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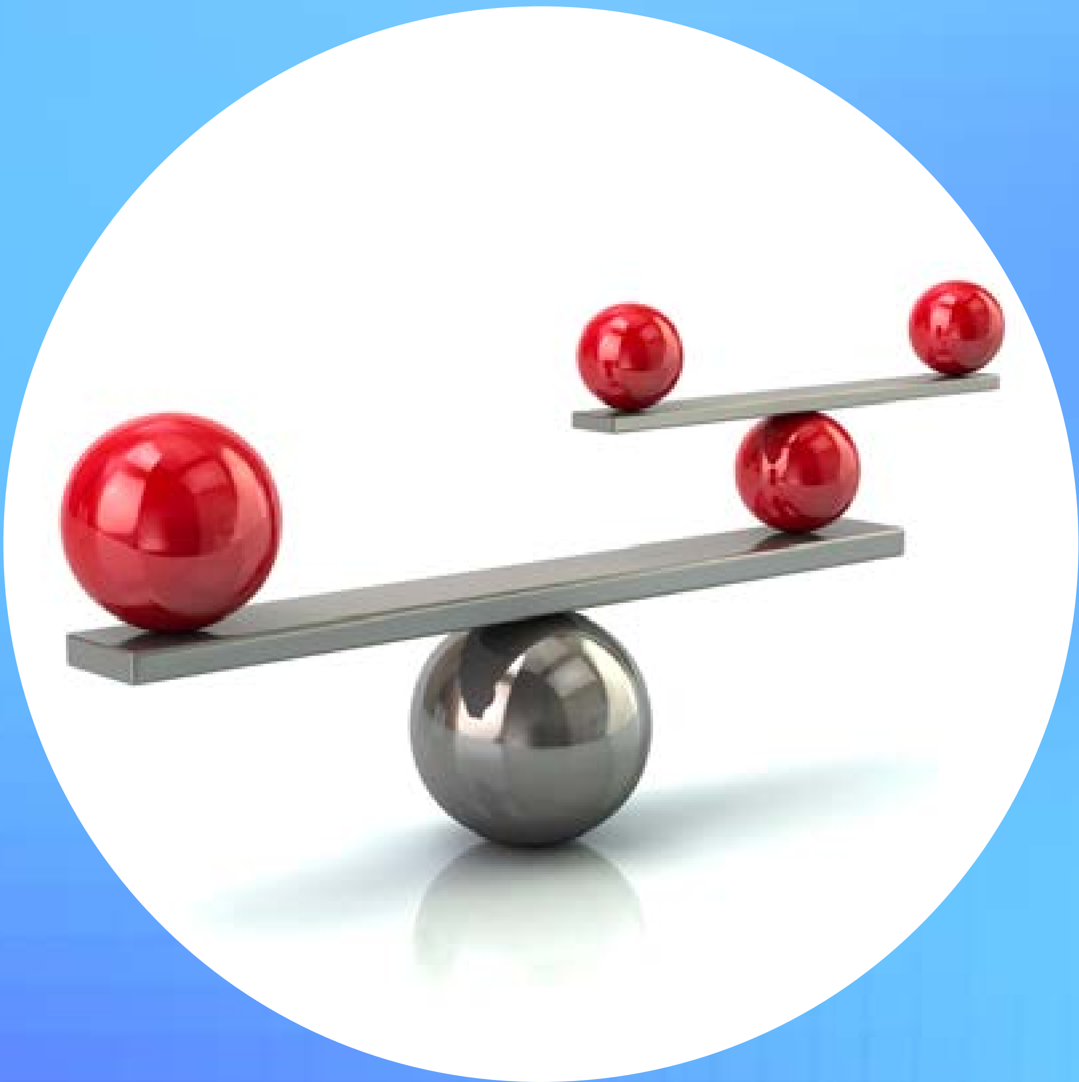
Regulatory Framework of Decommissioning, Legacy Sites and Wastes from Recognition to Resolution:

Building Optimization into the Process

Report of an international workshop , Tromsø, 29 October–1 November 2019



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Abstract:
Develop coherent and practical framework for optimization of protection for all prevailing circumstances in nuclear and radiological legacy management. To support international recommendations on holistic optimization, type of exposure situation and prescriptive and performance related regulations.

Referanse
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Emneord:
Atomarven, Dekommisjonering, Radioaktivt avfall, Optimering, Regulering

Resymé:
Utvikle sammenhengende og praktiske rammer for optimalisering av beskyttelsen for alle omstendigheter innen kjernefysisk og radiologisk arv. Støtte utvikling av internasjonale anbefalinger om helhetlig optimalisering, ulike type eksponeringssituasjoner og regulering.

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Regulatory Framework of Decommissioning, Legacy Sites and Wastes from Recognition to Resolution:

Building Optimization into the Process.

Report of an international workshop, Tromsø, 29 October–1 November 2019.

Preface

The following welcoming words set the scene for this report of a workshop hosted by the Norwegian Radiation and Nuclear Safety Authority (DSA) in Tromsø, 29 October – 1 November 2019, on the subject of Regulatory Framework of Decommissioning, Legacy Sites and Wastes from Recognition to Resolution: Building Optimization into the Process. The workshop was organized by the DSA and NEA in cooperation with the IAEA and ICRP and in association with the IUR.

"Dear colleagues,

I am delighted to welcome you all to Tromsø for this workshop on "Regulatory Framework of Decommissioning, Legacy Sites and Wastes from Recognition to Resolution: ***Building Optimization into the Process****".*

It is very gratifying to see many familiar faces and participation from organizations that attended the previous workshop hosted by DSA (formerly NRPA) in Lillehammer in 2017. I am very happy to say that the results from that workshop have fed through into on-going activities at the NEA and elsewhere. And perhaps because of that, I am therefore also very glad to be able to welcome so many people here this week, including many new faces.

The objectives and scope of the workshop have already been made clear through the various notices. I would like to highlight a few issues that appear to me to be most interesting and most important.

Firstly, some key points from the report of the previous workshop:

- → *For legacy sites and facilities, there is a need for pragmatic and flexible regulations that allow prevailing circumstances to be taken into account when deciding on management options, applying a risk-based and holistic approach.*
- → *There is a need to establish effective systems for an active society engagement that would encompasses communications as well consultations between relevant institutions and parties in society.*
- → *Dialogue between operators, implementers, regulators and researchers should be further encouraged to ensure a common ('both-direction') understanding of legacy issues and regulatory requirements and scientific results relevant to optimized solutions.*

Secondly:

- → *The work of the NEA's Expert Group on Legacy Management has followed up on many aspects of these issues, and we will hear more on that this week and the recent publication of the EGLM report as NEA 7419.*
- → *We can see other aspects being addressed in the work of the Expert Group on Characterization of Unconventional and Legacy waste and the other activities of the new high-level NEA Committee on Decommissioning and Legacy Management. It is my special pleasure to welcome Rebecca Tadesse and NEA colleagues.*

Thirdly:

- → *The role of all the international organizations working together to find solutions in these complex areas is vital. So, I am extremely pleased to see IAEA and ICRP represented at the meeting as well as colleagues from the IUR and CERAD, all with active participation in the meeting.*

Finally:

- → *I am delighted to remind you all that the Journal of Radiological Protection is preparing a special issue on the topic of "Management and Regulatory Supervision of Nuclear Decommissioning, Legacy Sites and Radioactively Contaminated Land: Development of a Coherent and Proportionate Process from Recognition to Resolution". Presenters and participants at this workshop are invited to put forward papers for this publication.*

With these reminders, I leave you in the hands of those who have worked so hard to put in place all the technical and administrative arrangements for this workshop. I am confident that our workshop will lead to closer cooperation at the international level and support the continuing development of practical guidance on application of nuclear safety and radiation protection at legacy sites based on very practical experience."

Per Strand, *Director: Department of Nuclear Safety and Environmental Protection, Norwegian Radiation and Nuclear Safety Authority*

Presentations given at the workshop, conclusions and recommendations are summarized in the current report. The DSA is very grateful for the support of the participants and the NEA, IAEA, ICRP and IUR at the workshop, and for their review of the draft of this report.

The opinions and other material presented in the report may not be taken to represent the views of the organizations involved. However, it is hoped that the results will support the further development and application of international recommendations, standards and guidance in the management and regulatory supervision of legacy sites and facilities.

Executive Summary

One of the aims of the workshop was to develop input for building a more coherent and practically applicable framework for optimization of protection. It should cover all types of prevailing circumstances but be practically adaptable within the framework's structure, to appropriately address specific circumstances from a multidisciplinary perspective. This was an ambitious objective, but the presentations and discussions during the workshop show that progress is being made and steps are being taken forward along the right path. The discussion and conclusions from the workshop parallel experience of the NEA EGLM (NEA, 2019), but add many more examples to support recommendations on holistic optimization, type of exposure situation and prescriptive and performance related regulations. Based on this progress, the following recommendations are made.

Recommendations

1. Further international guidance on addressing legacy sites and facilities should be developed, addressing aspects of decommissioning and the implications for radioactive waste management. The scope of the guidance should include holistic application of the process of optimization of protection, that is to say, addressing all hazards as well as a wide range of economic and social factors. The guidance should recognize that flexibility and adaptability can be helpful in reaching the optimum solution in different circumstances. Presentations and discussions during the workshop may be useful input to the development of such guidance, potentially providing the basis for prioritization of issues and needs. It may be appropriate to consider developing separate guidance for regulators and operators.

2. In developing the guidance, special consideration should be given to terminology, recognizing that countries differ in their legal definitions of key terms, and experts in different disciplines also sometimes use terms in specialist contexts. Descriptions of terms rather than strict definitions may therefore be preferable in international documents, to allow guidance to be readily adapted to national situations. A key objective will be to develop consensus around common understanding of terms across expert groups in the initial stages to avoid later confusion and conflicts. This approach will also aid communication and explanation of the guidance

3. The guidance should be illustrated with examples of best practice and lessons learned in the application of optimization of protection in different contexts. Such examples will demonstrate how different practices and approaches can deliver locally optimized solutions, according to the prevailing circumstances. Establishing databases on known legacy facilities could also be beneficial, aiding decision-making for newly recognized legacies and other complex existing exposure situations. Examples should include information on contractor processes, tools and technical solutions, which could support competitive procurement and help mitigate against non-optimal contractor behavior.

4. The effectiveness of stakeholder engagement techniques in different cultural and other contexts should be explored, bearing in mind that stakeholder engagement continues to be a challenge faced at a practical level. The results could then be used to better develop stakeholder processes in different complex site circumstances.

5. A framework should be developed by which different types of hazards, e.g. radiological, chemical and physical, can be ranked. This would support hazard reduction strategies and the implementation of a proportionate, graded and reasonable holistic approach to hazard management. In addition, it would also underpin the development of risk communication strategies to support stakeholder engagement.

6. The balanced integration of nuclear safety, security, protection from radiation and all other hazards is a key challenge. Much of the discussion and related suggestions within the workshop relate to balancing one factor against another, or several factors against several others. It is therefore recommended that the guidance examine how to achieve an appropriate balance among different attributes and the advantages and disadvantages of prescriptive and performance related approaches to regulation.

It is hoped that the results will support the further development of a coherent and practical framework for optimization of decommissioning, legacy site and waste management from a multidisciplinary perspective, and avoid creation of new legacies.

Abbreviations

ANSTO	Australian Nuclear Science and Technology Organization
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ASN	French Nuclear Safety Authority
CDLM	Committee on Nuclear Decommissioning and Legacy Management
CERAD	Centre for Environmental Radioactivity (Norway)
CEZ	Chernobyl Exclusion Zone
CNCAN	National Commission for Nuclear Activities Control (Romania)
CRPPH	Committee on Radiological Protection and Public Health (NEA)
DCRL	Derived Consideration Reference Level
DQO	Data Quality Objective
EA	Environment Agency (England)
EAN	European ALARA Network
ESC	Environmental Safety Case
FDNPP	Fukushima Dai-ichi nuclear power plant
FMBA	Federal Medical Biological Agency of Russia
FMBC	Burnasyan Federal Medical Biological Center of Russia
FSC	Forum on Stakeholder Confidence (NEA)
GRASP	Greenland Analogue Surface Project
GRR	Guidance on Requirements for Release from Radioactive Substances Regulation (UK)
HLW	High level waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IGSC	Integration Group for the Safety Case (NEA)
IRSN	Institute for Radiation Protection and Nuclear Safety (France)
ISF	Interim storage facility
KQA	Knowledge Quality Assessment
LFLS	Little Forest Legacy Site (Australia)
LMM	Low molecular mass
LLW	Low level waste
MADA	Multi-Attribute Decisions Analysis
MODARIA	Modelling and Data for Radiological Impact Assessments
MoE	Ministry of the Environment
NDA	Nuclear Decommissioning Authority (UK)
NDC	Nuclear Development Committee
NEA	Nuclear Energy Agency OECD
NORM	Naturally occurring radioactive material
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission
ONR	Office for Nuclear Regulation
ONR	Office for Nuclear Regulation
ORNL	Oak Ridge National Laboratory (USA)
PHE	Public Health England
RAP	Reference Animal and Plant
RIDD	Regulator-Implementer Dialogue for Disposal
RWDS	Radioactive waste disposal site
RWMC	Radioactive Waste Management Committee (NEA)
RWTLS	Temporary localization emergency radioactive waste sites
SCES	Starting Case End State
SF	Spent fuel
U.S. DOE	United States Department of Energy
UNEP	United Nations Environment Programme
UV	Ultraviolet
VLLW	Very low-level waste
VSP	Visual Sample Plan
WHO	World Health Organization
WNA	World Nuclear Association

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1 Introduction

1.1 Background

Decommissioning, legacy and waste management have become topics of great interest internationally. The management of decommissioning and legacy sites, and associated radioactive wastes, is recognized as highly complex. Practical guidance documents are required to support their efficient and effective regulatory supervision based on direct experience in different prevailing circumstances. The value on international cooperation in this area is illustrated through the recent setting up of the Nuclear Energy Agency (NEA) Committee on Decommissioning and Legacy Management (CDLM), and the case studies evaluated by the NEA Expert Group on Legacy Management (EGLM) that underpinned the development of a preliminary framework for the regulatory supervision of nuclear and radiological legacy sites and installations (NEA, 2019). Other important and related initiatives include the International Atomic Energy Agency (IAEA) projects of the European and Central Asian Safety Network (EuCAS), Remediation of Legacy Trenches Containing Radioactive Waste (LeTrench) and Definition of Environmental Remediation End States (DERES), and the International Commission on Radiological Protection (ICRP) Task Groups concerned with the application of Commission recommendations in existing exposure situations.

Knowledge and experience gained through different international activities has been shared through a series of workshops hosted by DSA in cooperation with the NEA, ICRP and IAEA. Conclusions from a workshop, held in 2015, on the '**Regulatory Supervision of Legacy Sites: from Recognition to Resolution**' (Sneve & Strand, 2016) emphasized the gap between theory and good practice and the need for further international guidance. A subsequent workshop, organized by the DSA in cooperation with the IAEA, NEA and ICRP, was held in Lillehammer in 2017 on the '**Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution**' (Sneve et al., 2018) to promote expert discussions and support the continuing development of practical guidance. A third workshop, hosted by the DSA in Tromsø from 29 October to 1 November 2019 and reported herein, follows up on the ideas developed during the previous workshops and the EGLM report setting out a preliminary framework and basis for discussion for the regulation of nuclear and radiological legacy sites and installations (NEA, 2019). The workshop was organized jointly by the DSA and NEA in cooperation with the IAEA and ICRP, and in association with the International Union of Radioecology (IUR).

1.2 Objectives and topics of interest

There are emerging practical, regulatory and implementation challenges in many countries as well as technical issues in relation to radioactive waste management, decommissioning management and legacy management. While the features of the optimum solution may vary significantly from case to case, a coherent and practical framework is needed to support the identification and characterization of that optimum that is effective in a range of circumstances. Noting this need, the workshop objectives were to:

→ Identify practical optimization issues, arising from operational programs, that are not clearly addressed by current regulatory system or guidance;

→ Identify approaches or paths forward to achieving accepted, sustainable protection solutions in radioactive waste, decommissioning and legacy management circumstances;

→ Identify a path forward to use experience from the practical application of optimization as feedback for consideration in the evolution of guidance and regulation of optimization; and,

→ Identify further recommendations for future international collaborative work on how to regulate and practically implement the optimization principle in these fields.

The topics of interest included:

- lessons learned from legacy site, decommissioning and waste management experiences;
- application of optimization in regulation and regulatory processes, coherently across decommissioning, waste management and legacy management, and implications for a common framework for regulation and application of optimization, distinguishing the generic from the specific;
- source term characterization linked to radioactivity and other hazards;
- site characterization that supports analysis of options;
- monitoring and measurement objectives, techniques and use of results;
- selection of reference levels, constraints and other criteria for control of risks to people and the environment;
- radiological and other risk assessment methods that support proportionate management of different hazards and risks to workers, the public and the environment;
- procedures for selection and achieving sustainable end-states;
- challenges to implementation of a holistic / multi-risk / graded assessment approach to end-states for different types of sites and facilities;
- stakeholder engagement in the optimization process that supports confidence in the decision-making process; and,
- procedures for transparent and traceable analysis of risks and benefits associated with different options, in assessing the reasonableness of protection objectives, and for their communication, in support of the overall options assessment and decision-making.

The workshop was conducted in an informal manner with a view to promoting free exchange of ideas. Simultaneous translation between Russian and English was provided.

1.3 Participation and program of the workshop

Participation included international organizations, regulatory authorities, operators, technical support organizations and academic institutions with an interest in nuclear and radiation legacy issues, decommissioning and waste management. The full list of participants and their affiliations is provided in Appendix A. They included 66 representatives from 17 countries as well as the IAEA, NEA and representatives of the ICRP.

The workshop was organized into the following topical areas:

- Implementation and regulatory challenges in the application of optimization in legacy, decommissioning and waste management.
- Existing international optimization guidance and implementation aspects.
- Optimization in different circumstances.
- Scientific, technical and social aspects of legacy management.
- Discussion of lessons and key issues
- Recommendations to support the development of a coherent and practical framework for optimization of decommissioning, legacy site and waste management and path forward.

The discussion of lessons and key issues was supported through feedback from structured break-out discussion sessions, aimed at eliciting input and views from as many participants as reasonably achievable, based on consideration of three questions:

- → What does 'optimization of protection' mean in circumstances of decommissioning, legacy and waste management?
- → What common elements of 'optimization of protection' should be included in an overall 'legislative / regulatory framework' encompassing optimization of protection for any circumstance?
- → What elements of 'optimization of protection' are specific to the circumstances of decommissioning, legacy and waste management?

