the ground is remediated, there is the possibility that society will consider the property in the same way. Whether or not the influence of radiation on the value of a property falls within the subject of radioecology was questioned, along with whether such issues should be considered in decision making.

3.5 Discussion relating to challenges for regulators and operators

In order to improve and validate assessment models that are used to support decisions around legacy site management and evaluate and select remediation options, it may be beneficial to evaluate these models relative to the post-remediation situation and compare the model output against what has happened in reality. Post-remediation assessment is done for some sites and, in some cases, deviations have been found. For example, radon emanation has been found to be much greater than modelled in remediated piles at one site resulting in additional measures being required. At other sites, however, all radionuclides may be removed and, as such, post-remediation monitoring may not be required, thus comparative models and data may not be available.

4 Session 3: Main radioecological uncertainties in up to date assessments - issues to be addressed in future collaborative work at international level

4.1 Systematic evaluation of knowledge base for demonstration of compliance

Ari Ikonen (EnviroCase) presented. The presentation was largely based on an earlier contribution to a radioecology conference[2].

For safety assessments, the verification and validation of models is needed, along with a focus on safety relevant issues. Qualitative uncertainties also need to be considered. Both SKB and Posiva have used protocols and questionnaires as part of a systematic evaluation of the knowledge base supporting models and assessments. A knowledge quality assessment (KQA) has been used in Posiva's biosphere assessment and has also been tested as part of the BIOPROTA programme in relation to biota dose assessment. The KQA approach has now been extended to other parts of the safety case programme of Posiva.

Most aspects of the KQA approach were derived from the NUSAP system, which is a notational system for the management and communication of uncertainty in science for policy. It is based on categories for qualitatively characterising any quantitative statement and is commonly further linked to sensitivity auditing. There are also several derivatives and similar approaches applied in various contexts, such as contaminated land management, climate change studies and policy, and pharmacology. The key question in many assessments, including those for nuclear waste and NORM, is whether or not there is sufficient confidence to allow decisions to be made on the next step of a programme.

Aspects that should be evaluated include:

- The purpose, context and evaluation criteria, i.e. framing the assessment context, which is important and helps to define the roles of people within the process;
- Model formulation and implementation;
- The main modelling assumptions;
- Data sources and their main uncertainties;
- Consistency;
- The meaning of assumptions, uncertainties and deficiencies / limitations (i.e. sensitivity, uncertainty and scenario analysis); and,
- The overall view and synthesis.

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[2] Ikonen, A.T.K. & Kangasniemi, V. 2017. Comprehensive and systematic knowledge quality assessment as a tool for model qualification. In: Garcia-Tenorio, R., Holm, E. & Majón, C. (eds.). II International Conference on Radioecological Concentration Processes (50 years later), Seville, Spain, November 2016: Book of proceedings. Department of Applied Physics II, University of Seville, Spain. ISBN 978-84-617-7629-0. pp. 621–628.

Assumptions will always be needed in assessments and their impact on the outcome can be more critical than that revealed by direct numerical modelling. It is therefore important that all assumptions are clearly documented to maintain transparency and consistency in assumptions across assessments to be maintained. Whilst there will always be uncertainties in assessments, whether or not those uncertainties matter should be evaluated.

For conceptual and mathematical models, comprehensiveness should be demonstrated, which is particularly important in public communication. To demonstrate comprehensiveness, lists of features, events and processes (FEPs) can be used to audit what is included in models and what can be justifiably excluded. Interaction matrices can also be useful in demonstrating comprehensiveness and linking the different FEPs. Once a conceptual model has been described it must be implemented as a mathematical model, which necessarily requires simplifications, each of which should be documented. The level of model complexity that is appropriate should also be considered. A further approach that can be taken is to evaluate the strength of process understanding, i.e. pedigree scoring. This considers the theoretical and empirical quality and the degree of acceptance.

To address the main assumptions in assessments, these can be categorised and considered in terms of the main assumptions and the consequences of the use of alternative assumptions. Strength scoring can also be applied to evaluate plausibility, subjectivity, the availability of alternative choices and the influence of situational limitations. The sources of data and associated uncertainties should also be evaluated, including the choice and justification of the use of deterministic, best estimate and distributed values. The rationales and systematics of data selection and the impact on the conclusions should be documented. An example of the categorisation of the main assumptions is illustrated in Figure 7. and strength of data basis in Figure 8.

Categorisation of assumptions for broad characteristics and evolutionary path followed by the system and conceptualisation of phenomena	
LE	Conceptual assumption corresponds to the likely/expected characteristics and evolution of the system.
PCA	Pessimistic conceptual assumption within the reasonably expected range of possibilities.
WRP	Within the range of possibilities but likelihood not currently possible to evaluate — other (and sometimes more pessimistic) assumptions may not be unreasonable.
ST	Stylised conceptualisation of system characteristics and evolution.
Categorisation of simplifications made for modelling purposes	
MS	Modelling simplification — not significantly affecting numerical results.
CS	Modelling simplification — intrinsically conservative.
CP	Modelling simplification — conservative given the assumed model parameters.

FIGURE 7. EXAMPLE CATEGORISATION OF MAIN ASSUMPTIONS (FROM POSIVA 2012-28[3], BASED ON NAGRA, 2002[4]).

[3] Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto - Data Basis for the Biosphere Assessment BSA-2012. Posiva Report 2012-28.
[4] Nagra 2002. Project Opalinus Clay: Models, Codes and Data for Safety Assessment. Nagra Report NTB-02-06.

Score	Empirical, statistical and methodological quality ᵃ	Parameterisation ᵇ	Spatial variability in the scale of the site ᶜ	Robustness against time scales and external conditions ᶜ	Appropriateness for the site ᶜ
3	Controlled experiments, direct measurements, historical or field data. Good or better fit to a reliable statistical model by most fitting tests. Best available practise, or reliable method common within established discipline.	An exact or good description or measure of the process.	It is *unlikely* that the process / parameter value is significantly different in other parts of the site, or the variability has been included in the model/data.	*Unlikely* that the process or parameter value will be *significantly* altered over time or due to changes in the external conditions.	Data specific to the site or to the Reference area (section 1.4.2); or site-independent data and *very likely* that the data are appropriate.
2	Modelled data, indirect estimates. Acceptable method but with limited consensus on its reliability.	Fairly good but simplified representation of the process, or an aggregate measure with adequate information on conditions.	There is a *medium likelihood* that the process / parameter value is significantly different in other parts of the site, or the variability has been included in the model/data but the spatial extent is inconclusive.	*Medium likelihood* that the process or parameter value will be *significantly* altered over time or due to changes in the external conditions.	Data from similar sites; *likely* that the data are appropriate.
1	Handbook estimates, indirect approximations. Preliminary methods with assessed reliability.	Very simplified representation or measure of the process, considering only basic properties.	It is *likely* that the process / parameter value differs in parts of the site, or the variability has not been included in the model/data.	It is *likely* that the process or parameter value will be *significantly* altered over time or due to changes in the external conditions.	Data from other similar sites; *medium likelihood* that the data are appropriate.
0	Educated guesses, rules of thumb, very indirect approximations. Preliminary methods with unknown reliability.	Poor representation of the process, or measurement likely not totally appropriate or likely not bound with relevant conditions.	It is *virtually certain* that the process/parameter value is significantly different in the areas not covered.	It is *virtually certain* that the process or parameter value will be *significantly* altered over time or due to changes in the external conditions.	Data from other sites; *unlikely* that the data are totally appropriate.

FIGURE 8. EXAMPLE SCORING SYSTEM FOR STRENGTH OF DATA BASIS (FROM POSIVA 2012-28[1]).

To evaluate consistency, the interactions and consistency between different modelling stages and disciplines could be evaluated in terms of which aspects are necessary, which have been implemented and how, and which have not been and why and what is the impact of the omission. Depending on the assessment context it may also be appropriate to compare consistency with understanding of the past evolution of the system or with observations from analogous systems. Consistency with past model versions could also be usefully evaluated as could consistency with other similar models through model-model comparisons. All these aspects can help in ensuring that underlying reasons and the overall significance of differences are understood and explained in appropriate detail.

It may also be useful to compare the strength of knowledge base with the sensitivity of the model/assessment to different parameters/assumptions, as illustrated in Figure 9. Such an approach can help to illustrate what uncertainty matters and to identify key focus areas that could be targeted to reduce assessment uncertainty.

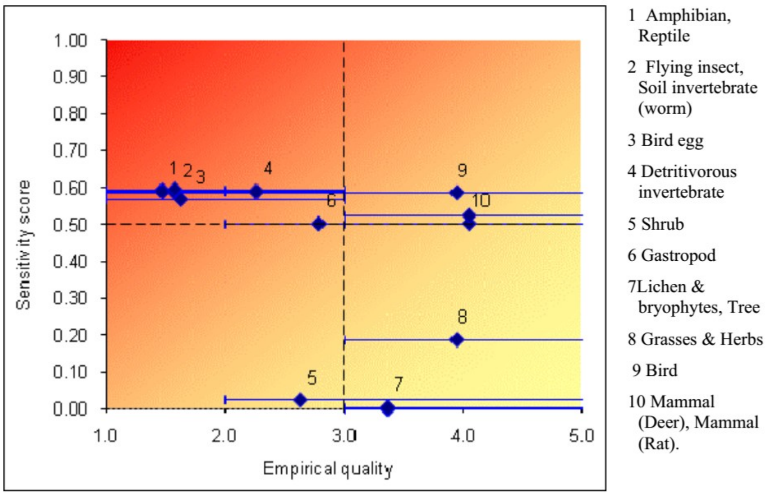

FIGURE 9. MEANING OF UNCERTAINTIES: STRENGTH VERSUS SENSITIVITY (FROM SMITH ET AL., 2010[5]).

Drawing an overall view of uncertainties through a synthesis of the different uncertainties and their importance can be beneficial and one approach could be to develop an uncertainty matrix that can help to illustrate the uncertainties. An overall statement on uncertainty within an assessment that

[5] Smith, K., Robinson, C., Jackson, D., De La Cruz, I., Zinger, I. & Avila, R. (2010). Non-human Biota Dose Assessment: Sensitivity Analysis and Knowledge Quality Assessment. Posiva Working Report 2010-69.

is set within the overall framing of the problem could be made and arguments put forward as to the confidence in the knowledge base and its reliability in supporting decision-making.

4.2 Estimation of radiation exposure for the population living at radioactively contaminated areas as a base for criteria development for its categorisation

Sergey Lukashenko (IRSE) presented.

The Institute of Radiation Safety and Ecology (IRSE) in Kazakhstan undertakes large-scale evaluations of risk from contaminated sites, with a particular focus on artificial radionuclides.