The feedback is provided in Appendix B. The full workshop program is provided in Appendix C.

1.4 Preparation and structure of this report

The report is structured in line with the workshop programme, as follows:

- → Chapter 2 presents summaries of presentations from Session 1 on 'Implementation and regulatory challenges in application of optimization in legacy, decommissioning and waste management;
- → Chapter 3 summarizes presentations from Session 2 on 'existing international optimization guidance and implementation aspects';
- → Chapter 4 outlines presentations given within Session 3 on 'optimization in different circumstances; and,
- → Presentations from Session 5 on 'scientific, technical and social aspects of legacy management' are summarized in Chapter 5.

Feedback from break-out discussion groups is summarized in Chapter 6.

Chapter 7 then provides overall discussion around lessons learned and key issues as well as recommendations to support the development of a coherent and practical framework for optimization of decommissioning, legacy site and waste management.

The report was drafted by DSA and reviewed by participants for correctness prior to publication.

2 Implementation and regulatory challenges in the application of optimization in legacy, decommissioning and waste management

2.1 Update on NEA's Radioactive Waste Management Committee (RWMC) and Committee of Decommissioning and Legacy Management (CDLM)

Rebecca Tadesse (NEA) presented.

The NEA brings together advanced countries to address global challenges associated with the use of nuclear energy. The main roles of the NEA are to:

- foster cooperation in developing scientific, technological and legal bases required for a safe, environmentally friendly and economic use of nuclear energy for peaceful purposes;
- develop authoritative assessments and forge common understandings on key issues as input to government decisions on nuclear technology policy; and
- conduct multinational research into challenging scientific and technological issues.

The agency has 33 member countries that operate around 84% of the world's installed nuclear capacity.

It has seven divisions and eight technical standing committees. The Radioactive Waste Management Committee (RWMC) and Committee on Nuclear Decommissioning and Legacy Management (CDLM) sit within the Division of Radioactive Waste Management and Decommissioning. The RWMC aims to define strategic policies and best practices in addressing safety, societal and economic issues in managing radioactive waste throughout the full nuclear fuel cycle with working groups looking at each of these aspects along with the impacts of decisions made from a broad perspective. The CDLM, which was approved by the NEA Steering Committee in April 2018, aims to define strategic policies and best practices in nuclear decommissioning and legacy management. The remit of the CDLM covers the decommissioning of all types of nuclear facilities and reactors and the management of legacy waste and waste sites from historical nuclear activities. Overall, these two committees aim to consider all activities together and cover them holistically and without duplication of effort. One of the key issues for decommissioning sites is knowledge management to avoid sites becoming future legacies.

Membership of the CDLM is broad, being comprised of senior experts from regulatory authorities, policy-making bodies, decommissioning implementers, research institutes and other interested stakeholders, with the objective of bringing together a wide range of expertise to cover all the different aspects of decommissioning and legacy management. The structure of the committee and associated working groups is under development, as are proposals for the tasks that will be undertaken. At the time of the workshop, 72 nominations had been received from 20 countries and EC. The IAEA, World Nuclear Association (WNA) and Electric Power Research Institute are observers.

The emphasis is on enhancing safety in back end nuclear fuel cycle activities using a holistic approach with work focusing on identifying opportunities to improve safety, economics, environmental impacts and public acceptance of long-term management of radioactive waste. In terms of environmental and operational safety, key aspects include assessing technologies for safe and environmentally acceptable radioactive waste management activities, examining effective practices for integrating new technological information in national decision-making around radioactive waste management, and continuing the development of information, data and knowledge management for waste management. Groups and activities within environmental and operational safety include:

- Evaluating the latest strategies and best practices in pre-disposal management of radioactive waste, for which a workshop will be held in Paris from 10th to 14th February 2020.
- An expert group on Characterization of Unconventional and Legacy Waste that aims to develop an integrated approach for managing large quantities of unconventional and legacy wastes. A report will be produced that includes consideration of characterization and sampling methods and recognizing that programs will need to be optimized in light of funding availability.
- A Regulator-Implementer Dialogue for Disposal (RIDD) group to assess challenges in constructing effective dialogues between regulators and implementers in developing geological disposal for radioactive waste.
- An Integration Group for the Safety Case (IGSC) aimed at developing strategies for compiling robust safety cases for geological disposal, focusing on high level waste (HLW) and spent fuel (SF). The expertise could be helpful to those looking to develop a range of facilities, including for the disposal of low level waste (LLW).
- A new group on robotics aimed at sharing experience and knowledge around the development of remote and robotic systems for nuclear back-end activities and developing strategies and recommendations for establishing an effective framework to enhance the wide application of such technologies.
- Consideration of the environmental safety and decommissioning technological issues associated with decommissioning and nuclear legacies and, specifically, identifying where there are clear differences and to use this information in support of the development of a holistic approach.

The enhancement of public acceptance in the back-end is being taken forward through a forum on stakeholder confidence (FSC). The public are becoming increasingly interested in activities associated with decommissioning and legacies and the FSC aims to look at the tools and approaches that can be applied in support of stakeholder communication and the enhancement of public confidence in developing radioactive waste management solutions. The FSC will work with both the RWMC and CDLM in addressing societal matters. More information on the FSC is available from http://www.oecd-nea.org/rwm/fsc/. To address economic issues, both RWMC and CDLM collaborate with the Nuclear Development Committee (NDC) to identify and evaluate economic factors that affect the selection and optimization of radioactive waste management strategies and subsequent impacts. Information exchange between the different sub-groups is encouraged to ensure synergies across groups are identified and discussed.

A number of workshops are being organized for 2020 by the NEA, on:

- Optimisation of and predisposal management of radioactive waste;
- Safety cases for storage and disposal facilities;
- Competency maintenance, focusing on regulatory challenges in areas of radioactive waste management, decommissioning and legacy management; and
- Characterization of unconventional and legacy waste, aimed at developing specific management strategies and methods for managing large volumes of unknown waste, including post-accident and legacy waste.

The NEA is also involved in a number of other activities, driven by regional requests to address specific issues and the objective of promoting knowledge exchange and regional cooperation.

- The NEA-China Forum on radioactive waste management and nuclear decommissioning aims to promote the exchange of knowledge and experience between NEA countries and China on topics such as national regulatory requirements and experience and technologies for decommissioning and radioactive waste management.

- A proposal for a HLW roundtable to be organized on international cooperation in the final disposal of HLW and SF resulted in a first roundtable in October 2019. A second roundtable is planned for 2020. The objective is to strengthen international cooperation and advance development of final disposal solutions for HLW and SF, harmonizing disposal policies and examining possibilities for bi- or multi-lateral collaboration amongst countries.
- The Nuclear Education Skills and Technology (NEST) framework, created in 2019 and involving 15 organizations from 10 countries, aims to build practical experience and expertise among young professionals in technological issues faced by countries and in developing programs by establishing links between universities, research institutes, industry and regulatory bodies. Projects are established to provide hands on experience. One such project is focused on the decommissioning of uranium graphite reactors and will focus on radioactive waste management, including characterization, decontamination and disposal of graphite.

2.2 Results of Lillehammer workshop and the NEA EGLM: Implications for the current workshop

Malgorzata Sneve (DSA) presented.

The DSA has been addressing legacy issues for over 25 years and has hosted previous workshops on legacy management, the last being held in Lillehammer in 2017. The workshop was attended by 63 representatives from 32 organizations from 18 countries, as well as the IAEA, NEA and ICRP. The high attendance illustrates the level of interest internationally on legacy issues.

The Lillehammer workshop was focused around the process from recognizing there is a legacy issue that needs to be addressed through to identifying and implementation of solutions that addressing the complex range of challenges faced in order to resolve the issue. The workshop provided the opportunity for sharing experience on the practical regulation of a wide range of nuclear and radiation legacies. A report of the workshop has been published (Sneve et al., 2018) covering the five areas of:

- International perspectives and current activities in regulatory supervision of legacies;
- Methodologies for legacy regulation and management for long-term site management and on-site disposal;
- Scientific, technical and regulatory aspects for remediation (safety and environmental assessments, remediation and environmental monitoring);
- Social and ethical issues: uncertainties, risk communication and engagement of stakeholders; and,
- Recommendations for future coordination of international activities and cooperation.

The documentation of presentations and discussions has ensured that issues are captured and can feed into further wider discussions.

Several recurring themes were identified from presentations and discussions, such as the need for holistic and proportionate approaches for legacy management and for flexibility in regulations to allow legacy issues to be addressed. Pragmatic and flexible regulations are needed that address the often unusual prevailing legacy circumstances. Such flexibility is partly supported through the concept of reference levels for existing exposure situations, but there is little experience in their application. Holistic approaches that consider remediation as a whole life-cycle and that take account of the different hazards that may be present are also needed, along with transparent methods that allow options for addressing the different hazards to be prioritized.

The NEA EGLM has produced a report (NEA, 2019) that proposes a preliminary framework for legacy management, informed by case studies from different countries. Thirteen case studies, inclusive of site visits, are described that reflect the complex issues that are encountered at real sites. The case studies consider how challenges were recognized and circumstances characterized, how end states can be achieved, and the long-term protection values being applied. The preliminary framework set out in NEA (2019) will continue to be developed and informed by further case studies and site visits.

Some of the key issues and recommendations arising from both the Lillehammer workshop and the work of the EGLM are as follows:

- → Legacies are unpredictable / unpredicted, or they would not have arisen (or they arose due to actions taken when priorities were different) and regulatory frameworks are not sufficient to address the abnormal situations faced. Furthermore, it can be difficult to allocate responsibilities and procedures for an effective legacy management process. A balance has to be made between being prepared for all eventualities and not being prepared for any.
- → Effective dialogue processes are most likely to be successfully implemented when they are supported by operators, government and/or decision-making authorities, engineering and scientific support organizations and other relevant stakeholders where the most important stakeholders are those affected directly by remediation decisions, having valuable input to selecting achievable end states.
- → A key issue for the resolution of legacy issues is the allocation of responsibilities, which is only effective where there are adequate resources. Resource limitation is a common issue, which drives for optimization to ensure the best use of available resources and that the focus of actions is on what is really feasible. It may also be necessary to undertake a staged approach to achieving the selected end state. Optimization can, however, be challenging in complex legacy situations, requiring an overall optimization process that addresses all risks and benefits.
- → How to select reference levels, apply appropriate constraints for planned exposure situations, and evaluate other risks associated with chemical and physical hazards can be issues. A holistic approach to risk management and its regulation is required. Without such an approach resources cannot be allocated on a proportionate basis. A holistic understanding of risks across different hazards is also needed in support of stakeholder engagement.
- → The process for reaching an end-state should be supported by a safety case, the development of which is an iterative process that should be updated at each stage in the remediation process. The same approach needs to be applied to both chemical and radiological risk assessment or interpreting results in a balanced way will be very challenging.
- → An important step in building sufficient confidence to support decisions is to recognize uncertainties in a transparent way. Building confidence does, however, take time and it may be necessary to take actions in the short-term to avoid major catastrophes later; uncertainties should not delay actions needed to mitigate major hazards. Communicating with decision makers that such decisions need to be taken in light of uncertainties can however be challenging.
- → Closer integration is needed between contaminated land management, the decommissioning of hazardous facilities and the wider waste management program.

The process of managing legacies from the point of recognition through to resolution is not linear. Long delays to programs have occurred, particularly in the management of old sites, which add to both costs and risks. It is, however, difficult to organize and address all the issues right from the beginning.

There were several ideas for next steps arising as a result of the work of the EGLM and the Lillehammer workshop. In order to build a bridge between theory and practice, legacy sites and facilities under decommissioning and the legacy wastes generated in their management should be reviewed and sites with mixed planned and existing exposure situations considered with learning being applied to convert the preliminary framework set out in NEA (2019) into a practical tool and to provide advice on its application. More site visits and case studies have been planned[1] to help distinguish between site-specific and wider issues. This should continue to build from real site experience, but also take into account experience from other groups, such as the NEA Regulators Forum and Forum for Stakeholder Confidence, but also the wider community such as the United Nations Environment Progamme (UNEP), the World Health Organization (WHO) and national chemical regulators.

2.3 Regulating radioactive waste management, decommissioning and legacy management: Key elements and challenges

Walter Blommaert (NEA Regulators Forum chair) presented.

The NEA Regulators Forum discusses regulatory issues and concerns in order to develop better understanding of best practice in various phases of radioactive waste management, decommissioning of facilities, and legacy management bearing in mind that each country has its specific history of regulating, but that fundamental issues are common to all. By exchanging information and experience amongst regulators, regulatory awareness and efficiency can be improved.

Radioactive waste management is a planned exposure situation with an operator available, responsible and accountable. Wastes are managed according to regulations although there can be unexpected issues faced. There is usually one regulatory authority responsible. There is no practical experience feedback for deep geological repositories for HLW and SF and international collaboration is encouraged. There are problems faced with regard to extended storage of wastes and some waste types, such as graphite, can be problematic. Decommissioning is also a planned exposure situation and, again, an operator is available, responsible and accountable and, usually, there is one regulatory authority.

New facilities may be required to facilitate decommissioning. Workshops are being organized aimed at highlighting gaps (if any) in regulations. In contrast, legacy situations present existing exposure situations and are mostly one of a kind. Policies and strategies are not always in place and, in most cases, operators are not present, and questions arise as to who is responsible and accountable. Many legacies involve mixed contamination and multiple regulatory authorities are therefore involved and the decision-making process and associated financing can be complicated. Regulations covering legacy situations may not be as fully developed since it is not feasible to prepare regulations in advance for all unexpected events/accidents and there can be issues in what to do with the large volumes of potentially poorly characterized wastes that can be generated as a result of remediation / clean-up activities. Application of the radiological protection framework for different exposure situation can also be challenging. Whilst legacies present existing exposure situations, remediation activities are planned (occupational) exposure situations. The transition between emergency and existing exposure situations is also challenging.

There are, nonetheless, several commonalities between the operation of a nuclear facility, decommissioning activities and legacy management. All require a legal, regulatory and organizational framework that that focuses on safety. Activities should be subject to justification and optimization and be subject to a licence, inspection, review and reporting. All involve multiple stakeholders and a stepwise, transparent decision-making process is needed. There is a requirement for safety and environmental impact assessments to be undertaken and for materials and wastes to be characterized. Decisions on end-points and on the transfer of ownership and routing of wastes for disposal or storage are required for all, as are monitoring and research and development programs. Integrated management systems, staffing and

[1] Two have been undertaken, to Malvesi in France, and to Maralinga in Australia,

competence management, memory keeping, and early dialogue between regulators and implementers are also important commonalities.

Differences in approach to the operation of a nuclear facility, decommissioning activities and legacy management can arise as a result of variation in legislative, regulatory and organizational frameworks between countries. The types of activities and associated risks can also vary from nuclear risks to conventional risks. There can also be differences in the level of societal impact, especially with regard to confinement issues with legacies. Waste characterization, waste volumes and availability and type of disposal facilities can also vary. Timeframes, resource availability and knowledge of past practices may also differ considerably.

Key elements include the need to demonstrate justification and optimization and to achieve an acceptable, sustainable solution. Operators always have prime responsibility for safety whilst the government and regulatory bodies have to ensure that radiation protection and safety for workers public and environment are secured, with respect of the principles of radiation protection, and that a risk-informed decision-making process is available with clear allocation of responsibilities for the various parties involved. Both operators and regulators should develop and maintain competencies. At present, the lack of disposal facilities and associated waste acceptance criteria (WAC) is a common bottleneck.

Regulating activities in a holistic and sustainable manner requires effective regulatory requirements and procedures to be in place that ensure the safety of the public and protection of the environment, account for societal and ethical aspects, and seek an optimal balance between the required level of safety and associated costs; all of which should be embedded in national legislative, regulatory and organizational frameworks. Prerequisites for developing adequate regulations include:

- applications of the ICRP principles of justification, optimization and limitation of doses;
- high-level support (national and policy) for the approval of laws, regulations, policy and strategy;
- the right competencies at all levels in the organization;
- good collaboration between peers through, for example, participation in relevant international fora;
- open and transparent dialogue with stakeholders;
- a stepwise decision-making process with clear allocation of responsibilities;
- a graded approach;
- avoidance of inconsistencies in international standards;
- time; and,
- regulations should be clearly communicated and understood and underpinned by a common understanding on the interpretation and implementation of safety requirements.

IAEA safety fundamentals, requirements and guides frequently refer to the principle of optimization, which is central to the system of protection and applies to all exposure situations. It is not, however, a simple process. It has many interlinkages.

The development and optimization of national regulations largely relies on factors such as a continuous, open and transparent development process that involves all relevant parties and a decisional process with clear allocation of roles for all parties involved. A choice has to be made between prescriptive regulations, objective-led regulations or a mix of the two where regulations are partially prescriptive and partially safety-objective led. Transposition of existing conventions, safety standards and related documents also supports the development and optimization of national regulations, as does cooperation between nuclear regulators on optimizing and harmonizing regulations and on review and inspection regimes. The process relies on vigilance with regard to new developments in scientific research, the regulatory impact of accidents and incidents and updating of developed standards and regulations with respect to such events. Harmonization with other national and/or regional regulatory regimes can also be beneficial.

Once a regulatory framework has been developed, an effective regulatory body is needed. Such a body should, amongst others:

- → be clear on its regulatory roles and responsibilities, purpose, mandate and functions;
- → have a regulatory framework and requirements that are realistic, clear and easily understood by all stakeholders;
- → make clear, balanced and unbiased decisions and be accountable for those decisions;
- → have a strong organizational capability in terms of adequate resources, strong leadership and robust management systems;
- → perform regulatory functions in a timely and efficient manner;
- → participate in relevant national and international fora;
- → be supported by high-level responsibilities;
- → have public safety as its primary focus;
- → have independence from any undue influence in regulatory decision-making;
- → have technical competence at its core;
- → be open and transparent in its regulations and decisions;
- → be a good communicator;
- → have a continuous self-improvement and learning culture, including the willingness to subject itself to independent peer review and audits;
- → be vigilant towards new developments and act proactively; and,
- → apply a graded approach.

Regulators continue efforts today to develop regulations that meet the needs of implementors and the need to provide for sustainable protection of people and the environment. This continued development benefits from input from international programs, scientific developments and bi- and multi-lateral collaboration between regulators.

Regulators (should) apply a holistic approach relating to the safety of waste management, decommissioning and legacy management when establishing regulations, and consider the independencies between all steps from the generation of waste to its disposal. Regulators should therefore strive to do more than simply establish standards; they should consider global optimization, i.e. the performance of the entire system that ensures safety. It should, nonetheless, be recognized that it is not possible to capture everything in regulations as it is not possible to prepare for the unexpected: accidents happen, and political and social aspects evolve. It should also be recognized that the major effects may not be limited to radiation exposure and people may have very different opinions around what are the main issues. Such situations should be managed in a holistic way, taking into account psychological and social aspects when planning and implementing remediation activities.