If we look back 25 years, there was a common perception that everything within the Semipalatinsk nuclear test site was contaminated. Nowadays, however, there is a much greater understanding that contamination is patchier. An inventory has been made of the hazards across the site and the reality is that, in many instances, the contaminated areas are very localised and, as such, there is no need to place controls on all of what is a huge territory. As such, full-scale environmental investigations were carried out between 2008 and 2016 across the 8,610 km^2 territory to investigate the levels of contamination spatially and to decide on whether areas could be used for economic purposes. Of the total territory area, only 300 km^2 was recommended to be used only for industrial purposes, and a much smaller area was deemed unsuitable for any use. The site investigations included:

- Detailed investigation of soil contamination by artificial radionuclides, including bioavailability;
- Assessment of the current hydrogeological conditions and characteristics of the water environment and forecasting dynamics in its change as radionuclides migrate;
- Evaluating radionuclides in plants and both wild and domestic animals; and
- Evaluating air pollution.

An assessment scenario was established around an assumed substantial farm to consider the doses that people living in the area may be exposed to. It was assumed that people would live in the area and grow vegetables and raise agricultural animals with produce being consumed. The assessment was to inform decisions around the possible future use of areas of the site. However, as the assessment progressed it became apparent that there were few data available for many of the required assessment parameters, such as the transfer of radionuclides to sheep's milk, eggs, mutton and horse meat. An experimental area was therefore established in 'ground zero' to obtain the required parameters under natural conditions. A variety of crops were grown and animals raised at the site.

Results for the transfer of radionuclides from soils to plants indicated that much of the literature data that were available were not appropriate to the site. It was also noted that there was a need to take into account the intake of soil by animals when foraging. The intake of radionuclides from soil and water were also very different.

On the basis of the data gained from the site studies, the annual effective dose was calculated for the different radionuclides. The radionuclide concentrations giving rise to a 1 mSv dose were also back calculated. When compared against information within the Basic Safety Standards, a large difference was observed. From this, it was concluded that more precise consideration of exemption / clearance levels is required on the basis of real estimates of dose for a given environment.

The dose from inhalation was also estimated for each radionuclide and, again, a reverse calculation was performed to derive the concentration in soil that would relate to a dose of 1 mSv. Large differences were again observed between data from a real site and those in the safety standards.

Whilst it is possible to calculate the intake of radionuclides from different pathways and resultant dose, it should be recognised that calculations may be wrong; exposure pathways may have been missed. An experiment was therefore conducted to provide reassurance to the population living in Sarzhal village, near to the test site. The village is located within the plume contamination area from the test site and is, as such, slightly contaminated. Investigations were undertaken of radionuclides in air, in livestock etc and biokinetic models were used to derive concentrations in the body. Body counts were also taken for individuals. The results showed some consistency between models and measured exposures, helping to provide reassurance to the population.

4.3 Long-term safety assessment: results from expert interviews

Claudia Koenig (Leibniz University Hannover) presented.

A series of expert interviews, based on two dose models, were conducted as part of the ENTRIA project on disposal options for radioactive residues: interdisciplinary analyses and development of evaluation principles. The interviews were based around regulatory establishment of dose assessment concepts for the final disposal of radioactive waste.

In Germany, a fixed calculation model is used for radioecological dose assessment for regulatory purposes and is used for routine discharges from nuclear power plants (atmospheric and surface water pathways). The model is used for licensing over a 40-year timeframe with doses being compared against a public dose criterion of 0.3 mSv/y. Whilst other models are available, this particular model has a strong position within the German regulatory framework. All model parameters are stipulated and the model is very conservative in terms of water and food ingestion rates and time spent outdoors.

A second dose assessment model considers the long-term safety assessment for final disposal where a distinction is made between processes in the near-field, far-field and biosphere and different scenarios and FEPs are considered. Different public dose criteria are also applied according to whether scenarios are probable (10 µSv/y) or less probable (<0.1 mSv/y). Assessments for waste disposal consider a time span of 1 million years.

Six interviews were held with experts from relevant institutions (Federal Office for Radiation Protection, German Commission on Radiological Protection, Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH, and the National Radiation Protection Association). Each interview was taped and transcribed anonymously, prior to being analysed.

The results of the surveys fell into two clusters:

- Dose models are too conservative; there is a view that the high demand on legal safety for licensing process for nuclear power plants has led to very conservative calculation assumptions. The survey results also highlighted a need for harmonisation of the two existing main models for dose assessment and that, while biosphere modelling has little impact on safety considerations regarding a waste repository, it is needed for communication around the migration of radionuclides.

- During the licensing procedure for low level waste and intermediate level waste there was repressed discussion on improvements to the radioecology dose assessment model. There was no interest among regulators to openly discuss the model since this could have resulted in greater issues.

There is a perceived and clear difference between how scientists and regulators work (Table). The reality is, however, that regulatory approaches do address many of the areas that are criticised. For example, regulators may commission work that then provides the results from studies and experiments that are required to support decision making. Whilst it may be perceived that uncertainties are not addressed, the regulatory approach tends to be conservative through, for example, use of worst case scenarios to ensure risks are not underestimated and, whilst it may be perceived that debate around policy and decision making is not possible, in reality there are court proceedings that are themselves a form of debate.

Radioecology helps in developing understanding and provides the basis for legal safety and decision making. The regulatory needs for a site have a large impact on how models are derived and applied.

TABLE 2 PERCEPTIONS IN THE WAY THAT SCIENTISTS AND REGULATORS WORK

Science	*Policy analysis/science based assessment*
Empirical validation	Prognosis without evaluation
Planned studies and experiments	Secondary use of information
Fully reproducible	Typically no repeatability
Publication after success	Assessment after request
Discussion of the results	Uncertainties incomplete
Peer review	Review is not standard
Open debate	Debate not possible

As a result of this work, a number of questions arose:

- How strong are the demands on legal safety to the radiological dose assessment?
- Is increasing conservatism a useful approach to strengthening the legal safety for long-term safety assessment?
- How to deal with the demand for information on dose when predicted dose becomes highly uncertain? When demonstrating compliance, every number used and created can be taken and evaluated and not enough thought given to the derivation of the numbers used; values are often taken as being reality. Whilst conservative approaches may be appropriate, consideration should also be given to realistic values to show what is really expected.
- How can radioecological dose assessment be improved during ongoing licensing processes?