The formulation of objectives and targets is a complex process, based on the international system of radiological protection, understanding of health issues in general, and iterations with stakeholders to achieve the optimal outcome under the local circumstances. This would benefit from an improved ability to communicate ‘what is safe’. During remediation, the principles of justification and optimisation should be applied to ensure that decisions on remediation actions balance both technical (e.g. exposure, cost etc.) and subjective (e.g. public perception, political views etc.) elements. Remediation should address not only radiation protection considerations, but also environmental, economic, social, psychological, cultural, ethical and political issues. Improved guidance is needed on practical aspects of remediation, such as defining end-states, establishing appropriate reference levels and making balanced decisions between risk reduction and remediation impacts.

2.4 Regulatory challenges and opportunities in the UK relating to optimization of nuclear site decommissioning and associated waste management practices

Steve Hardy and Andrew Fairhurst from the Environment Agency, England, presented.

The Environment Agency (EA) is the environmental regulator for England; environmental protection and waste management being devolved matters in the rest of the UK. The EA works closely with other regulators, including the Office for Nuclear Regulation (ONR) and other government bodies, such as the Nuclear Decommissioning Authority (NDA). The role of the EA is to implement government policy, for example, there is a 25-year environmental plan that addresses climate challenges and clean growth. The Environment Agency acts as both a regulator (e.g. of the nuclear industry and others) and operator (e.g. the management of flood assets).

The UK is a small country but is faced with a large nuclear decommissioning challenge. Nuclear licensed sites throughout the UK include radioactive waste disposal facilities, operational and decommissioning nuclear power plants (NPP) and fuel enrichment plants and reprocessing plants. Sites are located throughout the UK from Dounreay in the north of Scotland to Devonport Royal Dockyard in southwest England.

Decommissioning presents a 100 year plus challenge at some sites. There are diverse wastes to be dealt with and there is currently insufficient capacity and infrastructure to deal with all of those wastes. For example, in terms of lower activity wastes, civil nuclear decommissioning is estimated to produce around 4.5 million m^3 with potentially 6 million m^3 arising from related nuclear site clean-up activities. Consideration is therefore needed as to how to manage decommissioning and clean-up challenges as a country.

Decommissioning sites can also be legacies. For example, there may be unforeseen areas of contamination that can lead to significantly greater challenges. Wastes arising may be higher activity for which there is currently no disposal route, but a large volume of low activity wastes will also arise, including demolition rubble, contaminated soils, scrap metal and redundant structures such as building foundations and pipes. Whilst there are challenges faced in the decommissioning of these sites, there are also opportunities, for example in the rationalization of regulations for nuclear installations that would allow for more rapid decommissioning of sites and optimization of site management. A consultation on proposed amendments to the framework for the final stages of nuclear decommissioning in the UK has recently concluded. The amendments aim to enable earlier site delicensing and provide for a more sustainable approach through optimization in waste management.

To address the decommissioning challenge, joint guidance has been produced by the Environment Agency, Scottish Environment Protection Agency and Natural Resources Wales on the "*Management of radioactive waste from decommissioning of nuclear sites: Guidance on Requirements for Release from Radioactive Substances Regulation*" (the GRR). The GRR lays out in detail the standards and requirements expected of operators, including expectations around optimization, and details how demonstrations should be made. It provides information around options for on-site disposal of decommissioning wastes where this represents the optimized solution. The guidance, which is risk based and enabling, considers the whole journey for sites from new build through to decommissioning and achieving final end-states. This is achieved though the site-wide environmental safety case that exists throughout the lifespan of any nuclear facility. Development of the GRR began in 2014 and has been subject to wide consultation and experience gained from “lead and learn” trials at three sites that tested the guidance and provided feedback for further development of principles and guidance. The GRR was published in July 2018 and is now being implemented across all nuclear sites in the UK.

Overall, the aim for decommissioning is to achieve an optimized end-state, noting that it is not always feasible to return sites to greenfield sites; for example, in some cases, light industrial /commercial use may be more appropriate. At the time of permit surrender, operators need to demonstrate that people and the environment are safe from risks from radioactivity, including from general exposure as a result of migration in the environment, exposure resulting from inadvertent intrusion into buried radioactivity and exposure caused by natural disruptive events, such as erosion. The GRR is clear that no requirement for controls should be placed on future generations beyond permit surrender.

The fundamental objective of the GRR is to ensure that each nuclear site is brought to a condition whereby it can be released from regulatory control through a process that protects both the health and interests of people and the integrity of the environment throughout the period of regulation and beyond and which inspires public confidence and takes account of costs. Five fundamental protection principles are detailed in the GRR:

1. Protection from radiological hazards
2. Optimization (as low as reasonably achievable)
3. Protection from non-radiological hazards
4. Reliance on human action
5. Openness and inclusivity

These principles are supported by 15 management and technical requirements that must be met. Radiation protection standards are addressed through four of these requirements:

→ Requirement 9: Dose constraints during radioactive substances regulation;

→ Requirement 10: Risk guidance level after release from radioactive substances regulation;

→ Requirement 11: Inadvertent human intrusion dose guidance level after release from radioactive substances regulation; and,

→ Requirement 12: Natural disruptive processes after release from radioactive substances regulation.

Optimization is central to the guidance and is stipulated in two requirements:

→ Requirement 1: Optimization of waste management options, which calls for the best overall solution to be implemented for waste management across the site throughout its lifetime; and,

→ Requirement 13: Optimization of on-site disposals, which focuses on the best way to undertake on-site disposals if they are the optimized solution.

There are a number of potential options that can be considered for on-site disposals, including disposal within a dedicated disposal facility, filling existing structures or voids or disposal in-situ with engineered closure. Alternatively, contamination may be left in-situ.

Under the GRR, sites are required to have and maintain a waste management plan that covers all radioactive wastes and contamination throughout the remaining lifetime of the site. The plan is required to demonstrate optimization and be both holistic (addressing both radioactive and non-radioactive wastes) and proportionate. The waste management plan interacts with the site-wide environmental safety case

(SWESC), which is a second required deliverable of the GRR. The SWESC demonstrates environmental safety for chosen options during the period of regulation and until the site end-state is achieved and then beyond.

The GRR is being implemented at all nuclear sites across England, Scotland and Wales under a phased introduction program over the next 5 to 7 years. The implementation will be through environmental permit conditions requiring waste management plans and site wide SWESCs to be produced and maintained throughout the lifespan of the sites until permit surrender. It is recognized that there will be technical issues arising throughout the process of implementation and so there are technical work-streams established to address these and support regulators and industry. Implementation is being taken forward as a collaborative program between regulators and industry.

The GRR represents a significant new era for the environmental regulators in England, Scotland and Wales, setting out clear guidance on environmental safety standards that apply to end-states. The GRR is a framework for deciding when environmental regulation ceases and supports a more flexible and sustainable approach to the management of radioactive waste from nuclear decommissioning, supporting the Government's plans for the final stages of nuclear decommissioning.

2.5 Practical experience of FMBA of Russia in radiation protection optimization at the legacy sites of the Russian Federation

Nataliya Shandala (Federal Medical Biological Agency, FMBA) presented.

Optimization is the direct responsibility of the operator and is required to be undertaken with respect to several regulatory documents:

→ The 1996 Federal Law "On the Radiation Protection of the Population";

→ The 2009 Radiation Safety Standards (NRB-99/2009);

→ The 2010 Main Health Rules for Radiation Safety (OSPORB-2010); and,

→ The 2017 Guidelines on optimization of radiation protection for the personnel of enterprises under the State Atomic Energy Corporation Rosatom (MU 2.6.5.054-2017).

The 2017 guidelines set out the general provisions for optimization. Optimization is carried out in the range from dose limits to negligible effects and establishes a balance between the harm induced by exposure and the resources needed for protection. It is not, therefore, dose minimization. Optimization is a continuous cyclical process that involves several steps:

→ Statement of the problem

→ Setting out options and factors

→ Quantification of factors for each protection option

→ Comparison and selection of options, taking into account the efficiency / cost ratio

→ Presenting the results

→ Final decision

Individual doses of workers depend on several factors, including the radiation situation in the workplace and the duration of an operation. A key parameter for the optimization of exposure is effective dose.

Implementation of optimization is a continuous procedure that starts with work planning and the preparation for work, continues through the carrying out of radiation-hazardous operations and analysis and assessment of work results through to the involvement of the personnel in the process. Guidelines for occupational doses are introduced in stages.

Three nuclear legacy sites are located in the northwest region of Russia, close to the national border with Norway (Figure 1). Andreeva Bay was the location for the temporary storage of waste and spent nuclear fuel from nuclear submarines. The facility has degraded, resulting in hazardous contamination of the environment. The site has been included as a case study in NEA (2019). It presents a combination of both planned and existing exposure situations with the site being subject to remediation activities, under a close cooperation program with the DSA.

Figure 1: Location of nuclear legacy sites in the northwest region of Russia.

Special virtual reality software tools have been developed to support optimization of dose during technological operations. For example, for the extraction of SF from a storage facility at Andreeva Bay (described in detail in Sneve et al (2015), Chizhov et al (2017) and Chizhov et al (2018), steps in the process where personnel doses would be greatest were evaluated and optimized. The operation giving rise to the greatest risk was the extraction of the SF assembly and installation into transport containers. Detailed models were created around different options for the operations and two scenarios compared to find the optimized approach that would minimize occupational doses.

The software tools developed have also been used, along with active contamination surface maps and ambient dose measurements, to create dose rate fields that can be used to inform on doses to workers in simulations of hazardous operations in other buildings. For example, by finding the optimal route for operations within the building used for handling solid radioactive waste, it was possible to reduce worker doses by 1.6 times. Overall, remedial measures that have been carried out between January 2009 and February 2016 have resulted in a decrease in average individual personnel doses from 1.2 to 0.5 mSv.

Human risks and accidents are an important aspect of legacy management. An expert and diagnostic risk monitoring system has been developed that enables performance reliability to be evaluated amongst workers undertaking high stress operations such as SF management. The monitoring software evaluates the medical and psycho-physiological characteristics of personnel against the requirements of professional reliability (see section 5.8).

Environmental radiological protection has also been optimized, in line with methodological recommendations set out in MU 2.6.1.37-2007 on the organization of radiation monitoring of environmental media in the vicinity of SevRAO facilities. The radiation monitoring system has been optimized to increase the effectiveness of radiation supervision and a positive trend has been achieved over the last 10 years in the reduction of gamma dose rates.

The development of software tools that help visualize surface contamination and the radiation situation at sites has helped optimize occupational radiological protection at Russian legacy sites, informing on the development of methods and criteria for assessing compliance with the safety culture for the management of SF and radioactive waste. Developments have also informed on optimization in the field of environmental radiation protection, for example in assessing the effectiveness of different options for the remediation of sites.

2.6 Addressing optimization in decommissioning and legacy management: Australian experience

Jim Scott (Australian Radiation Protection and Nuclear Safety Agency, ARPANSA) presented two case studies from Australia: the remediation of a former uranium mining site and regulatory oversight of the Little Forest Legacy Site.

2.6.1 Remediation of a former uranium mining site

Extensive mineral exploitation took place at in the South Alligator River Valley between 1954 and 1965 following the discovery of uranium in the area at a time that coincided with the peak period of nuclear research and power generation. Much of the uranium, some gold and other heavy metals were processed in the area, primarily at processing plants near to the Rockhole and El Sherana mines. The area was later abandoned without any rehabilitation when mining was no longer economic.

The area sits within a World Heritage National Park and has a high Aboriginal population. Sacred sites are present. The area is known locally as “sickness country” with traditional landowners being aware of the potential adverse health effects associated with disturbing the land.

In 1987 the area was proclaimed part of the Commonwealth reserve of Kakadu National Park and the Government agreed to rehabilitate the mining sites in cooperation with local people to ensure sensitivities around sacred sites and land use were addressed. However, funding restraints meant that complete rehabilitation was not possible. A program of physical and radiological hazard reduction was therefore prioritized for the safety of National Park users. Between 1990 and 1992, shafts and pits were blocked off to prevent access and much of the radiological contaminated material and equipment, such as cores with high contact doses that had been left in the mining village, was buried in shallow trenches at four sites in the area.

In 2006, funds were allocated by the Australian Government for further rehabilitation works to be carried out. The rehabilitation program was undertaken in two phases. Phase A did not involve radiological contaminated sites. Phase B addressed sites with significant radiological contamination and was regulated by ARPANSA. The objective was to leave sites in a safe and stable state, and to minimize long-term cultural and environmental impacts, subsequent land uses and future liabilities.

An ARPANSA facility licence was issued in 2000, requiring all phase B works to be approved by ARPANSA. Guidelines were set for rehabilitation. Environmental surveys indicated a background gamma radiation level of 0.15 μSv/h at 1m above ground level. A threshold dose rate of 1.25 μSv/h ± 20% at 1m above ground level was therefore set to maximize human and environmental safety and distinguish native soils from radioactive tailings. Material associated with gamma dose rates above this level were to be removed to a new containment site.

The National Park is located in the tropics, in a monsoon affected area, with high rainfall during the wet season having the potential to cause a lot of damage. The area is remote with limited access although some people do camp in the area, which had to be taken into account.

The containment, to be located on a disused airstrip was designed to accommodate 25,000 m^3 of contaminated material in a trench 240 m long and 30 m wide with a cap of 2.5 m thickness and with a minimum of 0.5 m of compacted native clay. A slope provided for natural drainage. Monitoring boreholes were included in the conceptual design.

The licensing process was complex since ARPANSA regulations did not anticipate remediation of legacy sites. Following the original facility licence being issued in 2000, a request to site and construct the facility was received from the Director of National Parks in April 2009. The application detailed the site selection process against siting criteria established by ARPANSA with the El Sherana airstrip being the proposed location for the containment. Following review of the application, the licence was issued in June 2009.

Construction of the containment began in the dry season of 2009. Environmental monitoring stations were established around the containment, including radon gas monitoring stations, to meet the licence condition to acquire data on the state of containment at least twice per year and to provide ARPANSA with an annual facility report. A dose assessment was undertaken for various critical groups, in order to establish a dose constraint for the facility. A maximum annual dose of 6 µSv was calculated, linked to use of the site for camping. A request to set the dose constraint level at 30 µSv/y was agreed and imposed as a licence condition by ARPANSA in 2013.

In the first wet season following containment construction and before revegetation of the area could occur, deep erosion gullies developed due to the extreme nature of the wet season. To mitigate against further erosional issues and maintain containment integrity, a spoon drain was constructed in the following dry season in order to divert water around the containment, allowing vegetation to become established. No significant erosion gullies have developed since this time and the most recent monitoring around the site indicates that the facility is stable. There is no evidence of radionuclide migration out of the containment. Increased levels of iron and manganese have, however, been detected that may indicate degradation of steel containers disposed in the containment, but radon and gamma dose rate measurements remain at background levels, indicating that containment is performing well. Signs are in place around the area to deter camping. The area is also cordoned off to limit access.

2.6.2 Regulatory oversight of the Little Forest Legacy Site

The Little Forest burial site was established in the 1960s for near-surface disposal of LLW. The site is located to the southwest of Sydney and is close to the only research reactor in Australia. Wastes were disposed between 1960 and 1968 when the site closed. Around 1,600 m^3 of waste, including equipment and material contaminated with low level radioactivity, effluent sludge and chemicals, was disposed in a series of trenches excavated into the clay-rich soil. The waste inventory is known to include fission and activation products, several grams of plutonium and about 1 tonne of beryllium oxide.

The site has been maintained since closure, most recently by the Australian Nuclear Science and Technology Organization (ANSTO). Maintenance has included grass cutting, maintaining fences around the site and adding topsoil in the event of any subsidence. Subsistence has occurred due to the collapse of buried structures such as waste drums over time. Environmental monitoring has detected radioactivity on the surface. The addition of topsoil over contaminated soil is intended to prevent the possible spread of contaminated material.

In 1999, ANSTO submitted a licence application for the facility, but at that time the licensing basis was uncertain as it did not meet the requirements for a disposal facility, and ARPANSA did not have regulations in place for legacy sites. A revised application was submitted in 2014 and a licence issued in 2015 to 'possess or control' the site as a 'prescribed legacy site' in accordance with a 2015 amendment to the Australian Radiation Protection and Nuclear Safety Act .Other categories of licence created by the amendment include 'remediate' and 'abandon', which may be applied for in the future by ANSTO. The licence granted in 2015 imposed a condition for medium and long-term plans for management of the Little Forest Legacy Site (LFLS), including options for long-term disposition of the waste.

A project has been developed by ANSTO to fulfil the licence condition on the future management of the facility, including in-situ grouting options. Radiation migration has been investigated over time at the LFLS. There is little evidence for the migration of radionuclides, with the exception of tritium. The presence of beryllium is, however, a particular issue, requiring input from other regulators. The plan, providing options for the medium to long-term disposition of the waste, is due to be submitted to ARPANSA by 31st December 2019. An IAEA Technical Meeting took place in August 2019 on the remediation of legacy trenches containing radioactive waste (the LeTrench project) and several management options have been identified, including:

→ Continued maintenance and monitoring
→ Targeted retrieval
→ Full retrieval with waste conditioning and return to trench, disposal at an alternative facility or in an engineered vault at LFLS
→ In-situ solidification and stabilization or vitrification
→ Construction of an engineered cap
→ Construction of a hydrological barrier or water-resistant roof
→ Pump and treat plumes / groundwater and trench water
→ In-situ chemical conditioning
→ Phytoremediation above trenches

A proposal for the way forward is to be submitted in the options plan by the end of 2020.

2.7 National regulations addressing optimization in waste management: US DoE experience

Patricia Worthington (United States Department of Energy, U.S. DOE) presented.

There are a number of national regulations that provide the requirements for addressing nuclear hazards. At the top level there are federal rules that must be implemented. These are underpinned by guidance to ensure success. Standards give specific guidelines and directions. Optimization is required. For example, DOE Order 458.1 on Radiation Protection of the Public and the Environment requires a graded level of control and oversight to be used in the as low as reasonably achievable (ALARA) process and that decisions made as a result of ALARA are beneficial and cost effective. Optimization is the result of an evaluation that balances the benefits from exposure reduction with costs; the best option is not necessarily the one with the lowest dose.