4.4 Safety assessment for remediation of a legacy waste facility: a Dounreay case study

Russell Walke (Quintessa) presented.

Dounreay in the UK was a centre for fast-breeder reactor research from the 1950's to 1990's that included full fuel cycle capabilities. The site is currently being decommissioned and restored.

The site has a shaft that was excavated in 1956, during the construction of a liquid effluent discharge tunnel under the sea. The shaft is situated just above the present-day foreshore. The geology consists of sandstone and siltstone with both major and minor faults and fractures being present.

The shaft was authorised for the disposal of intermediate level radioactive waste, with around 700 m^3 being disposed between the 1950's and 1970's. In 1977 there was a build-up of hydrogen that led to an explosion in the top of the shaft. Disposals ceased following this event. The wastes that were disposed remain below the present-day sea level. The records of the waste that was disposed are not of the standard that would be required today, so there is some uncertainty around the inventory.

In 1998, the UK Government approved a strategy for retrieval and treatment of waste from the shaft. The first phase of the work involved the drilling and grouting of 400 boreholes to hydraulically isolate the shaft and the construction of a raised working platform; this phase was completed in 2006. The second phase of work will involve the retrieval and treatment of the waste prior to appropriate disposal / storage. This second stage is due to begin in 2020 with the construction of new facilities required to achieve this objective.

An environmental safety case for the remediated shaft was completed and submitted to regulators in 2009. The safety case included an assessment of the post-closure safety of the residual contamination that would remain in the rock around the shaft after the wastes have been retrieved. The post-closure safety assessment followed the IAEA ISAM methodology. The main objective was to assess the potential risks associated with residual contamination against a risk target level of 10^{-6} for people and against a screening dose rate of 10 µGy/h for biota.

During drilling for installation of the hydraulic isolation barrier, measurements were made to help improve understanding of contamination that will remain in the rock after the wastes have been retrieved. Results of the measurements gave an inventory of residual contamination of 5.2E11 Bq, dominated by a few radionuclides, primarily Cs-137, Sr-90 and Am-241. In addition to the measurements, a second inventory was developed by modelling an estimate of the historic disposals. The modelling gave an inventory of 5.5E12 Bq and was taken as providing an upper-bound estimate of the residual contamination. The measurements illustrate clear zones of contamination that match onto the horizontal fractures and groundwater flows.

The post-closure safety assessment took account of different future scenarios. A normal evolution scenario assumed that the coastline is subject to continuous coastal erosion with sea level rise continuing over the next 10,000 years, resulting in erosion of the rock above the shaft and the residual contamination being beneath the sea. In the very long term (after 100 000 years), the sea level will fall and the land above the shaft will re-emerge from beneath the sea. Alternative scenarios were used to test uncertainties about the time scales of these changes and to consider events such as inadvertent borehole intrusion.

Conceptual models were developed for how residual contamination may migrate, taking account of near-field and geosphere evolution and key processes in the biosphere such as foreshore erosion, exchange with marine water, sea to land transfer and sea level rise and fall. The complex time-dependent spatial evolution of the system was therefore explicitly represented.

The location of fractures in the geosphere is known as a result of the hydraulic isolation barrier boreholes, however, the potential groundwater discharge pathways from the contamination to the surface are not so well known. The discharge pathways will also evolve over time as the grout curtain evolves and the relative position of the sea changes.

Two conservatively defined local exposure groups were considered (a farmer and a fisherman), to help ensure that potential risks will not be underestimated. In addition, groups representative of more typical habits were also included. Non-human biota dose rates were assessed using ERICA for biota in terrestrial, foreshore, marine and future freshwater environments.

The three-dimensional, time-evolving post-closure assessment model was implemented in the AMBER compartment modelling code. The flow of radionuclides along fractures was modelled, allowing for sorption onto fracture surfaces and diffusion into the rock matrix. An irreversible sorption capacity was observed in measurements for caesium and reflected in the modelling. Probabilistic modelling was used to explore sensitivities.

The model results for fracture surface concentrations in the vicinity of the shaft were found to be consistent with observations. The model shows that much of the residual contamination is expected to remain within the hydraulic isolation barrier, and so containment is considered to be good. The highest calculated discharges to the surface were only 0.1 GBq/y, which is lower than present-day authorised discharges from the facility.

For the normal evolution scenario, calculated conditional risks remain more than two orders of magnitude lower than the risk criterion throughout the assessment, even for the conservatively defined local exposure groups. The highest calculated dose to humans was calculated for a borehole driller through inadvertent intrusion and was only 0.04 mSv/y. In addition, this scenario is also of likelihood because it may only arise in a window of time between the end of institutional control after 300 years and inundation of the site, which is expected to occur within 1000 years. The highest calculated biota dose rate was a factor of 100 lower than the screening value

The environmental safety case for the remediated shaft has been accepted by the regulator.

The case study demonstrates how understanding of complex legacy sites can be used to support assessments of post-closure safety. Tools like AMBER have the capability to handle the time-evolving, three dimensional characteristics inherent in assessing these types of system.

4.5 Discussion relating to assessments and uncertainties

Although necessary for compliance purposes, assessments based solely on conservative assumptions with regards to human habits may not address concerns of local stakeholders, who will be interested in seeing that those living with lifestyles consistent with their own will not be adversely affected. The use of more realistic exposure groups to complement the traditional conservatively defined groups can help to answer those concerns. Such an approach also helps to demonstrate the additional 'safety margin' that is inherent in adopting conservative exposure assumptions.