The DOE Handbook (U.S. DOE, 2014) provides additional information on how to carry out the ALARA requirements for optimizing radiation protection as required under DOE Order 458.1 and for requirements to be implement in an effective way. The handbook contains several well documented case studies to assist in implementing the ALARA process and is a good source of lessons learned. The case studies are from across the USA and it is important to recognize that there are different stakeholders in different locations and what constitutes ALARA will differ depending on the stakeholders. Five case studies that demonstrate semi-quantitative ALARA analysis were described.

Case study 1: Colonie, New York. The site formerly processed uranium and operated for some time without functional stack controls resulting in contamination in the surrounding environment that required remedial action. Significant lessons were learned as a result of this case study and the overarching statement was made that the study demonstrated the importance of realistic assumptions when evaluating benefits and assessing expected outcomes.

Case study 2: Elza Gate Site, Tennessee. A former storage site for waste and contaminated material that was remediated and released to the standards in effect in the 1970s that is now an industrial park. The primary radionuclides of concern were Ra-226, Th-230 and U-238. Authorized limits for clean-up were defined and remedial action undertaken. The case illustrates the cost benefit approach and how authorized limits developed separately for various radionuclides, when used together, will likely result in greater dose reduction than projected. Cost benefit analysis provides insight into what would be considered reasonably achievable in this case. For example, increasing the uranium limit by around a factor of 2 would have decreased waste volume by less than 10% and resulted in little cost saving. However, decreasing the authorized limit by less than a factor of 2 would increase waste volume by 2.4 times and would have resulted in a corresponding increase in cost.

Case study 3: Maywood, New Jersey. Site of a former thorium and rare earth ore processing site with properties in the vicinity containing residual radioactive material from the site, primarily Th-232. The case study demonstrates the importance of using best estimates of expected risks when comparing options. Mixing reasonable and worse-case assumptions can bias the results. Works case scenarios should only be applied for screening purposes and never in relative risk comparisons. The case study also illustrates the importance of communicating the results of an ALARA analysis with regulatory authorities or other responsible parties in determining final remediation goals.

Case Study 4: Ventron, Massachusetts. A former metal hydrides site that processed uranium compounds and scrap resulting in contamination of portions of buildings and grounds on the site plus some properties around the site. Conservative assumptions around food production around the site and in critical group habits were applied in deriving standards. Remedial action to the authorized limits would reduce doses well below the dose constraint for likely use scenarios and, for the worst plausible use scenario, the selected authorized limit was well below the primary dose limit. The case is therefore a good example of unrealistic and conservative exposure scenarios and assumptions used in many guideline development efforts.

Case study 5: Weldon Spring Site, Missouri. A former ordnance works and site of uranium and thorium ore concentrate processing from 1957 to 1966 with liquid waste streams ultimately draining through sewers to the Missouri River via a 2.4 km natural drainage channel. Site contamination was extremely heterogeneous, with a few highly concentrated areas that extend to a depth of a few tens of centimeters and the bulk of the soil area relatively lightly contaminated on the surface only. It has not been feasible to date to reduce lifetime hypothetical risks to the target level due to radon exposure and the dose limit could not be achieved for the residential site-specific scenario in all site locations. This is an interesting site that is now managed by the DOE. It provides a good example of instances involving wide variation in contamination distribution and of remediation decisions based on both radiological and non-radiological considerations.

The overall approach to radiation protection optimization presented in the Handbook case studies provides detailed information, including analysis and justification, that could be used as lessons learned for others. The DOE's ALARA process helps ensure that optimization techniques are integrated into the design and analyses of programmatic options necessary for the protection of the public and the environment in accordance with the requirements of DOE Order 458.1. The process of optimization should be integrated into the design and analysis program early on with cost-benefit analysis informing on what can be done to achieve the required level of control. Many different aspects need to be considered in regard to optimizing a situation, of which ALARA is one. The engagement of stakeholders when considering different options and developing standards supports the decision-making process. ALARA, as applied by DOE, is not a level or limit to be achieved in controlling radiation exposures or doses, but rather a process used to ensure that appropriate factors are considered in making decisions that could affect protection against radiation.

2.8 Cleaning up the UK's earliest nuclear sites: Building optimization into decision-making

Anna Clark (Nuclear Decommissioning Authority, NDA) presented.

There are currently 36 nuclear sites in the UK of which 17 have been designated to the NDA. These consist of nuclear power reactors, research reactors, fuel fabrication and enrichment and radioactive waste disposal sites. Sellafield combines all of these in addition to being a nuclear fuel reprocessing site. The estimated cost of decommissioning sites is £121 billion over 120 years, with the majority of funding being provided by the Government. Sellafield receives by far the largest share of funding at over 75%.

The earliest nuclear sites in the UK were neither designed nor operated with decommissioning in mind. They were operated to the regulatory standards in place at that time (beginning in the 1950s), but those standards have changed over time. Decommissioning operations also occur over long timescales, during which regulations, practices and social contexts can change. Assessments of what is safe and sustainable for a site need to be based on current knowledge and understanding, irrespective of the sites history and origins.

The NDA is a non-departmental body that was created through the Energy Act 2004. The NDA works as a strategic body between the Government and operators. It is the authority responsible for strategy and planning, governance and assurance, delivery optimization and managing and reporting performance for nuclear decommissioning sites. The NDA's mission is to clean-up the UK's earliest sites safely, securely and cost-effectively with care for both people and the environment.

There are two key strategic decisions to be made in decommissioning: the timing (priority and pace) of decommissioning, and the target of decommissioning, i.e. the end state. In terms of pace, the preference is for continuous decommissioning unless there are clear benefits associated with deferral. For end-states, the NDA's preference is to adopt pragmatic, risk-informed remediation objectives that enable beneficial reuse of sites and, if needed, use controls to protect people and the environment from residual hazards.

The NDA strategy is risk-informed and flexible; it is not about getting doses as low as possible as quickly as possible, but rather case and site-specific solutions are sought. Where risks are intolerable, urgent action is taken to reduce them with risk being the overriding factor in decision-making. Where risks are less significant, risk and hazard reduction remain key considerations, but options appraisal considers a broader range of factors. Where risks are broadly acceptable, there is a greater flexibility with regard to the timing of remedial actions and options appraisal aims to balance a broad range of factors in terms of benefit (value) and detriment (cost).

There is a wide variety of issues and contexts across the NDA estate, including the presence of existing exposure situations. The nature of risks varies from site to site, as does the sensitivity of the environment, both in terms of impacts of the site on the environment (e.g. local sensitive habitats and sensitivity of groundwater) and impacts of the environment on the site; for example, many sites in the UK are located on the coast and may be affected by coastal erosion whereas Trawsfynydd is situated in an upland location in Wales and is subject to freeze-thaw cycles. The dependency of the local community also varies. Nuclear sites in the UK are typically located in areas that are not highly populated although some are in the vicinity of cities. This affects the dependence of the local community on the site for employment and can affect land and property values. Information on the dependence of local communities on sites has been gathered to inform the pace of decommissioning. For example, the optimum pace of decommissioning at Wylfa on Anglesey takes account of impacts on the local community, which is highly dependent on the economy that surrounds the nuclear site. Local infrastructure (e.g. roads, railhead, shipping ports, electrical grid connections) is also variable between sites, affecting both logistics for decommissioning, such as ability to transport waste from sites, and end-state options (e.g. due to presence of on-site disposal facilities). Case-specific solutions are therefore required that consider all elements of value and all elements of cost.

In recognition of this, the NDA has developed a value framework consisting of a comprehensive and consistent set of relevant factors that can be used to compare options and supports decision-making (Figure 2). In order to make balanced decisions between available options, holistic assessment of options is necessary (i.e. looking at the performance of options from multiple perspectives), taking account of the full lifecycle (i.e. balancing the value of what is delivered against the cost of getting there for that site and beyond).

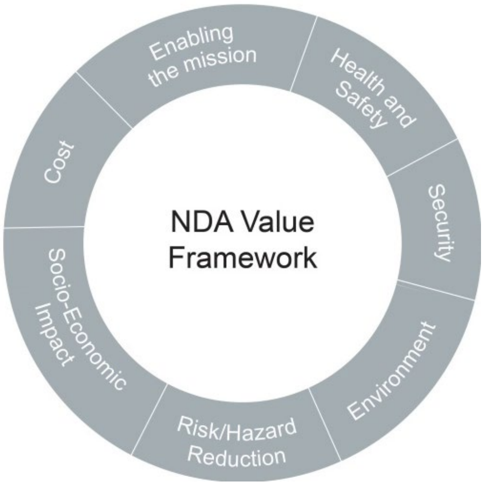

Figure 2: Factors for comparing options within the NDA Value Framework.

End-states are a challenge for optimization in a broad sense. Often, the hazards present are more conventional than ‘nuclear’. As nuclear hazards are removed from a site, the nature and level of risk changes considerably until, toward the final stages of decommissioning, the nature of hazards becomes broadly similar to that at a non-nuclear demolition site.

The NDA strategy aims to be enabling rather than prescriptive in guiding the selection of end-states. For example, the end-state for the Winfrith site is to release the site as open heathland for public recreation. Whilst decommissioning of the research reactors appeared relatively simple, extensive sub-surface features and voids posed a real risk to workers involved in excavating these structures. There will also be considerable impact on the environment and local community associated with the transport of materials off-site and with importing clean infill. As such, the site operator has compared the risk of leaving the lightly contaminated substructure in situ with the risk of excavating the substructure for disposal elsewhere and concluded that the preferred option is to leave subsurface structures in situ and to infill voids using lightly contaminated materials (e.g. decommissioning rubble and soils) from the site. This still meets the chosen end state and allows release of the site for public access, while also minimizing lifecycle risks to workers and the environment.

The Trawsfynydd site, which also has considerable sub-surface structures including a bio-shield and ponds complex as well as an on-site ILW store and an asbestos landfill. The operator is assessing the impact of excavating the subsurface structures for disposal elsewhere compared with the impact of leaving subsurface structures in situ and reusing waste for the purpose of void-filling. It is predicted that with focused, targeted decontamination, the majority of land (~90%) can be available for unrestricted use in the near-term and in the longer-term restrictions on land use will only apply to 7% of the land. These remaining restrictions will be due to the historical asbestos landfill present on the site (Figure 3), not residual radiological risks, such that the land could be released from radioactive substances regulation (RSR). With 100% of the land being available for reuse, albeit with 7% subject to some restrictions, we are asking ourselves whether the costs associated with further remedial work would be justifiable.

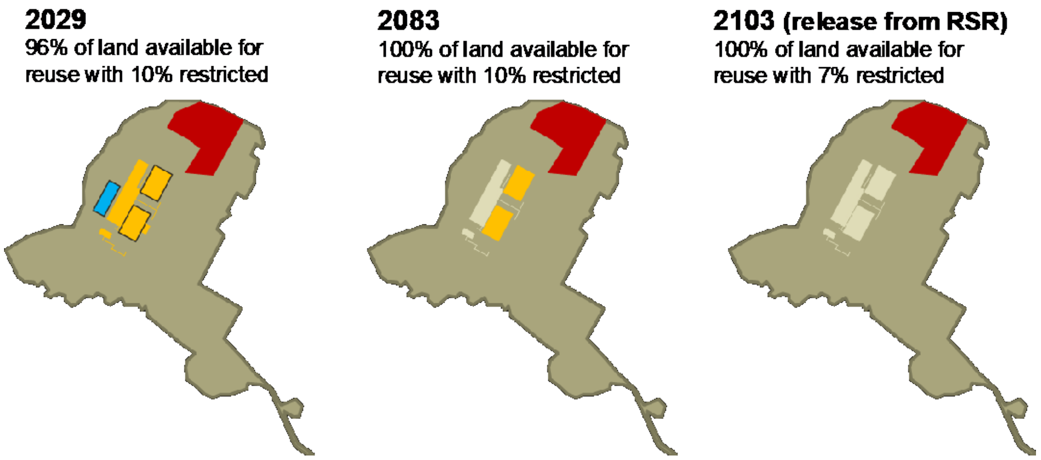

Figure 3: Trawsfyndd site end-state over time as sub-surface features (yellow) are decommissioned and the ILW store (blue) is removed, leaving only an asbestos landfill area (red) subject to land use restrictions.

Defining an end-state means defining the physical state, any controls required to protect people from residual contamination and the nature and length of any future land use restrictions. Early decision-making enables progress, but there is the potential for new information, learning and changes in context over time. An iterative and adaptive approach is therefore needed that allows end-states to be re-evaluated and refined in light of new input.

UK government has proposed to modernize the legislative framework that applies to nuclear sites in the final stages of decommissioning and clean-up (https://www.gov.uk/government/consultations/the-regulation-of-nuclear-sites-in-the-final-stages-of-decommissioning-and-clean-up). One of the key benefits of the proposed amendment is that site operators will be able to optimize end states on a site by site basis, in consultation with local stakeholders and under regulation by the relevant environment agency.

NDA experience therefore suggests that:

→ Optimization is required in its broadest possible sense (holistic impact over full lifecycle).

→ Different sites will require different solutions (case/site-specific solutions), based on a common understanding of what is safe and sustainable.

→ Iterative and adaptive approaches enable progress when the end state will not be achieved for decades and/ or our starting assumptions are uncertain.

→ Regulations need to be flexible enough to enable optimization and accommodate a range of end states.

→ Clear and appropriate metrics are needed to describe the impact of actions and demonstrate sound underpinning for all decisions. The metrics should encompass all aspects of value and provide a clear means by which risk is communicated and progress demonstrated.

3 Existing international optimization guidance and implementation aspects

3.1 The global nuclear safety regime and optimization for decommissioning, legacy sites and radioactive waste management

John Rowat (IAEA) presented.

Under its Statute, which came into force on July 1957 and amended in 1989, the IAEA is authorized to establish or adopt safety standards for protection of health and minimization of danger to life and property and to provide for the application of those standards to its own operations[2]. The provision and application of safety standards is to be in the context of all Member States, which provides a large variability of challenges.

The departments and major programs within the IAEA are illustrated in Figure 4. The department of nuclear safety and security (NS) draws together all safety-related activities of the agency in order to emphasize the independence of the safety function. The safety function relates to the IAEA statute, but also includes facilitating and servicing international conventions and other undertakings.

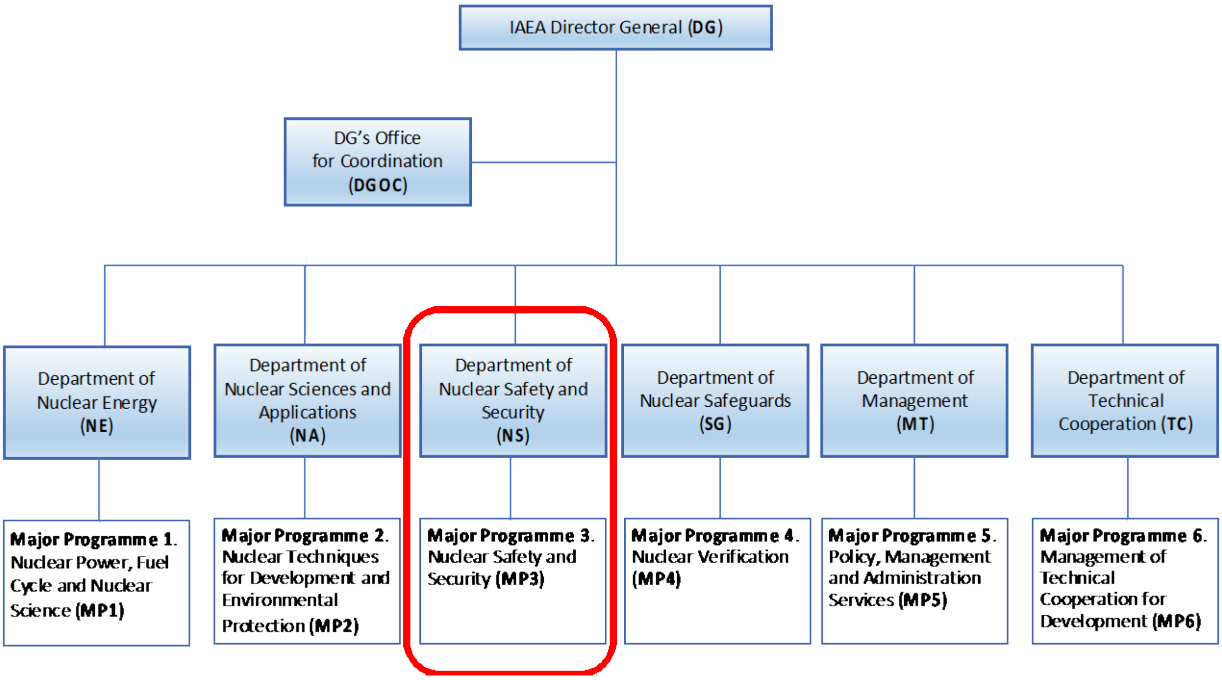

Figure 4: IAEA departments and major programs.

A key principle of the IAEA safety fundamentals is that facilities and activities giving rise to radiation risks must yield overall benefits. There will always be some radioactive waste generation and contaminated infrastructure as a result of beneficial activities such as nuclear power generation that have to be managed as liabilities. However, where management has been sub-optimal or not consistent modern standards, legacies may result.

There are three key criteria for liability management (i.e. decommissioning, remediation and radioactive waste management):

[2] www.iaea.org/about/overview/statute

- **Safety**. Solutions must be safe and be authorized by a competent and independent regulatory body.
- **Cost**. Solutions must be affordable.
- **Interested parties**. Projects should not proceed without the involvement of interested parties (the “social licence”).

Optimization is a prospective and iterative process for making good decisions that ensures the best possible level of protection under the prevailing circumstances, requiring both qualitative and quantitative judgements to be made. Optimization is, therefore, contextual, taking account of factors such as scale (a single project versus national program), situation (planned versus existing situation), geographical setting, and both financial and human resources. Whether or not optimization has been achieved can be difficult to judge.

In the early 2000’s, the IAEA elaborated the Global Nuclear Safety Regime that provides “*the institutional, legal and technical framework for ensuring the safety of nuclear installations throughout the world*” (IAEA, 2006). Whilst the focus of the safety regime was on nuclear power plant operations, in anticipation of new nuclear build internationally, the principles are broadly applicable. It is not sufficient to be nations to be internal facing; a broader engagement is necessary.

The IAEA Safety Standards are revised systematically to ensure they remain up to date and need for revision of Safety Requirements is evaluated every 10-years. One commission and five safety standards committees oversee the development and approval of the Agency’s standards with Member States nominating committee members.