5 Session 4: Key Conclusions from the Workshop

Decision making at most legacy sites requires integrated assessments of the risks associated with both radionuclides and chemicals that are present together. Whilst approaches for impact assessment have been established separately both for chemicals and radionuclides, these are not necessarily consistent and it is evident from examples presented that issues can be faced when addressing risks from chemicals and radionuclides, both on people and the environment. Whether a fully integrated assessment approach could be developed that is balanced and proportionate to risk from radionuclides and chemicals both on people and the environment, or whether a separate risk assessment approach should be preferred, it will require further thought and discussion at an international level, involving both decision makers and scientist. A fully integrated assessment should take account of impacts on both humans and non-human biota and both chemicals and radionuclides.

Further development of specific areas of impact assessments in terms of EIA and ERA are also needed. For example, further dynamic based model development and improved parameterisation of key processes, including updated databases etc. are needed to help determine ecological consequences under realistic circumstances.

A first step in dealing with legacy sites is to characterise the situation. Once characterisation has been completed it is possible to assess transfer and dispersion if radionuclides (and other contaminants) and resulting exposure. The dose criterion together with other criteria to be considered should allow to indicate whether it would be appropriate or not to undertake remediation. Where remediation is appropriate, the remediation options should be optimised. For legacy sites Reference Levels should be set relative to the specific situation, i.e. on a case-by-case basis. Remediation options should then aim to provide a solution that results in the selected Reference Level being met thereby still considering other criteria. Throughout the process it is important to draw together the people with appropriate skills that can assess the situation, identify what is important, and what should be done.

It is also important to consider the characteristics of the contaminated environment when undertaking assessments and selecting parameter values. The chemical form of a radionuclide and the environmental characteristics will affect transfer and dispersion processes to a large extent. The chemical form of a radionuclide will also affect whether or not ruling dose coefficients are appropriate. There has been a recent example where dose coefficients for C-14 have been challenged, resulting in a factor of 40 reduction in the dose coefficient for C-14 ingested via drinking water due to the chemical form of C-14 in water as compared with foods. Carbon-14 is an important dose contributor in many radioactive waste disposal safety assessments and this reduction has therefore had important implications for the radioactive waste disposal community.

It is recognised that the evolution of a site over time is an important factor to take into account in assessments and decision making, and also in post-remediation assessment. Furthermore, land use and restrictions all have to be tied back to pathways and exposures. Radioecology has an important and essential role to play in answering these site-specific questions. It can help identify what is relevant to a site, provide guidance on aspects from monitoring approaches and frequency to assessing the implications of the movement of contamination from one area to another, and in identifying and evaluating exposure pathways, amongst others.

Communication of uncertainty, risk and dose are particularly important aspects of legacy site management, particularly when technical people are required to communicate technically complex or potentially contentious issues to a broad stakeholder group. Regulators need to show compliance against dose limits, but presenting and demonstrating compliance can be difficult. Even if results of dose assessments are well below dose limits, there can still be a perceived risk as far as members of the public are concerned. For example, particular concerns may arise in relation to the persons' activities or of their children and regulators must be prepared to answer these questions (there is no 'average person' or 'average concern'). The needs of the people may not therefore be met by simply demonstrating that impacts will be below a limit. It is also important to recognise that the public does not always understand limits and communication therefore should be targeted at an appropriate level. The use of scales for comparison that the public can readily understand can help in communication. This could involve comparing one situation to another or placing risks associated with one situation relative to accepted risks (e.g. flights, medical treatments etc.).

Experience has shown that the early engagement of stakeholders, and maintaining that engagement throughout the lifecycle of a remediation programme is beneficial. Engaging with the public contributes to transparency, helps reduce controversy and build public acceptance; whilst people may not want the responsibility for decision making, they do want to have their voices heard.

Whilst it is recognised as highly beneficial to engage with stakeholders, there can be issues encountered. For example, identifying relevant stakeholders can be difficult, particularly for smaller sites. It is important to recognise that wide engagement may be an ideal situation, but it may not be practicable; stakeholders will have other day-to-day commitments and it may be necessary to find ways to work around these commitments.

It was considered that there could be benefit in learning from how regulators in different countries have approached stakeholder consultation, particularly around how stakeholder engagement processes have started for different programmes, the strategies that are proven to be beneficial and particular lessons learned. This could also involve lessons learned around the identification of appropriate stakeholders. Training in communication could also be beneficial or, alternatively, experienced mediators can be used to manage the stakeholder engagement process. The use of mediators can help ensure that people have the opportunity to express their views, ensure that technical information is presented in an appropriate way and support the making of decisions that are within regulatory boundaries.

Radioecologists can contribute to discussions and to the overall decision building process to help address stakeholder concerns. For example, experiments could be established to address specific issues or measurements could be taken of food products etc. to assess levels of contamination or to address unknown aspects of exposure assessments. For example, in Australia, there is work ongoing on oil and gas decommissioning and decisions need to be made as to whether offshore rigs and pipelines can be left in place or whether they need to be removed. There is, however, little information available on the environmental impacts of rigs and pipelines. Notable knowledge gaps arise in relation to the precipitation of NORM scale and dose to non-human biota from exposure to that scale. Experiments are needed that look at pipe degradation and the implications for biota that occupy the degraded pipes. Where the exposure of an individual is evaluated, there are then difficulties associated with extrapolating that exposure to impacts at the population level (and in defining what the relevant population is). Radioecology can help address these issues, but it is important to ensure that funding is directed to addressing the key radioecology issues that will support decision making.

Radioecology therefore has an important role to play in NORM and legacy site management, from characterising the situation, through identifying exposure pathways and calculating doses, to supporting decision making and communicating with stakeholders.

Key to addressing the need for holistic and integrated assessments of the risks associated with legacy sites is ensuring that there is coordination and consistency in international activities and the guidance they produce.

Appendix A. List of participants

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

Participant	Institution	Country
Tom Cressvell	Australian Nuclear Science and Ecotoxicology Organisation (ANSTO)	Australia
Tamara Yankovich	International Atomic Energy Agency (IAEA)	Austria
Geert Biermans	Federal Agency for Nuclear Control (FANC)	Belgium
Hildegarde Vandenhove	Belgian Nuclear Research Centre (SCK CEN)	Belgium
Wu Qifan	Tsinghua University	People's Republic of China
Petrus Bompere Lemo	Comité National de Protection contre les Rayonnements Ionisants	R.D. Congo
Ivana Tucakovic	Institute 'Rudjer Boskovic'	Croatia
Andrei Goronovski	University of Tartu	Estonia
Alan Tkaczyk	University of Tartu	Estonia
Rein Koch	University of Tartu	Estonia
Maria Marouli	European Commission (EC)	European Union
Ari Ikonen	EnviroCase Oy, Ltd	Finland
Ville Kangasniemi	EnviroCase, Ltd.	Finland
Jean Francois Lecomte	International Commission on Radiological Protection (ICRP) and IRSN	France
Edward Lazo	OECD NEA	France
Karin Wichterey	Bundesamt für Strahlenschutz (BfS)	Germany
Claudia König	Leibniz University, Institute for Radioecology and Radiation Protection	Germany

Rainer Gellermann	Nuclear Control & Consulting GmbH	Germany
Sergey Lukashenko	Institute of Radiation Safety and Ecology	Kazakhstan
Zhanat Baigazinov	Institute of Radiation Safety and Ecology	Kazakhstan
Nina Bratteteig	Norwegian Radiation Protection Authority	Norway
Solveig Dysvik	Norwegian Radiation Protection Authority	Norway
Marte Holmstrand	Norwegian Radiation Protection Authority	Norway
Jelena Mrdakovic Popic	Norwegian Radiation Protection Authority	Norway
Malgorzata Sneve	Norwegian Radiation Protection Authority	Norway
Per Strand	Norwegian Radiation Protection Authority	Norway
Bogusław Michalik	Silesian Centre for Environmental Radioactivity Central Mining Institute	Poland
Maria de Lurdes Dinis	Centre for Natural Resources and the Environment (CERENA/University in Porto)	Portugal
Chizhov Konstantin	SRC - FMBC	Russian Federation
Alexey Kiselev	Nuclear Safety Institute, Russian Academy of Science	Russian Federation
Adriaan Joubert	National Nuclear Regulator	South Africa
Marta García-Talavera	Consejo de Seguridad Nuclear	Spain
Thomas Hjerpe	Facilia	Sweden
Wayne Oatway	Public Health England	United Kingdom
Karen Smith	RadEcol Consulting Ltd.	United Kingdom
Graham Smith	GMS Abingdon Ltd.	United Kingdom
Russell Walke	Quintessa Ltd.	United Kingdom

Appendix B. Workshop programme

3 September 2017, Berlin, Germany

09:30 – 10:00 Registration (coffee, snack)

10.00 – 10.15 Brief opening welcome and objectives from Malgorzata K. Sneve (NRPA) and Hildegarde Vandenhove (SCK•CEN)

10.15 – 12.00 Session I

International initiatives concerning need on closer collaboration among scientists, regulatory bodies and operators

1. Tamara Yankovich, IAEA, 'IAEA initiatives in support of remediation planning and implementation'

2. Jean Francois Lecomte, ICRP and IRSN, 'Update on the progress of ICRP TG76 - Application of ICRP recommendations as applied to NORM materials'

3. Edward Lazo, NEA 'Ongoing NEA and ICRP Legacy Management Activities (NEA EGLM and ICRP TG98) and Links to Radioecology '

4. Hildegarde Vandenhove, SCK CEN, 'A European Perspective of the radioecology research needs in context of NORM legacy management'

5. Per Strand, IUR and NRPA/CERAD, 'Coordinating radioecology input to safety assessments for NORM, legacy and waste disposal sites – role of IUR and IUR Forum'

12.00 – 13.00 Lunch buffet

13.00 – 14.15 Session II

Main challenges for regulators and operators in decision-making and management processes at legacy sites

6. Geert Biermans, FANC, Belgium, 'Regulations and Decision Making in the Management of Belgian NORM Legacy sites'

7. Jelena Mrdakovic Popic, NRPA, Norway, 'Norwegian legacy sites — experiences and lessons learned'

8. Alexey Kiselev, IBRAE RAN, Russian Federation, 'The problems of implementation of the international safety criteria (BSS 2014) in modeling systems for public safety justification'

9. Rainer Gellermann, Germany, Nuclear Control & Consulting, GmbH, Germany, 'NORM and other radioactive legacies of a multifaceted history'

14.15 – 14.30 Coffee break, snacks

14.30 – 16.00 Session III

Main radioecological uncertainties in up to date assessments - issues to be addressed in future collaborative work at international level

10. Ari Ikonen, EnviroCase Ltd. Finland, 'Systematic evaluation of strength of knowledge base for demonstration of compliance'

11. Sergey Lukashenko, Institute of Radiation Safety and Ecology, Kazakhstan, 'Estimation of dose burdens for population living at radioactively contaminated areas as a base for criteria development for its categorization'

12. Claudia Koenig, Leibniz University, Hannover, Institute for Radioecology and Radiation Protection, Germany, 'Long-term safety assessment – results from expert interviews'

13. Russell Walke, Quintessa, UK, '3D modelling of legacy sites, based on Dounreay case study'

16.00 – 17.00 Session IV

Discussions and Conclusions from workshop

The main intention is to obtain a picture of how radioecology can support regulatory decision making and identify the radioecology research needs in the context of assessment and safety cases for NORM and other legacy sites and related waste management and disposal.