There are several principles within the IAEA’s Safety Fundamentals (IAEA SF-1) that relate to optimization:

- Principle 5 on the optimization of protection requires protection to be optimized to provide the highest level of safety that can be reasonably achieved, with resources allocated to safety being commensurate with the magnitude of the radiation risk.
- Principle 7 on the protection of present and future generations requires that both people and the environment, present and future, be protected against radiation risks with future generations not being required to take significant protective actions. Furthermore, radioactive waste generation should be minimized and wastes generated should be managed in such a way as avoid placing any undue burden on future generations.
- Principle 10 requires protective actions to reduce existing or unregulated radiation risks to be justified and optimized to ensure the benefits of those actions outweigh any radiation risks and other detriments associated with them and to produce the greatest benefit reasonably achievable in relation to costs.

These fundamental principles are embedded in safety standards for predisposal management of radioactive waste (IAEA GSR Part 5) and for the disposal of radioactive waste (IAEA SSR-5 (IAEA, 2011)). For example, safety objective for the disposal of radioactive waste disposal is to site, design, construct, operate and close a disposal facility to ensure protection after closure is optimized, taking account of social and economic factors. Protection following closure is optimized through considering alternative management options within a safety assessment.

In terms of facility decommissioning, IAEA GSR Part 6 requires that licensees select a decommissioning strategy that provides the basis for decommissioning planning and financial provision for decommissioning is required to be set out in national legislation with cost estimates for decommissioning being periodically updated. Licensees are also required to prepare and maintain decommissioning plans throughout the lifetime of a facility to show that safe decommissioning can be achieved to meet the defined end-state.

Legacy sites are addressed under the GSR Part 3 that requires governments to ensure that identified existing exposure situations are evaluated to determine occupational and public exposures that are of concern and that remedial actions are optimized. Remediation actions need to be planned and supported by a safety assessment that is reviewed by the relevant authority and should aim to progressively reduce radiation risks and, if possible, remove any restrictions on use or access to the affected area.

Optimization is therefore built into IAEA Safety Standards on many levels, both explicitly and implicitly and can be achieved by implementing the Global Nuclear Safety Regime.

3.2 The evolution of optimization regulation and implementation: NEA views

Ted Lazo (NEA) presented.

There are several different definitions of optimization available. Within ICRP Publication 103 (ICRP, 2007), two different definitions are given:

> "***The Principle of Optimisation of Protection****: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors*" (ICRP, 2007, Para. 203).

> "***Optimisation of protection (and safety)*** *- The process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and societal factors being taken into account*" (ICRP, 2007, glossary).

ICRP Publication 9 (ICRP, 1966) provides one of the earliest references to what can be considered the process of optimization:

> "*As any exposure may involve some degree of risk, the Commission recommends that any unnecessary exposure be avoided, and that all doses be kept as low as is <u>readily achievable, economic and social considerations being taken into account</u>*" (ICRP, 1966, Para. 52, emphasis added).

ICRP Publication 26 (ICRP, 1977) also refers to the process of optimization, bringing cost-benefit analysis into the picture:

> "*Most decisions about human activities are based on an implicit form of balancing of costs and benefits leading to the conclusion that the conduct of a chosen practice is "<u>worthwhile</u>". Less generally, it is also recognized that the conduct of the chosen practice should be adjusted to maximize the benefit to the individual or to society"* (ICRP, 1977, Para. 11, emphasis added).

> *"In cost-benefit analysis the benefits are taken to include all the benefits <u>accruing to society</u>, and not just those that will be received by particular groups or individuals"* (ICRP, 1977, Para. 70, emphasis added)

> *"It may thus be necessary to make <u>subjective value judgments</u> in order to compare the relative importance of the costs imposed on human health by radiation exposure with other economic and social factors"* (ICRP, 1977, Para. 71, emphasis added).

In 2001, the ICRP Main Commission approved the formation of a new Committee 4 Task Group with the remit to develop guidance on the principle and application of the optimization of radiological protection.

The outcome, developed in parallel to the 2007 Recommendations of the ICRP (ICRP, 2007), was ICRP Publication 101, Part 2: The optimization of radiological protection: broadening the process (ICRP, 2006).

Optimization is increasingly about stakeholder involvement (interested parties in IAEA terminology) and the prevailing circumstances. The NEA's Committee on Radiological Protection and Public Health (CRPPH) has been engaged in the stakeholder engagement process since 1992 when a workshop on Radiation Protection on the Threshold of the 21st Century was held and from which a key outcome was the recognition of the importance of stakeholder involvement in radiological protection decision-making. The integration of societal aspects into radiological protection was, in part, driven by the Chernobyl accident. At that point in time, however, stakeholder involvement was viewed by many as the radiological protection community explaining decisions to the public rather than true involvement in the decision-making process. This has steadily evolved with the CRPPH discussing the nature of optimization, specifically with regards to social and economic aspects being taken into account. The Chernobyl accidents radiological impacts were studied leading to the importance of social aspects of the accident being recognized both in terms of short- and long-term consequences. Listening to and working with stakeholders was recognized as important in helping to rebuild trust and as a useful resource in terms of identifying problems and practical solutions on the ground. In 2011, the NEA published a report on Science and Values in Radiological Protection that distinguishes between radiation protection science and social values (NEA, 2011). A series of workshops were organised on the topic from which the following were key learning points:

→ Protection of children is a universal objective, and a focus of recovery activities

→ Low-dose health effects are poorly understood by stakeholders, and their concerns need to be better addressed

→ Stakeholder involvement should be central to emergency and recovery management planning

→ A multi-disciplinary team of professionals is needed to deal with the spectrum of stakeholder issues

Following the Fukushima accident, a series of stakeholder dialogue symposia were organized by the ICRP in order to listen to affected people and share experience from people affected by Chernobyl. Structured discussions were held on specified topics, in addition to presentations of scientific and post-Chernobyl experience. Around 20 symposia have been held with the CRPPH participating with a view to learning around post-accident recovery management. Learning from these symposia and other workshops includes:

→ Radiation protection aspects should be integrated into societal decisions, rather than integrating societal values into radiation protection decisions

→ Radiation protection experts should be at the service of stakeholders

→ Decisions should be informed by science, but driven by social values

→ A multi-disciplinary approach is central to appropriately addressing stakeholder concerns

→ Trust is essential to help assure that affected stakeholders inform their decisions with valid science and utilize government support.

The assessment of prevailing circumstances is a key element of the radiation protection system. Prevailing circumstances drive stakeholder's radiological protection concerns and the elements of the radiological protection system used to achieve acceptable and sustainable protection decisions will therefore be driven largely by stakeholder assessment of the prevailing circumstances. The optimal protection solution for a given prevailing circumstance is a judgmental selection of what best addresses stakeholders concerns and the role of radiation protection is to help stakeholders appreciate all relevant aspects of a situation and the implications of their choices.

Optimization has, over the years, become more central to the decision-making process and has shifted to be a source-specific process that encompasses all aspects of prevailing circumstances, including social and economic aspects alongside radiological aspects. The focus on source-specific optimisation and individual risk has significantly increased the importance of the prevailing circumstances in radiological protection decision making. Decisions in similar circumstances will be taken within a common radiation protection framework but will not necessarily be the same (for example, clean-up criteria, evacuation criteria and environmental release criteria may be variable) with acceptable and sustainable protection decisions being framed by the prevailing circumstances and driven largely by stakeholder concerns and values. A preliminary framework and basis for discussion has been provided in the EGLM report (NEA, 2019), which notes that:

- a coherent framework is needed to characterise optimization in any circumstance;
- aspects considered to identify the optimum solution will vary significantly depending on the circumstances being considered;
- there are emerging, practical regulatory and implementation questions coming from various existing circumstances in many countries; and
- radioactive waste management, decommissioning management, and legacy management are significant, practical issues in many countries.

As such, regulatory frameworks for optimization will need to be general and flexible to allow for any type of prevailing circumstances to be taken into account and will need to account for and support stakeholder involvement in the decisions process at some level. Specific regulations for specific prevailing circumstances may also need to be developed.

3.3 Optimization of the technical solutions for spent nuclear fuel retrieval from building 5 at Andreeva Bay

Igor Pavlov (SSTC NRS) presented.

An accident occurred in 1982 within building 5 at Andreeva Bay, a former naval base. The building was the storage location for spent nuclear fuel (SF). No remedial actions took place following the accident and the building remained in its post-accident state until recent years.

Preliminary investigations took place in 2013 with the building being surveyed which led to the discovery of SF assemblies on the bottom of the storage pool. A 3-dimensional model of the building was developed (Figure 5), along with dose estimates to support the selection of technical solution options and a safety case was issued. In 2015, a tender for the development of design and equipment for the retrieval of SF assemblies was issued. In 2017 the equipment was produced and demonstrated using a replica of the facility that was built for this purpose, allowing the retrieval procedure to be tested and optimized. Retrieval of SF assemblies was successfully achieved in October 2019. A video was shown that illustrated the complex operations undertaken within Building 5.

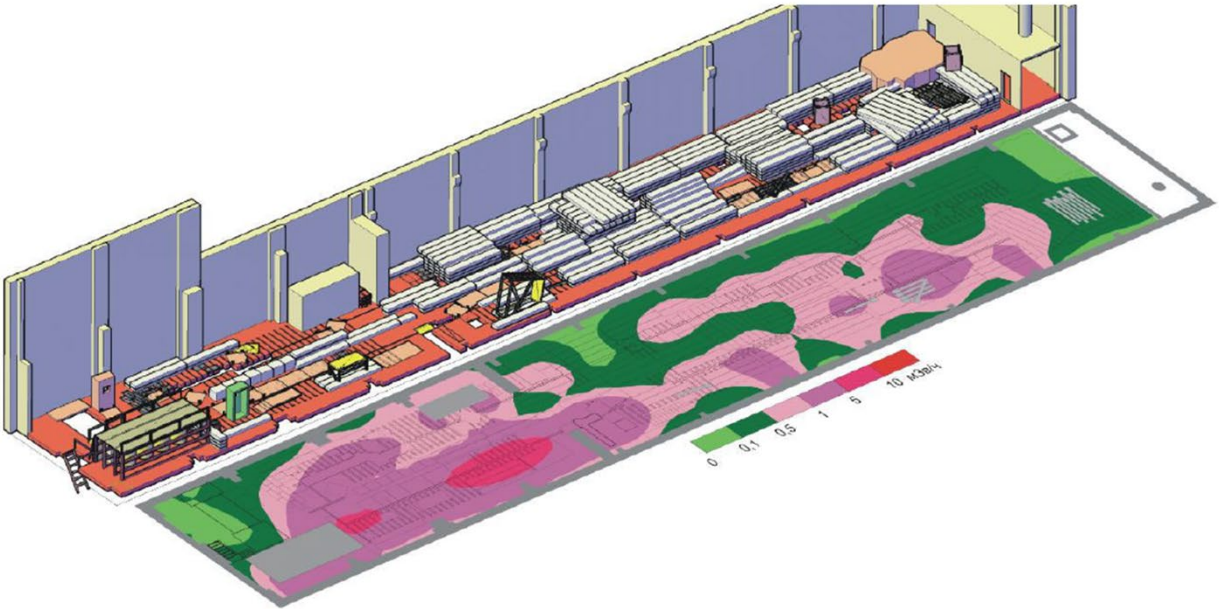

Figure 5: 3-dimensional model of Building 5 process hall and associated dose map.

Dose rates in the building were very high and there were considerable uncertainties with regard to the number, size and condition of the SF assemblies. There was also a lot of dust and rubbish present, no in place lighting or heating, leading to a need fora remote power supply, and the condition of lifting equipment in the building was uncertain. In light of the considerable hazards, access times had to be severely restricted during preparatory work. During retrieval operations, human access was not feasible and remote operations were necessary.

A lot of work was undertaken to understand where different equipment was situated, to inform the development of the 3-dimensional model. All operations were trialed in advance within a mock-up facility. Images of the bottom of the pool were used to develop an understanding of the condition, geometry and size of the SF assemblies although this was complicated by many of the assemblies being obscured by the presence of other objects or by sediment cover.

Circular saws were remotely operated to gain access to the building with operators working from a control room in another building. Holes were also cut within the building to gain access to the pool containing the SF assemblies and debris was removed. The condition of the storage area prior to works is illustrated in Figure 6. The work was complicated, requiring three operators to work in harmony from the control room to operate up to four pieces of equipment at any one time. The preparatory works to gain access to the assemblies was far more costly and time consuming than the retrieval operations themselves.

Figure 6: Condition of the SF storage pond prior to retrieval operations.

Mitigation activities were defined. One of the most important initiatives was to involve international expertise in the identification of conceptual solutions. Another important decision was to implement a flexible approach since the full condition of the SF assemblies was not known. The decision was made to employ the same personnel that designed the retrieval equipment in the retrieval process itself. Both cost and personal dose estimates were criteria that underpinned decisions on successful contractors to take the work program forward. Several solutions for the installation of process equipment were tested, including the use of bio-shielding. A platform was lowered to the bottom of the pool that provided the means for handling fuel assemblies, a unique approach to handling the assemblies that took advantage of available technologies. Assemblies were placed into canisters within a specially made overpack for safe long-term storage.

There are several lessons learned from the project:

→ The use of the mock-up facility also allowed the retrieval operations to be optimized. Dose rates within the building were significantly higher than expected, requiring remote operations to keep worker doses within set constraints.

→ The locations and geometries of the SF assemblies were not in line with presumptions, requiring a new cask design for one assembly.

→ The testing of all equipment in a mock-up facility ensured that all equipment and facilities worked without issue during the retrieval process.

→ Doses received by personnel were significantly less than the design estimate (by up to 40 times).

→ The work undertaken within Building 5 has alleviated risks from the presence of SF, but the building itself is in a critical condition and could collapse at any time.

The main objective during the work was to ensure the safety of on-site personnel. This objective was achieved, with 95% of the work being carried out remotely. Preparation for the retrieval of SF assemblies took 1-year, but the retrieval process itself was achieved in 10 days. The project illustrates the use of equipment that is readily available, but adapted to the very challenging circumstances faced.

With the removal of the SF assemblies, Building 5 no longer presents nuclear threat, but radiological and conventional hazards do remain. A further survey of the building will be needed to inform on the decommissioning process for Building 5.

4 Optimization in different circumstances

4.1 Optimization of radiological protection and existing exposure situations: Recommendations of ICRP

Ludovic Vaillant (Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire and ICRP Scientific Secretariat) presented.
It is a key objective of the ICRP for its Recommendations to be applied across all sources and exposure situations, where:

- → planned exposure situations (previously termed practices) are situations involving deliberate introduction and operation of sources such as nuclear power generation that require public and worker exposure to be considered;
- → emergency exposure situations may occur during the operation of a planned situation, or from a malicious act, or from any other unexpected situation, and require urgent action in order to avoid or reduce undesirable consequences; and,
- → existing exposure situations are exposure situations that already exist when a decision on control has to be taken.

ICRP Task Group 98 is focused on the application of ICRP recommendations to areas contaminated as a result of past activities, i.e. existing exposure situations.

Existing exposure situations are wide ranging and include prolonged exposure situations after emergencies. ICRP Publication 103 (ICRP, 2007) provides the following description of existing exposure situations:

> *"There are many types of existing exposure situations that may cause exposures high enough to warrant radiological protective actions, or at least their consideration. Radon in dwellings or the workplace, and naturally occurring radioactive material (NORM) are well-known examples.* ***It may also be necessary to take radiological protection decisions concerning existing man-made exposure situations such as residues in the environment resulting from radiological emissions from operations that were not conducted within the Commission's system of protection, or contaminated land resulting from an accident or a radiological event.*** *There are also existing exposure situations for which it will be obvious that action to reduce exposures is not warranted.* ***The decision as to what components of existing exposure are not amenable to control requires a judgement by the regulatory authority that will depend on the controllability of the source or exposure, and also on the prevailing economic, societal, and cultural circumstances."*** (ICRP, 2007, Para. 284, emphasis added)

In addressing existing exposure situations, limits are not applied, but rather the focus is on the application of reference levels and the optimization and justification of strategy, which is driven by the prevailing circumstances.

Historically, the system of radiological protection was focused on the protection of people, under the assumption that, by protecting people, the environment would also be protected. More recently, the decision was taken that protection of the environment should be demonstrated explicitly, leading to an ICRP framework for environmental protection from ionizing radiation being developed. The framework is based around a set of 12 Reference Animals and Plants (RAPs) that are considered typical of the major environments that are likely to be of interest (marine, freshwater, terrestrial). The RAPs are described in ICRP Publication 108 (ICRP, 2008), along with a band of dose rate for each RAP aimed at providing a starting point for considering what action, if any, should be undertaken in relation to protection of the

RAPs. These bands of dose rate are termed Derived Consideration Reference Levels (DCRL). The principle of optimization is central to the system of protection and applies to all exposure situations and considers all exposures and thus includes environmental exposures. The application of DCRLs under different exposure situations is described in ICRP Publication 124 (ICRP, 2014a). With regard to remedial strategies, consideration should be given to the likely consequences for radiation exposure of biota so that the overall outcome does more good than harm.

Radon exposure commonly falls within an existing exposure situation. Radiological protection against radon exposure is addressed in ICRP Publication 126 (ICRP, 2014b). The management of radon exposure is mainly based around the application of the optimization principle with a reference level being set within the range of 1 to 20 mSv, but with a value of the order of 10 mSv annual dose being considered as a benchmark for setting a reference level for radon by the Commission. Furthermore, the Commission recommends that national authorities set national derived reference levels for radon that are ALARA in the range of 100 to 300 Bq/m^3, taking prevailing economic and societal circumstances into account, which is broadly consistent with WHO recommendations with regard to radon. The Commission also recommends that an integrated approach to radon management is applied to all buildings, irrespective of the building function or occupancy status.

ICRP Task Group 76 is focused on radiological protection from naturally occurring radioactive material (NORM) in industrial processes. A report from the task group is due to be published that recommends an integrated and graded approach to the protection of workers, members of the public and the environment. The approach includes characterization of the exposure situation, which will drive the protection strategy, and optimization of radiological protective actions within that protection strategy. Reference levels for the protection of workers (excluding exposure to radon and thoron that should be managed according to ICRP Publication 126 (ICRP, 2014b)) should reflect the distribution of exposures and should, in the majority of cases, be less than a few mSv annual effective dose. Very rarely would it be expected that a value exceeding 10 mSv annual effective dose would be necessary. For the protection of the public, reference levels should also reflect the distribution of exposures and would generally be less than a few mSv annual effective dose.

ICRP Task Group 98 is considering the application of the Commission's recommendations to exposures resulting from contaminated areas from past industrial, military and nuclear activities. Post-accident phases following nuclear accidents are not covered since such scenarios fall within the scope of Task Group 93. The meaning of the term 'legacy' can vary internationally, hence the term 'contaminated areas' has been adopted. According to ICRP recommendations, contaminated areas are commonly to be considered as existing exposure situations. Due to the variety and complexity of cases, a flexible approach is required that takes account of the prevailing circumstances. Whilst each case is unique, a number of practical cases have been used as the basis for developing recommendations.