We hereby would like to enforce the interaction between science and regulation (and hence scientists and regulators) and emphasize the use of science in a regulatory perspective.

Finally, we propose to examine how we could establish mechanisms so that this type of event maximally aids in meeting the needs identified.

Appendix C. Highlights of previous workshops

The following highlights of previous workshops are provided as background material to the current workshop and to consolidate the comments and suggestions made, especially as regards the scope for continued international cooperation in the area.

C1: Radioecology and Assessment Research in Support of Regulatory Supervision of Protection of the Environment and Human Health at Legacy Sites, Barcelona, 2014

This workshop was held on 6 September 2014, in conjunction with the 3rd International Conference on Radioecology and Environmental Radioactivity (ICRER) in Barcelona, 7 - 12 September 2014. The key objective of the workshop was to exchange and discuss information on the results of projects designed to provide radio-ecological information and wider scientific understanding of remediation options, to support regulatory supervision of legacy sites. A key focus will be the areas affected radiologically by Mayak PA operations and related facilities in the Chelyabinsk oblast. Attendance included a wide range of organizations and presentations were provided on:

• Strategic Issues for Radioecology in Support of Legacy Supervision (Brit Salbu, NMBU, Norway)

• Role of radioecology and radiological impact assessment in the implementation of IAEA Safety Standards on remediation and management of sites affected by enhanced levels of natural or man-made radionuclides (Gerhard Proehl, IAEA)

• Russian National and International Efforts in Nuclear Legacy Regulation (Vladimir Romanov, FMBA of Russia)

• US NRC Research in Environmental Remediation (Stephanie Bush-Goddard, US NRC)

• Derivation of Environmental Reference Values for Uranium in River Water and Sediments (Laureline Fevrier, ISRN, France)

• Dose Estimation on Contaminants by the Fukushima Daiichi NPP Accident (Tadao Tanaka, JAEA, Japan)

• Regulatory Supervision and Assessment of the Radiation Situation at Former Military Technical Bases (Nataliya Shandala and Sergei Kiselev, FMBC of Russia)

• European SOLO Project: Informing Assessments of Radiation Risks at Nuclear Legacy Sites (Joanne Brown, PHE, England)

• Update of US EPA Assessment Methods for Contaminated Sites, (Stuart Walker, US EPA)

• Internal Exposure Levels due to Protracted Exposure to Long-lived Radionuclides in Population Residing in the Vicinity of the Mayak PA Area (Sergey Romanov, SUBI, Russia)

• Characterization of the Current Status of Icthyofauna in the Techa River, (Evgeny A Pryakhin, URCRM, Russia)

• Natural and Anthropogenic Treatment of Surface Water Bodies Contaminated by Radioactive Substances due to Releases from FSUE Mayak PA (Malgorzata Sneve, NRPA and Yuri Mokrov, Mayak PA, Russia)

Regulatory questions and issues identified included:

• Justifying clearance levels for contaminated areas: can an existing situation be eliminated?

• Demonstrating compliance: monitoring – how to do that efficiently and with an appropriate level of confidence?

• Regulations and procedures that work for chemicals and radioactivity at one site.

• Practical interpretation and application of international recommendations at the national and site level.

• Addressing uncertainties in a regulatory context.

• Continuing need for improved regulatory documents (rules and guidance) and procedures to address abnormal conditions at legacy sites.

A complex range of scientific issues was recognized and it was noted that many different disciplines, including radioecology, are involved, involving different environments at different, and even within, sites. It was noted as important to understand the connections between: the radioactive sources terms; the dispersion and distribution of radionuclides in the environment; the potential for radiation exposure; relevant in each case dosimetry and metabolic modelling, and implications for human and environmental health. Within the context of overall legacy management, these aspects might be better considered together and not treated as separate issues. In particular, from a regulatory perspective, there is a continuing need for greater coordination across all four areas, to avoid duplication and share resources to resolve common key issues.

It was suggested that abnormal conditions typically arise legacy sites. These might include the following:

• Previous absence of, or loss of, effective control of radioactive material, such that current standards for radiation and nuclear safety and security are not met, and they therefore should attract the attention of regulatory authorities.

• Non-compliant status of control measures for radiation conditions, including physical containment, as well as institutional measures, e.g. control of access to areas.

It was also noted that new or lost information can come to light, and standards for protection evolve as well as regulation of those standards, so that a site that was previously not a legacy may have to be newly recognised as such.

Distinguishing factors affecting legacy management were recognised as:

• Radionuclides involved in all cases are relatively long-lived, else there is no legacy. However, some legacies are manageable within a socially manageable time-frame without need for off-site disposal, while others require consideration of disposal off-site.

• Some legacies involve large areas and volumes of material, while others are small.

• Large legacies are not usually highly radiologically hazardous to individuals, but have potential to affect a lot of people; small ones may present a serious hazard, though in that case, only a small number of people is likely to be affected.

• Some involve radioactivity mostly at the surface, which is relatively easy to measure; but some are opposite, or involve radionuclides which are not easy to detect.

• Some involve lots of different radionuclides with different radiative, chemical and physical properties; some, only one or a few radionuclides, which are then easier to analyse.

• Some involve physical and chemical hazards, while others only present a radiological hazard.