Task Group 98 suggests that reference levels below20 mSv/y be applied as the starting point for optimization and discussion is provided around setting an appropriate level, taking account of the local circumstances, including relevant stakeholders. Exposure of workers undertaking planned remediation works should be considered and managed as occupationally exposed workers, even though the source of radiation is existing, which is consistent with ICRP Publication 103 (ICRP, 2007). Protection of the environment is then part of the optimization process. The need for an integrated and graded approach to remediation is recognized, noting that ionizing radiation is unlikely to be the only hazard present and, where multiple hazards being present, radiation may not be the dominant hazard. Indeed, case studies have shown that conventional risks associated with remediation strategies often dominate and strategies may not be justifiable where contamination levels are low. Decisions on remedial actions therefore need to be based on a holistic and balanced view of all risks and benefits and not just those associated with radiation. The long-term protection objective for the public is still under discussion. There is also ongoing discussion around the management of waste arising from remediation work and whether or not this should be treated as radioactive waste; the amount of waste generated as a result of remediation activities may be high and national radioactive waste strategies may not be sufficient to address such wastes.

Consistency is needed in the way existing exposure situations are addressed, including NORM, contaminated areas (legacies) and radon exposures and is being addressed in the implementation of the ICRP system for radiological protection through the application of the optimization principle and the use of reference levels within a flexible, integrated and graded approach. Stakeholder engagement is important within any strategy for addressing existing exposure situations, in order to help them appreciate the situation and contribute to the decision-making process.

4.2 Waste management in France

Jamal Chaouki (French Nuclear Safety Authority, ASN) presented.

The French Nuclear Safety Authority (ASN) was established in June 2006 with the mission to regulate nuclear safety and radiation protection in order to protect workers, patients, the public and the environment in France. The ASN also has a role to inform members of the public. The Authority is supported by technical support organizations, including the Institute for Radiation Protection and Nuclear Safety (IRSN).

Waste management in France rests on three pillars:

→ A clear legal and regulatory framework;

→ A dedicated public agency (Andra); and

→ A triennial national plan.

The key principles underlying the waste management policy are as follows:

→ Those producing wastes remain responsible for the wastes until they are disposed of.

→ Waste producers have to provide funding for decommissioning and waste and SF management.

→ Long-term charges are secured through dedicated assets.

→ The amount of wastes generated, and their harmfulness, must be minimized.

→ No foreign waste can be disposed of in France.

→ The general public are to be involved in decision-making on issues that could affect future generation.

The regulatory framework has been defined by three European directives:

→ Council Directive 2011/70/Euratom of 19 July 2011 on the responsible and safe management of spent fuel and radioactive waste.

→ Council Directive 2013/59/Euratom of 5 December 2013 on Basic Safety Standards for protection against dangers arising from exposure to radiation.

→ Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom of 25 June 2009 on Nuclear safety of nuclear installations.

The main acts relevant to waste management (Act of 30 December 1991 relative to research in the management of high-level long-lived radioactive waste; Planning Act of 28 June 2006 on the Sustainable Management of Radioactive Materials and Waste (Waste Act); and, Act of 25 July 2016 relative to the creation of a deep geological repository) are codified in the Environment Code and are supplemented by implementing orders and ASN resolutions. Various non-binding guides have also been published that underpin the legal and regulatory framework.

ASN Guide 23[3] on establishment and modification of waste zoning in nuclear installations provides guidance on establishing defined areas for the management of conventional (including hazardous) wastes and activated or contaminated wastes.

ASN Guide 14 on structures' remediation in nuclear installations provides guidance on the elimination of parts of structures categorized as nuclear wastes in order to downgrade the possible nuclear waste zone to a conventional waste zone. The position of ASN is that complete clean-out of structures must be implemented such that all radiological or dangerous substances have to be removed where feasible. If, for technical reasons, this is not feasible then remediation must be undertaken as far as possible to avoid use restrictions. Within the possible nuclear waste zone, structures are to be treated as radioactive waste until they are proven not to be contaminated. The general doctrine for determining waste zoning is based on the use of independent and successive lines of defence where by the first line of defence is to understand the contamination (and/or activation) of each structure to define the total thickness to be removed, as illustrated in Figure 7.

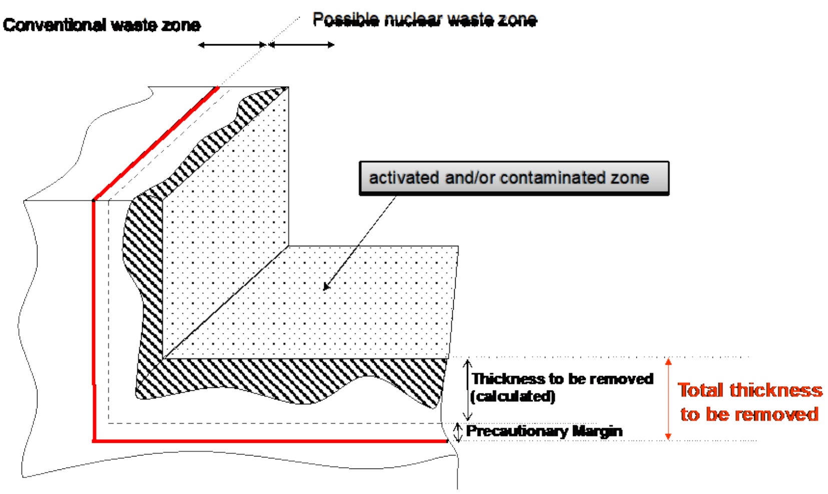

Figure 7: Defining conventional and possible nuclear waste zones for the remediation of structures in nuclear installations under ASN Guide 14.

The second line of defence is then to confirm the conventional nature of structures after clean-out through a radiological inspection program. The third line of defence is radiological inspection of all conventional waste leaving the site. This latter barrier is maintained at least until delicensing of the installation.

There is no clearance level in France so specific disposal routes for very low-level waste (VLLW) are required. The reasons for clearance levels not being used are threefold:

→ It would be difficult to have internationally defined levels accepted nationally;

→ The clearance of waste would be difficult to control; and,

→ There would be incentive for wastes to be diluted in the environment.

Disposal or storage routes are therefore required for VLLW, although there is the option for reuse or recycling of materials that are or could be contaminated on nuclear sites.

[3] See https://www.asn.fr/Informer/Publications for ASN guides.

Andra is the public agency in France responsible for radioactive waste management. The agency was created in 1991 and is in charge of the management of existing disposal facilities; research, design and construction of new disposal facilities; and, the national inventory of radioactive material and waste within the French territory.

The Planning Act of 28 June 2006 on the Sustainable Management of Radioactive Materials and Waste (the "Waste Act") requires a public national plan for the management of radioactive materials and waste. The plan is completed by ministerial decree and is, hence, a binding framework. It has two objectives:

- → To draw up a periodic assessment of the radioactive substance management
- → To define improvement path or needs for new waste routes and set objectives to be met in the future, mainly in terms of research and studies

The underlying principles are as follows:

- → Reduction of the quantity and the harmfulness of waste by reduction at source and by SF reprocessing.
- → Storage for radioactive waste waiting for treatment or disposal.
- → Waste that cannot be disposed of in a surface disposal or in a low-depth disposal for safety reasons are disposed in a deep geological repository.

The plan is prepared by a group of stakeholders comprising ASN, the ministry of energy, environmental protection associations, experts (e.g. IRSN), radioactive waste producers and Andra. The development within a group of stakeholders allows a shared vision for the management of radioactive wastes to be developed. There are only a few large waste producers in France that operate the 58 power reactors that are in operation (a further installation is being constructed) and 12 fuel cycle facilities (enrichment and manufacturing and SF processing and storage). The producers are tasked by law to manage wastes safely during production, treatment, conditioning and storage. Andra is then responsible for designing, siting and managing the storage and disposal facilities for radioactive waste. ASN is responsible for the control of installations at all phases (conception, construction, operation, decommissioning and monitoring).

It is considered by ASN that the long-term management of radioactive waste is a nuclear safety matter for which safe management routes have to be developed for each type of waste. ASN does not, however, promote any particular project, but is tasked with controlling the safety of projects. A particular obligation is avoiding any undue burden on future generations in relation to radioactive waste management.

At the current time, around a quarter of the 125 nuclear installations in France are decommissioning and eight facilities are due to be delicensed over the next 10 years.

There is also an issue around legacy wastes in France. Long-term management solutions exist for around 90% of the radioactive waste volume that will be generated, but remaining wastes are being stored, pending solution. Some of these wastes were stored and/or packaged several decades ago when less stringent regulatory requirements were in place and now need to be retrieved and repackaged, as necessary, to meet the requirements for future disposal. The law stipulates that all intermediate level long-lived waste produced prior to 2015 must be retrieved and packaged by 2030.

There are three radioactive waste repositories in France, one of which is closed. There is also the Bure underground research laboratory that is located at a depth of 500 m and is being used to evaluate the suitability of the geology for the disposal of high-level and long-lived intermediate level radioactive waste. Waste routes by category are detailed in Table 1. Ultimately, waste routes are defined by the WAC of the disposal facility. The WAC can stipulate the physical, mechanical or chemical properties of wastes in addition to radioactivity content.

Table 1: Management routes for radioactive wastes in France.

<table>
<tr><th>Waste classification</th><th>Very short lived
(half-life < 100 days)</th><th>Short lived
(half-life < 31 years)</th><th>Long lived
(half-life > 31 years)</th></tr>
<tr><td>Very low level (VLL)</td><td rowspan="3">Management by radioactive decay on the production site then elimination in the conventional management solutions</td><td colspan="2">Surface Disposal
The Aube disposal centre for VLL waste
Recycling management route</td></tr>
<tr><td>Low level (LL)</td><td rowspan="2">Surface Disposal
The Aube disposal centre for LL/IL-SL waste)</td><td>Low depth disposal
Under study in compliance with the law of 28th June 2006</td></tr>
<tr><td>Intermediate level (IL)</td><td></td></tr>
<tr><td>High level (HL)</td><td>Not applicable</td><td colspan="2">Deep geological disposal
Under study in compliance with the law of 28th June 2006</td></tr>
</table>

An integrated view from conception to disposal is needed for radioactive wastes. Appropriate waste plans are necessary with waste routing optimized by ensuring that the sorting, treatment, characterization, packaging and storage of wastes is compatible with waste transport and disposal.

4.3 Overview of remediation activities of the territories of the former Baku iodine plants contaminated by natural radionuclides

Aysel Hasanova (State Agency on Nuclear and Radiological Activity Regulation of the Ministry of Emergency Situations, Azerbaijan) presented.

The development of the oil industry in Azerbaijan, mainly in the 20th Century, resulted in the formation of a number of associated industrial facilities, including oil and gas refineries, petrochemical industry and iodine and bromine production plants. Insufficient attention to environmental protection resulted in a environmental problems on the Absheron Peninsula, including areas contaminated by oil and/or NORM, hydrocarbon pollution of air and water and the swamping and salinization of land. To address these situations, the Government approved a plan of measures aimed at improving the ecological situation in 2006 and, in 2007, a project for remediation of NORM contaminated sites of former iodine-bromine production facilities was launched as part of this plan. Specifically, radioactively contaminated charcoal formed in the process of iodine-bromine production was to be removed.

Iodine production was carried out at two sites – Ramany and Surakhany. The sites operated from 1934 and 1956, respectively, with both sites closing in 1994. Natural iodine was extracted from oilfield water pumped out together with oil and collected within an artificial lake following separation. Iodine was then extracted from water by adsorption on activated charcoal. In addition to iodine, isotopes of radium (Ra-226 and Ra-228) and their decay and other harmful substances products accumulated on the charcoal and remained on the charcoal following processing. Heaps of contaminated charcoal remained at the sites following their closure (Figure 8). Equipment with similar contamination were also present along with soils contaminated with oil and oil products, bitumen and crude oil, asbestos tubes from underground communications with NORM contaminated scale and construction debris with surface NORM contamination.

Figure 8: Contaminated charcoal heaps at former Baku iodine production plants.

The contamination presented a hazard to both people and the environment, with both sites being located near to settlements. Gamma dose rates at the sites ranged from 0.15 to 7 μSv/h. Specific activities of Ra-226 and Ra-228 in charcoal, soil, scale and lake sediment samples ranged from 10 to 13,000 Bq/kg and 1 to 3,000 Bq/kg, respectively. The concentration of oil products in soils ranged from 170 – 650 mg/kg, compared to a background concentration of up to 100 mg/kg.

There were several challenges faced in the implementation of remediation activities at the Ramany and Surakhany sites for which solutions were required. There was limited national policy or regulatory framework in place and no strategy for remediation was available in the country. As such, the President of Azerbaijan signed a Decree in April 2008 establishing a nuclear and radiological regulatory authority - the State Agency on Nuclear and Radiological Activity Regulations, within the Ministry of Emergency Situations.

This was also the first project on remediation of iodine plants in Azerbaijan and there was, therefore, a lack of experience and appropriately skilled personnel. A Technical Cooperation programme was established with the IAEA in 2007 to overcome the issue around lack of experience. The project had the objective of improving the ecological situation on the Absheron peninsula through the establishment of a program to monitor the regional biosphere and to develop recommendations for rehabilitation of the contaminated areas.

A series of joint expert missions involving experts from the IAEA and Member States were implemented to assess the situation on the ground, consider options for remediation, review plans and make recommendations on disposal of NORM waste, and assist in developing interim criteria for remediation activities. The resultant remediation concept, agreed in 2010, was for debris and contaminated material to be removed from the sites and for a waste disposal facility to be constructed at a suitable and geologically stable location, with wastes being disposed in endurable cells. Following remediation actions, verification would ensure compliance with radiation protection regulations and sites rehabilitated for reuse.

Deriving site end-states was challenging. Both sites are in close proximity to settlements, the Ramany site is also close to an oil production field and Surakhany is close to an airport and highway. The initial decision was for Surakhany to be rehabilitated for unrestricted use whereas for Ramany there would be some restrictions.

For site remediation activities a gamma radiation dose rate criterion of 280 nSv/h at a height of 1 meter above the ground surface was adopted for both sites. At Surakhany, 160,000 m^3 of NORM contaminated waste was to be removed and from Ramany, was 48,000 m^3. However, there was a limited waste management system in place in Azerbaijan and no disposal system was available. A disposal facility was therefore constructed near the location of the national radioactive waste management facility for the interim storage of industrial, medical and research derived radioactive waste, which was located around 46 km from Ramany and 53 km from Surakhany. The area was deemed suitable for a co-located disposal facility, having a thick clay layer present to serve as a non-permeable liner, and a deep groundwater table such that groundwater infiltration would not be an issue. Precipitation in the area is low.

The disposal facility constructed for the project was comprised of 29 near-surface disposal cells, each with a depth of around 12 m. The base and side walls of each cell were lined with bentonite-filled bags to prevent contaminant migration. Disposal cells were then filled with successive layers of waste and fill material prior to capping with a 1.5 m layer of fill material.

Clean-up activities began in July 2012 in Ramany and completed in September 2012. Rehabilitation works in Surakhany began in May 2012 and completed October 2012. Monitoring post-remediation shows gamma dose rates at a height of 1 m above ground have reduced considerably with dose rates at Ramany and Surakhany sites being within the range of 0.05 to 0.11 and 0.06 to 0.22 μSv/h, respectively. The radiation doses received by workers involved in the remediation of the sites ranged from 81 to 384 μSv.

The project resulted in the two former iodine production plants, with a combined area of 32.5 hectares being decontaminated and rehabilitated. Around 236 500 m^3 of NORM contaminated waste was removed from the sites and was safely transported and disposed in a purpose-built facility located in a geologically stable location. Considerable expertise was gained as a result of the project and the environmental situation was greatly improved, with both sites being rehabilitated. In the case of Ramany, the site is now a recreational park. The Surakhany site has been released for industrial use.

4.4 Off-site clean-up and interim storage after FDNPP explosion: Constraints and optimization

Haru Hashizume (Obayashi Corporation) presented.

There has been ongoing work on the off-site clean up and interim storage of radioactive wastes following the 2011 explosion at the Fukushima-Daiichi nuclear power plant (FDNPP). Soon after the accident the Government promulgated an Act on Special Measures that enabled off-site activities to be carried out. This was the first step in addressing the off-site contamination situation. Prior to the accident there were no specific rules or regulations for off-site waste management activities. The Act established the Ministry of the Environment (MoE) as the responsible body for off-site clean up and interim storage public works. Previously, the MoE was a ministry overseeing waste and recycling, air and transportation, health and chemicals and nature and parks etc. rather than being an implementer. There was a lack of management skills available in the ministry for such large projects. Officials and engineers from the Ministry of Land, Infrastructure and Transport, which did have such expertise, were therefore seconded to the MoE to assist in developing the interim storage facilities (ISF) and related skills.

The MoE's initial estimate for contaminated soil resulting from the contaminant plume from the FDNPP was originally between 22 and 26 million m^3, but this was ultimately reduced to around 14 million m^3. There has been considerable collaboration between the prime contractors to accumulate and store contaminated soil. Large segregation plants have been constructed that have the capacity to handle around 400,000 m^{3}of soil over a 40-month period. There are 10 similar plants in total to handle the overall volume of contaminated soil. Storage areas are linked to each of the segregation plants. However, the total storage capacity is considerably less than the estimate on the volume of contaminated soil, suggesting the MoE has considered initially only a small proportion of the target soil providing an opportunity to optimize contracts to address the remaining soil. Each ISF plant will therefore work to improve productivity in terms of both time and budget order to gain future contracts for the remaining soils.

The inlet area of the plant receives supersack-loaded dump trucks. The equipment present in this area includes a dumping chute and incline belt and a supersack breaker. A challenge has been to avoid potential queues of dump trucks and achieve the needed turnaround of 140 supersacks per hour to meet the volume target for soils within the contract duration. Once supersacks have been unloaded from the trucks, bulk soil is moved through a segregation process that is comprised of modified conventional equipment used to segregate large to small non-soil items (e.g. stones, rocks, metal etc.) from the bulk soil. Rotational drums along a long belt are used in the segregation process with any items above 20mm being removed and transported to alternative plants for further processing. Segregated soil is placed on another belt for transport to storage area.

During the initial stage of the program, soil sorting focused on a sort and store scheme with clear demarcation on the sorting of soils according to a Bq/kg threshold and a storage layout blueprint in line with the demarcation. Several years later, the feasibility of setting up a soil recycling scheme was considered for the sorting and shipping out of soils to future consumers of recycled soils following the interim storage period, with the interim storage facility becoming the outlet for recycled soils to consumers for use in public works. The soils under this latter scheme would be sorted on a Bq/kg basis prior to shipping to consumers, in line with quality control criteria to meet future needs. A gradual shift between these two schemes has occurred over time (Figure 9).

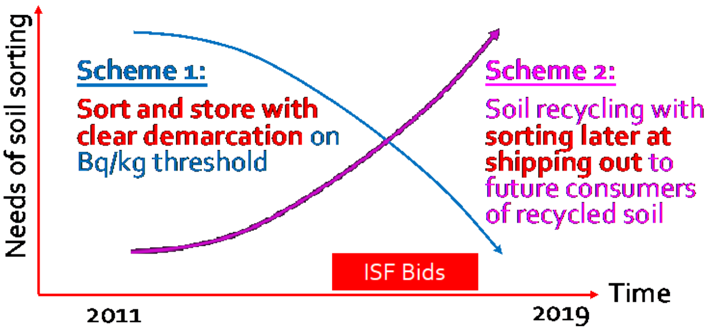

Figure 9: Shift in contaminated soil sorting schemes over time, in line with the potential for reuse of soils.

With soil remediation activities being public works, a bidding process for contracts was used to optimize value for money. Proposals were evaluated both in terms of commercial and technical scope. Pricing of the scope of works was the most influential aspect for the commercial part of bids. The technical part of the process ensured that bidders intensively study the scope of works to gain greater technical evaluation marks. The bidding mechanism allowed for higher marks in technical evaluation to compensate for higher price in the commercial evaluation, i.e. to optimize between value and money.

The technical aspects focused on during the evaluation of bids were:

- → Safety measures, including minimization of worker doses;
- → Care for the community, including assurance of traffic safety and avoidance of traffic jams;
- → Reliability and efficiency of 1) workflow from temporary storage to the ISF and 2) breaking of supersacks;
- → Continuity of workflow; and

→ Quality assurance and maintenance of impermeable shuttering membrane.

Two technical aspects therefore focused on maintaining productivity. The breaking up of supersacks was one of the key questions. The supersacks are large and consist of durable two-layered heavy-duty container bags that are difficult to break up. The bags were not allowed to be broken into small pieces that could mix with the soils since this would add to the segregation issues and risk increasing the overall volume for storage whilst reducing the quality of recycled soil.

The damaged NPP is surrounded by the ISF's. They have been located on paddy fields on a 30-year lease basis to the Government. If the soil recycling scheme does not go ahead within that lease period then soils will be required to be moved to an as yet undetermined final storage scheme, unless another option is identified in the interim.

In terms of lessons learned, there was a lack of preparedness. The event that unfolded was unplanned and the nation was unprepared. Responding to the incident has therefore been a national exercise in response. The project that resulted to address contaminated soils off-site was extremely large and was different from anything experienced up to that point and constraints were multiple and everywhere. A further learning point is that there can be issues around the terms 'expected event' and 'unexpected event'. Rather than using such terms, scientist, engineers etc. should look at events in terms of whether they are 'foreseen' or 'unforeseen'.

Whilst the nation was unprepared for the incident and its aftermath, it is not easy to be prepared for all eventualities. The need for the soil remediation project was triggered by an unforeseen accident, requiring a solution focussed on the particular circumstances that unfolded. Constraints and optimization inform on the ultimate goals. However, the constraints and goals can be complicated with the involvement of various stakeholders acting in response to the circumstances brought about by a sudden and unforeseen event.

4.5 Use of performance assessment in finding optimal solutions to decommissioning and radioactive waste disposal problems

Cynthia Barr (United States Nuclear Regulatory Commission, U.S. NRC) presented.

The NRC regulates all commercial uses of radioactive materials, including waste disposal in the USA. It conducts safety reviews focussing on radiological risks and, together with other federal agencies, undertakes environmental reviews to evaluate environmental impacts of proposed federal actions in order to inform decision-making. Radiological and non-radiological impacts are considered in environmental reviews to allow overall risk to be optimized. Independent modelling and analysis informs the reviews, and helps us to ask better questions and make better decisions.

For decommissioning sites, a 1,000-year compliance period typically applies with dose modelling being used to assess risk and determine clean-up levels. The risk associated with the residual radioactivity considering transport of radioactivity along various pathways of exposure (e.g., groundwater extraction for irrigation or drinking water for people and/or livestock; vegetable and animal/animal product ingestion). Direct radiation exposure and inhalation are also considered. Screening level or site-specific analyses are performed considering the dose to the average member of the critical group which could be an on-site or off-site receptor. Similar exposure pathways are considered for radioactive waste disposal but typically disposal facilities attempt to isolate waste from the biosphere such that other aspects are also considered. Performance assessments are used to evaluate factors such as the performance of barriers, the waste form, and degradation of the barriers over extended timeframes, in order to assess risk and determine compliance against dose-based criteria. Two examples were provided to illustrate the approach taken in performing complex decommissioning and LLW disposal facility reviews.

The first example concerned historic radium contaminated sites. The risks from radium exposure were originally unknown. After the risks were known, sites of historic radium contamination were inconsistently regulated until 2005 when the Atomic Energy Act was amended, giving the NRC the authority to regulate "discrete sources" of radium. In response, the NRC issued a 'Naturally occurring and accelerator-produced radioactive material' rule in 2007 and took action through a methodological approach to identify and address sites with risk-significant quantities of radium.

Radium was historically used in a range of products, including radio-luminescent paints, watches and children's toys as well as health products. Oak Ridge National Laboratory (ORNL) was contracted by the NRC to conduct research into sites where radium was used or processed, to gather available information on the sites, including the nature and extent of contamination, and to develop a methodology that would enable sites to be prioritized in terms of potential hazard to members of the public. Historical records, databases and literature searches resulted in factory locations being identified where Ra-226 had been used. Review of site information and data then provided information on the operational history, remedial activities, current status of structures, radiological and site conditions, demographics and past and current government involvement at each site and a four-tier prioritization system was established.

The NRC established an inspection procedure that detailed conduct of initial site visits and established procedures for radiation surveys to determine whether or not immediate controls were necessary at a given site. Immediate controls were deemed necessary if survey readings were 0.4 μSv/h above background at industrial sites or 0.15 μSv/h above background at residential sites, which would lead to a potential dose of 1 mSv/y, the public dose limit stipulated in NRC's regulations, considering expected occupancy times for industrial and residential scenarios.

A dose assessment technical document was also developed, using a 0.25 mSv/y screening level criterion, the unrestricted release limit in NRC's decommissioning regulations, and different scenarios were considered including industrial building occupancy or residential building occupancy for sites with radium associated with buildings; and a resident farmer for sites with radium associated with soils. The objective was to screen sites quickly and avoid placing undue burden on current site owners. DandD, a code for screening analyses for license termination and decommissioning, was used with its default scenarios, pathways and parameters, but with some site-specific considerations. For example, the removable fraction and resuspension factors were revised to be consistent with expected conditions at the contaminated sites. Revised occupancy times and breathing rates for residential rather than industrial building occupancy were also applied, as appropriate, and the area of contamination was taken into account with higher screening values being applied to smaller contamination areas. Inspectors confirmed whether sites were consistent with screening value assumptions. Where screening values could not be met, more site-specific modelling was undertaken using more complex models and/or taking more detailed account of real site conditions.

The NRC categorized identified sites according to whether surveys confirmed that (i) they did not warrant a visit, or (ii) they warranted a visit. The sites warranting a visit were determined to either (i) meet NRC's unrestricted use standards, or (ii) radium contamination was in excess of the unrestricted use standards and therefore required remediation.

There has been considerable progress in just a few years to address radium contaminated sites. Of around 50 sites identified, five sites needed further characterization or remediation. Of these, two sites have completed remediation and two have had remediation plans approved. Remediation plans are being developed for the fifth site.

The second example is the Western New York Nuclear Service Center (WNYNSC) and the current West Valley Demonstration Project (WVDP) (located on part of the WNYNSC), which was a site for commercial SF reprocessing from 1966 until 1972 when the licensee determined the plant was no longer economically viable. Remediation work at the site include decontamination and decommissioning of process buildings, treatment ponds, HLW tanks, and radioactive waste disposal facilities as well as addressing radiological contamination of soils, groundwater, and surface water and sediments. The site is complex and presents several waste disposal issues and technical challenges. Working groups were established to obtain information to better understand uncertainty in the following areas to inform future risk assessments:

- Erosion: The site is subject to active erosion and a working group was established to evaluate rates of erosion and to update erosion models to reduce uncertainties and enable the impacts of erosion on long-term performance to be evaluated.
- Waste Inventory: The waste inventory is also very uncertain due to the nature of past record keeping and so an inventory-exhumation working group was established. The objective of this working group was to decrease uncertainty of inventory estimates and to evaluate the costs and benefits of full or partial exhumation.
- Engineer Barrier Performance: A third working group was created to evaluate the performance of engineered barriers and in-place closure containment technologies in connection with any decision should it be made to leave wastes in place.

An environmental impact statement (EIS) was prepared to assess the environmental impacts of various alternatives to addressing the waste disposal issues, including site-wide removal of wastes, site-wide close-in-place and phased decision-making. Both radiological and non-radiological impacts were considered. Several organizations were involved in developing an EIS, under the leadership of the DoE, who is currently responsible for cleaning up approximately 200 acres in the center of the WNSNSC, referred to as the WVDP. The NRC constructed independent models to assist with the review of the EIS and decommissioning plan in order to identify the most risk-significant sources.

An aerial survey of the site was undertaken that identified off-site contamination on the nearby Seneca Nation territory. On-ground surveys were therefore undertaken to confirm results of the aerial survey and further assess the associated risks. Surveys were conducted at individual properties and communication with property owners identified how land was used as input to dose modelling. Multiple realistic scenarios were considered for current land use, as well as reasonably foreseeable land use scenarios. As a result of the independent review and analysis, the NRC concluded that risks associated with the off-site radioactivity were low. Results were presented to the Seneca Nation. By engaging with land users throughout the process, including gathering information on their use of the land, the Seneca Nation appeared to be more accepting of NRC's conclusion that resources would be better spent on remediating higher-risk sources on-site rather than being spent to address the low-risk, off-site radioactivity .

The examples support the conclusion that complex decommissioning and legacy sites are each unique and require novel approaches to address the technical or programmatic challenges faced. The use of screening analyses can be useful in helping to prioritize sites and identify where additional effort may be needed, but it may be necessary to undertake additional characterization to inform on whether or not remediation is needed to meet established criteria. Independent analysis is important to develop better understanding of the risks and ensure the right questions are being asked. This, in turn, will support more optimal decision-making, ensuring that resources are spent cost-effectively.

4.6 Optimizing the regulatory framework for legacy management in Romania

Cornelia Sabina Virtopeanu (National Commission for Nuclear Activities Control, CNCAN) presented.

Phosphate fertiliser production was shut down in Romania for economic reasons, but large phosphogypsum dumps remain that contain radioactivity. Other legacies in Romania include oil and gas contaminated sites, fossil fuel energy production sites and metal processing industries. All of these sites are non-nuclear, and most belong to the state. Since 1990, some facilities became private and current owners argued that they were not responsible for decontamination actions since the problems were not specified in sale contracts, costs for addressing these historical issues would be high and funding was not set aside. Furthermore, there was a lack of understanding as to why radiation had become of great interest when activities at the sites had been undertaken for some time without concern.

The regulatory framework was updated in 2018 to transpose Council Directive 2013/59/EURATOM of 5 December 2013 on Basic Safety Standards for protection against dangers arising from exposure to radiation. It now comprises:

- Law 111/1996 on the safe deployment, regulation and licensing of nuclear activities, modified and completed in 2018;
- The Regulation on Natural Sources, approved by CNCAN Order 316/2018;
- The Basic Radiological Protection Regulation, approved by CNCAN Order 752/3978/136/2018; and
- Governmental Decision 526/2018 on the National Radon Action Plan.

Law 111/1996 on the safe deployment, regulation and licensing of nuclear activities, as amended, requires an appropriate regulatory control to be applied to all planned, existing or emergency exposure situations and ensures the system of protection against ionizing radiation is based on the principles of justification, optimization and dose limitation. The National Commission for Nuclear Activities Control (CNCAN) is the regulatory authority for the nuclear field, with responsibility for regulation, licensing and control. CNCAN is a public institution of national interest, chaired by a president with rank of state secretary appointed by the prime minister. The Commission has all the necessary legal powers to issue mandatory regulations and licenses and to perform evaluations, inspections and enforcement actions.

Under the Law, the natural or legal persons, private or public, that own sites contaminated with radioactive materials are obliged to develop and implement optimized protection strategies for the management of those sites, including:

- delimitation of contaminated areas and identification of affected population;
- assessing the exposure of different population groups;
- assessing the need for, and extent of, protection measures to be applied;
- adopting protection measures; and
- implementing remedial actions.

The requirements for protection strategies are detailed in the Basic Radiological Protection Regulation and in the Regulation on Natural Sources. The former sets out requirements with regard to reference levels for exposures due to past practices.

- For an existing exposure situation involving contamination of the environment as a result of a past practice, which has not been under regulatory control, the reference level expressed in terms of residual dose is established as effective annual dose within the range of 1-20 mSv.
- For an existing exposure situation involving residues from past activities for which the undertaking is no longer legally accountable, the reference level is 1 mSv/year.
- In specific situations, a reference level below 1 mSv per year may be considered, where appropriate, in an existing exposure situation for specific source-related exposures or pathways of exposure.

Optimization of protection is prioritized for exposures above reference levels but continues to be implemented below the reference level. Remediation actions are required to be justified by the initiator in the sense that they should do more good than harm.

Under the regulations, for programmes relating to existing exposure situations, CNCAN is required to ensure that measures are taken, upon indication or evidence of exposures that cannot be disregarded from a radiation protection point of view, to identify and evaluate existing exposure situations, considering the types of existing exposure situations, and to determine the corresponding occupational and public exposures. CNCAN may decide, having regard to the general principle of justification, that an existing exposure situation warrants no consideration of protective or remedial measures. Existing exposure situations which are of concern from a radiation protection point of view, and for which legal responsibility can be assigned, shall be subject to the relevant requirements for planned exposure situations and, accordingly, such exposure situations are required to be notified to CNCAN.

CNCAN is required to take measures for the establishment of strategies to ensure appropriate management of existing exposure situations, commensurate with the risks and with the effectiveness of protective measures. Strategies are required to detail the objectives pursued and the appropriate values of reference levels from the range set out in the regulation.

For the implementation of strategies, CNCAN assigns, through specific regulations, responsibilities for the implementation of strategies for the management of the existing exposure situations and ensures appropriate coordination between relevant parties involved in the implementation of remedial and protective measures. The stakeholders are required to be appropriately involved in decisions regarding the development and implementation of strategies. The form, scale and duration of all protective measures considered for implementation of a strategy are required to be optimized and the distribution of doses resulting from the implementation of a strategy is to be assessed. If exposures remain above the reference level, then further efforts are to be considered in order to optimize protection and reduce exposures. Strategies are therefore required to be commensurate with risks and the effectiveness of measures.

Those responsible for the implementation of a strategy are required to regularly:

- → evaluate the available remedial and protective measures for achieving the objectives and the efficiency of planned and implemented measures;
- → provide information to exposed populations on the potential health risks and on the available means for reducing their exposure; and
- → provide guidance for the management of exposures at individual or local levels;

With regard to activities involving NORM and that are not managed as planned exposure situations, information on appropriate means for monitoring concentrations and exposures and for taking protective measures must be provided.

For areas with long-lasting residual contamination in which it has decided to allow habitation and the resumption of social and economic activities, the regulations require CNCAN, the Ministry of Health and the Ministry of Environment to establish, in consultation with stakeholders, measures for the continuous control of exposure, with the aim of establishing living conditions that can be considered as normal. The measures are detailed in the specific regulations, and include:

- → establishment of appropriate reference levels;
- → establishment of an infrastructure to support continuing self-help protective measures in the affected areas, such as information provision, advice and monitoring;
- → if appropriate, remediation measures and delineated areas.

The Regulation on Natural Radiation Sources details the scope and purpose, application of radiation protection principles and requirements for both planned and existing exposure situations. For existing exposure situations, chapters set out requirements around the identification of remedial actions needs and assignment of responsibilities and requirements for the remediation of contaminated areas.

For the identification of the necessities for remediation and allocation of responsibilities, CNCAN, in cooperation with other relevant competent authorities and with the owners of the sites, are required to prioritize those existing exposure situations for which remedial measures are required. Where remedial actions are needed, CNCAN in cooperation with relevant competent authorities is required to establish the responsibilities regarding the development and implementation of remediation plans.

The party responsible is required to develop a remediation plan for each contaminated area in line with regulations in cooperation with all interested parties, including:

- CNCAN and other relevant competent authorities;
- the party responsible for causing the contamination, if it can be identified, still exists and can be located;
- the owners, tenants and users of the contaminated sites;
- local and municipal authorities and local communities; and
- other relevant non-governmental organizations and environmental associations.

Remediation plans should take into consideration all relevant factors, including:

- the characteristics of the exposed population and the associated health risks;
- the reduction in health risks expected to be achieved by the remediation;
- the environmental impact;
- social and economical considerations;
- the need for minimizing the amount of generated radioactive waste;
- the need for minimizing the extent of post-remediation institutional control;
- the amount of funds likely to be available; and
- the availability of suitable remediation techniques and equipment.

Remedial actions set out in the remediation plan are required to be justified in that they provide a positive net benefit and optimized, in that form, scale and duration of remedial actions are such as they provide the greatest possible net benefit.

Parties responsible for developing remediation plans are required to submit them to CNCAN for approval prior to any remediation work being carried out. If the party causing the contamination can be identified, is still in existence and can be located, that party is liable for the cost of the remediation work. Where the party responsible for causing the contamination cannot be identified, is no longer in existence, or is unable to bear the cost of the remediation work, then the party responsible for identifying adequate sources of funding should attempt to negotiate the provision of the necessary funding through voluntary and cooperative action. This may be achieved by engaging with other competent authorities, as appropriate, and with other potential contributors such as the owners, tenants and users of the contaminated site and of nearby property; local and municipal authorities and local communities; potential developers of the site after remediation; and/or liability insurance companies. If adequate funding for the remediation of a site cannot be guaranteed, CNCAN will not approve the implementation of the remediation plan.

Remedial works are required to comply with the applicable requirements for planned exposure situations set out in the regulation, including those associated with radiation protection, notification, determination of activity concentrations, prior radiological evaluation, authorization, protection of workers and management of residues.

The deadline for notification of existing exposure situations to CNCAN was 1 year from publication of the regulations. To date, there have been no notifications received. Identification of situations requiring remediation, as well as industrial and scientific activities relating to natural sources in Romania, remain challenges for the authorities.