• Some have a linked social or political legacy which complicates decision making; some do not.

These factors affect the legacy risks and therefore should comprise the focus of legacy regulation and management, not the cause of the legacy.

Overall conclusions included:

• Regulatory development and application needs continued and enhanced interaction with the science base.

• Not all legacies are the same. The distinguishing features identified in the list above can support the organisation of, and provide the focus to, different research aspects.

• The scope of concerns and preparedness includes not only old legacies, but also the possibility for new ones; future accidents and other events including those related to security concerns.

• There is a need a prompt and effective procedure for response when a potential legacy is reported.

• Environmental Impact Assessments, Safety and Risk Assessments should include consideration of uncertainties. This process will help identify the priorities for scientific research.

C2: Application of Radioecology to Regulation of Nuclear Legacy Management, Bergen, 2008

A major "International Conference on Radioecology & Environmental Radioactivity" was held 15–20, June 2008 in Bergen, Norway. In conjunction with the Conference, a workshop titled: "Application of Radioecology to Regulation of Nuclear Legacy Management" was held 14 – 15 June 2008. Representatives of regulatory authorities and technical support organizations from 6 countries took part. The aim was to promote cooperation among all these organizations, and to investigate the challenges in the application of good science within the regulatory process for nuclear legacy management.

For operational safety, and day to day site management, radiation monitoring can be used directly to confirm compliance with standards. By contrast, for long-term legacy management, it is necessary to rely on an understanding of the site combined with 'assessment models'. Together, these allow us to make prospective assessments of alternative options for site management and plan responses to possible future accidents. There are many complex issues relating to interpretation of radio-ecological data within the context of specific eco-systems, and how they are coupled with engineered features of sites and facilities. Questions arising at the workshop included:

• How do we interpret the measurements for use in the assessments, taking account of the uncertainties?

• Can we learn from the waste repository community, which has been studying the longer term for many years?

• Can we develop a common and documented understanding of the priority issues which deserve further attention to resolve uncertainties?

• Can we do more to share existing information?

• Should there be a wider regulator's forum on nuclear legacy management?

There was a wide range of presentations made at the workshop, offering different perspectives from different countries. These prompted substantial discussion and the following points of consensus emerged:

• Regulatory decisions should be supported by science. However, there are significant uncertainties in scientific information relating to management of emergencies, routine present day situations and long-term site management and waste disposal, all of which are relevant to nuclear legacy management.

• These uncertainties relate to different radionuclides and on different relevant temporal and spatial scales. There is no single solution, but a broad range of scientific and other factors to address.

• Factors associated with large possible impacts that may affect the progress of strategic plans and absorb large resources are clearly more important than those which do not.

It was recommended that regulators should:

• maintain an understanding of the operational strategy;

• make Regulatory Threat Assessments to support regulation of the major hazards;

• maintain regulatory development to provide:

- adequate and relevant norms and guidance,
- an efficient regulatory review process, and
- compliance monitoring;

• maintain an independent Environmental Impact and Risk Assessment capability; and

• be aware of the weaknesses in those assessments and account for uncertainties.

It was suggested that uncertainties can be managed most efficiently through a tiered approach to assessments, as illustratively outlined below:

Tier 1. This involves simple models with limited data requirements and robust, conservative assumptions. They are not resource intensive. If the results suggest that the impacts meet regulator and other requirements, then this is a sufficient level of assessment.

Tier 2. If Tier 1 assessment raises some concerns, then closer analysis of the local situation: source, pathway receptor etc., may be called for. More source and site specific data is required to support more detailed process orientated, dynamic models used in such analysis.

Tier 3. If Tier 2 still raises concerns then site specific measurements and experiments to support the a third Tier of assessments may be necessary, including where appropriate, development of new models. The specific research needs will be identified by uncertainty analysis component of the Tier 2 assessments.

This approach, combined with Threat Assessments, helps to ensure that the research resources are applied to problems which impact most heavily on people and the environment.

Specifically challenging issues identified included:

Responsibility: Regulatory bodies should contribute to their national strategy for legacy management and take account of all the steps in the wider radioactive waste management strategy.

Knowledge Management: The entire community should learn from past events, and maintain records not just for immediate events management but also for the future, and make use of the memory of older or retired staff.

Uncertainties: Knowledge of important uncertainties comes from properly implemented safety assessments. If these assessments have not been done, this becomes the first priority.

Training: We should provide training courses for younger persons to develop the necessary skills. Competence levels in radioecology and other assessment skills need to match needs for managing the legacy, but also to support new developments in nuclear power and other uses of radioactive material.

Regulatory Functions: We should improve the integration of regulatory branches, to support application of the optimization principle and achieve a balanced approach.

Data Resources and Management: It was recommended to:

• make data acquisition and interpretation an integral part of environmental impact and risk assessments; and

- make wider use of data resources at the IAEA and other organizations, such as the International Union of Radioecology (IUR), and provide our own experiences and inputs to such international initiatives.

Coordinated Research: Some of the challenges are very fundamental and very complex, e.g. multi-stressors. The funding for resolving such issues needs combined funding systems, to produce core competence and sufficient resources.

Communication: Better communication strategies are needed to explain: international recommendations, the national policy in each country, the strategy to deliver the policy, what the safety standards mean, and how regulatory supervision is applied to ensure the standards are met. Risks and uncertainties identified by the assessment process need to be better communicated to risk managers and other non-specialist stakeholders.

Sharing Experience: There is a need for improved mechanisms for sharing experience on: data acquisition, site generic data, assessment methods, regulatory processes such as licensing and compliance monitoring, communication etc., for legacy site management. Exchange of information among research groups and with regulators is to be encouraged.

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