4.7 Implementation of a graded approach in ensuring safety of management of emergency and legacy radioactive waste in Ukraine

Kateryna Fuzik (State Scientific and Technical Center for Nuclear and Radiation Safety, SSTC NRS) presented.

About 2 million m^3 legacy radioactive waste is present in Ukraine, mostly as a result of the Chernobyl accident. Radioactive waste disposal sites (RWDS) are located in the Chernobyl Exclusion Zone (CEZ). Temporary localization sites for radioactive waste are also present both in or near the CEZ. Other legacy waste relates to old post-soviet radon-type facilities relating to medicine, research and industry and legacy wastes resulting from former Soviet Union military programs.

Ukrainian legislation follows a hierarchical structure. Uppermost are the Law of Ukraine on Radioactive Waste Management, the Law of Ukraine on State Goal-Oriented Ecological Programme for Radioactive Waste Management and the Strategy for Radioactive Waste Management in Ukraine. Norms, rules and standards support these and are themselves supported by lower-level guidelines and recommendations.

Guidelines for safety assessment have been developed, including guidelines for safety re-assessment of existing storage/disposal facilities and decision-making criteria concerning subsequent measures on these facilities and guidelines for safety assessment of temporary localization emergency radioactive waste sites (RWTLS) in the CEZ. The guidelines provide detailed requirements and provisions from regulatory acts of Ukraine and IAEA documents.

The guidelines covering RWDS within the CEZ aim to ascertain the adequacy of safety achieved, considering the existing conditions of radioactive waste disposal sites and whether the sites comply with safety principles and criteria, and to define possible measures to improve safety. Where safety is not sufficient, the guidelines cover the definition of possible options and measures for radioactive waste removal and management and decisions around the terms, sequence and options.

The guideline for safety assessment of RWTLS within and near to the CEZ is applied in the assessment of radiological impacts on the public, staff of the nearby facilities and on general environment and is aimed at making decisions on the needs and scope of measures on remediation of RWTLS and further management of legacy radioactive waste. Safety assessment is performed iteratively and aimed at ranking of RWTLS according to the degree of their potential hazard:

→ Stage 1: conservative assessment of radiological impacts of RWTLS

→ Stage 2: Upgraded assessment of radiological impacts of RWTLS

→ Stage 3: Determination of remediation measures to ensure adequate safety of RWTLS

During the active phase of the Chernobyl accident, waste was collected from several sites and placed in disposal sites in the CEZ. Around 4,000 m^3 of HLW was placed in the Pidlisnyi RWDS which is a concrete monolith disposal facility. Around 20,000 m^3 of HLW and ILW was placed in the Chernobyl nuclear power plant (ChNPP) III stage RWDS. Assessment has shown that the storage site is safe at the current time, but waste may be relocated to other facilities for final disposal subject to decision-making. A further 886,000 m^3 of radioactive waste from the territory around Chernobyl was placed in the Buryakivka RWDS located around 15 km from the NPP. Waste, equating to around 2.5 PBq total activity, was disposed in a series of 30 trenches at this site.

The LLW generated as a result of the accident was collected and placed in a series of temporary location sites, 9 of which are located around the Chernobyl NPP. There are an estimated 1,000 trenches covering an area of 12 km^2. The total amount of LLW in the trenches is estimated at around 1 million m^3. The trenches have no engineered barriers. An additional 53 RWTLS were created in areas near the CEZ for wastes from decontamination of settlements, including topsoil, roofing materials and construction wastes) as well as waste from the decontamination of equipment.

The second type of facility with legacy wastes are radon-type facilities. There were five enterprises in the 1960s that were initially designated as radioactive waste disposal sites for the temporary storage of radioactive waste from non-nuclear cycle activities. The facilities include closed disposals in concrete modules, closed wells for sealed radioactive sources, stores for sealed sources or solid radioactive waste in containers. There is also liquid radioactive waste storage at two enterprises.

Several military sites of the former Soviet Union are also located on the territory of Ukraine and are associated with legacy radioactive wastes. A pilot project was implemented at one site (Vakulenchuk) under a NATO program. Vakulenchuk was a radioactive waste storage facility located at a former military site of the former Soviet Union. Expert review of licensing documents was undertaken along with review of the site survey remediation programs. A final independent radiological survey was also performed.

The storage facility was built in the late 1970's and consisted of reinforced concrete rings with an external diameter of 1.6 m and 5.5 m depth. The facility stores disused radioactive sources (alpha, beta, gamma and neutron emitters), but few data on the characteristics of the radioactive waste was available. A radiation survey identified that radioactive waste was also present around the storage structure, suggesting some human disturbance may have occurred. The absence of initial data resulted in the need to adopt a conservative approach for safety assurance purposes and in the organization of field work. It also limited options for waste characterization, development of remediation criteria and the scope of the final radiological survey.

The primary criterion for remediation of the storage site was that theannual individual effective dose to people who may reside in the future at or near the site of the liquidated storage facility, should not exceeding 10 µSv/y. A conservative estimate of the predicted exposure dose was made, based on measured specific activities of radionuclides in soil samples taken from an agricultural area approximately 3 km from the storage site and in soil samples extracted during construction of a pit around the body of the storage facility during dismantling works. Human exposure doses were estimated as 0.72 µSv/y in relation to agricultural area soils and 1.49 µSv/y for soils around the body of the storage facility. All dose estimates were considerably lower than the dose constraint of 10 µSv/y.

Remediation of the site involved backfilling the pit formed during dismantling works using soils, including those extracted from around the storage facility where estimated dose from soil was lower than 10 µSv/y. To ensure a conservative approach, all materials of man-made origin were to be removed from the site, whether contaminated or not. A staged approach was applied in the process to remediate the Vakulenchuk storage site consisting of site investigation, site preparation for remediation activities, radioactive waste removal and waste containerization, management of liquid radioactive waste and its transport, removal of the repository body and then final remediation of the site. The stages are illustrated in Figure 10.

Figure 10: Stages in the remediation of the military radioactive waste storage site Vakulenchuk.

A final survey of the site was performed, including gamma radiation dose rate, neutron flux density and surface contamination measurements to confirm radiological hazards had been removed after which measures for final remediation were implemented, including levelling of the site, incorporating fertile soil and planting trees.

The next former military site that will be remediated in Ukraine will be Tsybuleve. Remediation will again be performed within a 2019-2020 NATO project on remediation of a radioactive waste burial site in Ukraine. The store consists of three concrete cylinders, each with an inner steel liner, that are buried in soil next to each other. One cylinder is completely filled, one is about half-filled and one cylinder is about one quarter filled. Available information suggests the cylinders contain disused sources of ionizing radiation (sealed sources are primarily ^{60}Co, ^{137}Cs, ^{90}Sr and ^{239}Pu etc.), but the exact types, forms and the activities of the waste are unknown. The project licensing documents are currently under expert review.

A further pilot project example is the remediation of the RWTLS facility 'Pisky-1. A safety assessment and ranking of the 53 TWTLS sites near the CEZ was performed, with the Pisky-1 site being selected as a pilot facility for remediation. The storage facility was built between 1987 and 1989 and consists of a trench around 1.8 m depth at its maximum. No engineered barriers are in place. The overall storage area is estimated at approximately 124 m^2 and waste volume is estimated at 187 m^3. The trench was covered with a protective top layer of local sandy soil up to 0.6 m thick. Drainage ditches are arranged along the perimeter of the object. As a result of the radiation survey of the Pisky-1 site, it was established that the disposed radioactive waste consists mainly of construction debris (roof tile and slate) and contaminated soil.

An analysis of practical experience in setting criteria for remediation throughout Europe and the USA was undertaken to support the setting of remediation criteria for Pisky-1. A review of the technical solution and safety analysis report for the pilot facility has also been undertaken. The main dose criterion for remediation is 100 μSv/y for a person located in the area after remediation. The justification of the criterion took account of world experience in remediation of such objects, the level of contamination in the surrounding area and optimization of the volume of materials to be disposed. Based on this criterion, and using conservative assumptions, a derived criterion for Cs-137 in soil was established at 1 Bq/g. Soil exceeding this criterion was to be removed and disposed of as radioactive waste. Material with specific activity lower than 1 Bq/g could be used for backfilling of the trench with non-contaminated soil being used to cover the top of the trench.

Preliminary characterization of the site was undertaken using a gamma camera to identify hot spots of contamination near the surface. Gamma dose rate mapping was also performed, and four wells were drilled to a depth of 2.5 m to allow sampling at 50 cm intervals. Those samples were analyzed in the laboratory to confirm activity concentrations and detect possible contamination spread below the storage trench. Geo-radar and metal detector surveys were used to identify large and metal objects and to confirm the boundary of the site. Groundwater monitoring was also undertaken to confirm assumptions around hydrogeology and for groundwater analysis.

Radioactive waste removal was performed layer by layer with each layer being around 25 cm thick. Prior to layer removal, the surface was surveyed to detect any hot spots. Any identified hot spots were prioritized for removal and packaged separately. This sequence was repeated for each layer.

Waste excavated from the trench was placed in large bags that were transferred to a buffer storage area for characterization and sorting (Figure 11). Each bag was subject to gamma dose rate measurement. Packages with activity above the remediation criterion were classed as radioactive waste and routed to temporary storage. Other waste bags were transported to a site storage area for later use in trench backfilling. Following the completion of the remediation activities, monitoring was performed, and activity concentrations were confirmed as below the end-state criterion.

There are a lot of legacy sites and associated radioactive waste in Ukraine and safety assessment of facilities and their ranking by potential hazard has been supported by the development of regulatory guidelines, leading to a range of projects being implemented to address the most hazardous facilities. The criteria derived for remediation of each legacy site are based on the prevailing circumstances, including the proximity of sites to communities. Pilot studies are being used to derive lessons learned for future remediation projects.

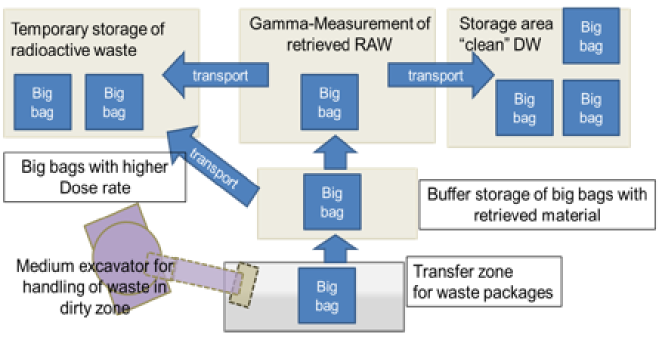

Figure 11: Process for radioactive waste characterization and sorting following excavation from the Pisky-1 storage trench.

4.8 Delicensing of UK nuclear sites: Survey optimization leading to dose assessment

Darren Bungay (Public Health England, PHE) presented.

The UK Office for Nuclear Regulation (ONR) contracts Public Health England (PHE) to carry out an independent technical verification of the approach taken by any UK site undertaking a delicensing application. Sites are typically large and undertake partial delicensing with the aim of staged release of areas for public use. PHE undertakes independent review of the documentation submitted by sites in support of delicensing and carries out independent surveys and sampling to compare against the application and to provide the basis for making an overall judgement against the delicensing criteria.

However, new plans in the UK mean that site may no longer have to be delicensed; on-site disposals may be permitted (see section 2.8).

The ONR stipulate a 'no danger' criteria for site delicensing, corresponding to a one in a million risk of death from ionizing radiation. The criterion applies to any residual radioactivity, above background radioactivity, which remains on the site, whether or not it arose from licensed activities, giving rise to a risk of death to an individual using the site for any reasonably foreseeable purpose, of no greater than 1 in a million per year. This equates to an effective dose to an individual in the order of 10 μSv in a year.The primary radiological basis for establishing values of activity concentration for the exemption of bulk amounts of material and for clearance is contained within IAEA RS-G-1.7 'Application of the Concepts of Exclusion, Exemption and Clearance' (IAEA, 2004).

In the UK, site licensees are responsible for undertaking decommissioning and waste commissioning in support of the delicensing process. Historical studies (review of decommissioning and waste sentencing processes, abnormal events etc) is used as a starting point to site characterization, along with pre-assessment sampling campaigns. These methods can be used within characterization programmes that, together, support assessment of the level of contamination present on the site. The information gathered informs site zoning and, where possible, fingerprints for each zone are set. The Data Quality Objectives (DQO) process is then undertaken that provides input to the design of the final end-state survey and sampling campaign. The results of this lead into a dose assessment, considering various exposure scenarios.

The DQO Process is a seven-step planning approach aimed at developing sampling designs for data collection activities that support decision-making, i.e. the output will provide a statistically defensible decision. The process uses systematic planning and statistical hypothesis testing to differentiate between two or more clearly defined alternatives. The final outcome of the DQO Process is a design for collecting data (e.g., the number of samples to collect, when, where, and how to collect samples) together with limits on the probabilities of making decision errors. The process therefore aims to ensure that there are sufficient data to support decisions within a reasonable uncertainty, whilst preventing the collection of too much data that wastes resources. The final stage in the DQO process is optimization of the site survey, including making decisions on whether additional data collection will be required. Visual Sample Plan (VSP) can then be used to map the building(s), land and randomly pick sampling locations including additional judgemental samples, depending on the criteria set in the DQO, including the accepted level of uncertainty.

In the early stages of a project, PHE undertakes a desk study to identify the constraints and activity concentrations for radionuclides, availability of dose assessments and safety cases as well as monitoring and sampling strategies, with one of the objectives being to ensure that all radionuclides can be accurately assessed by the sampling strategy that has been employed: the instrumentation used and the level of detail in sampling strategies can vary considerably between sites. The Licensee site characterization data and history information are then reviewed to gain an insight into the site and any known areas of particular concern. Groundwater characterisation can be challenging since the regulator considers that a site extends down to groundwater aquifers, aquifers can be located at depths of >50 m and contamination within the profile from the surface of the site to the aquifer needs to be ascertained.

The next stage is site surveying, with instrumentation being selected according to the delicensing criteria and contaminants of interest. A site / building walkover survey is undertaken first to identify contamination areas, typically using large volume scintillation detectors for gamma and/or large area (thin) scintillation detectors for alpha/beta. Any areas of surface contamination detected would result in a sample being taken for analysis in order to accurately quantify the activity.

The walkover survey equipment is designed to be very sensitive and provide a fast response. Counts per second and GPS location are stored every second. A walking pace of 1 m/s is employed, allowing thousands of spatial datapoints to be derived. This approach to surveying is much quicker and cheaper than random sampling and allows heterogeneity in contamination to be evaluated and hotspots of contamination to be identified. The inclusion of GPS monitoring allows tracking maps to be generated that gives confidence that all areas of a site have been covered and for any inaccessible areas or areas for which more measurement data are required to be identified. The tracking maps therefore act as a useful audit tool. Minimum detectable and maximum missable activities are also evaluated to inform on whether appropriate detectors are being employed and in the correct way. Detection will be affected by any height adjustment of the survey equipment or survey speed. Surveyor training is therefore extremely important.

Judgements against the ‘no danger’ delicensing criteria are made considering the whole process on the assumption that a site is contaminated until proven clean. Survey and sampling results are compared and a dose assessment for any residual contamination carried out. Where the DQO process has been used, this provides a statistically defensible decision around site conditions. If IAEA RS-G-1.7 activity values are not met, dose justifications or ALARA statements for leaving some activity in place can be presented to the ONR for consideration on a case by case basis.

IAEA RS-G-1.7 (IAEA, 2004) provides activity concentrations (Bq/g) of artificial radionuclides in bulk material (> 1 tonne) that meets the criteria of an effective dose under typical conditions of 10 μSv/y (i.e. representing a trivial level of dose where regulatory control is unlikely to be justified). Eight exposure scenarios are considered with the quoted RS-G-1.7 value being the most restrictive. In many instances, this relates to drinking water. This is not appropriate to many delicensing applications where land is likely to be reused for housing or recreation. Furthermore, the values provided in RS-G-1.7 are more applicable to waste sentencing rather than leaving land contamination in situ since they were not designed for that purpose. An alternative approach is detailed in NRPB-W36 (NRPB, 2003), which provides a methodology for estimating doses to members of the public from future use of land previously contaminated with radioactivity, again using a series of scenarios. The main differences in approach are detailed in Table 2.

Table 2: Main differences in approach between RS-G-1.7 (IAEA, 2004) and NRPB-W36 (NRPB, 2003).

RS-G-1.7	**NRPB-W36**
Radionuclides present in dust blown onto land.	Direct exposure to radionuclides in bulk soil on the land.
Limited to residential production of food. No exposure to a farmer.	Agricultural and residential production of food. Includes exposure to a farmer.
Radionuclides present IN building materials.	Radionuclides present UNDER buildings / in associated gardens.
Recreational use of paved area.	Recreational use and maintenance of grassed area. Use of paved area.
Exposure to workers handling waste material.	No ‘workers’ assessed. Construction workers assessed.
Adults and 1-year olds considered	Adults, 10-year olds and 1-year olds considered

The scenarios within NRPB-W36 are more applicable for leaving land contamination in situ. For example, scenarios include exposure pathways relating to radionuclides in gardens and under buildings, as well as agricultural and garden food production. The use of data from NRPB-W36 is therefore considered more applicable than RS-G-1.7 for decisions about site delicensing. For unrestricted land use, the activity concentration values for the same 10 μSv/y dose criterion in RS-G-1.7 and NRPB-W36 vary quite considerably (Table 3). Generally, lower activity concentrations are estimated using a contaminated land model.

As illustrated in Table 3, delicensing activity values are very low, and may be lower than natural background in the case of natural radionuclides. Subtraction of background can make a difference, but local rather than national average background values are required for a similar geology and a location unaffected by site operations and based on similar sampling methods. Natural background can be an issue where imported backfill is used on sites. The backfill may be uncontaminated but natural radioactivity may be present. Whether or not the material is considered 'clean' when used as backfill on a site may be uncertain. There is also the potential for the 'no danger' criterion to drive for greater clean-up of a site than would be necessary in terms of allowable contamination off-site.

Table 3: Activity concentration values (Bq/g) equating to 'no danger' for unrestrictive land use.

Radionuclide	**RS-G-1.7**	**NRPB-W36 (large area, surface contamination)**	**NRPB-W36 (small area, buried contamination)**
^{137}Cs	0.1	0.1	1.0
^{60}Co	0.1	0.01	0.1
^{241}Am	0.1	0.1	10^4
^{3}H	100	1000	10^9
$^{226}Ra+$	1	0.001	0.1
$^{232}Th+$	1	0.01	0.1

A key issue for delicensing of sites is balancing the 'no danger' criterion against conventional safety. Where excavation to depth is required to meet the no danger criterion to the depth of an aquifer, considerable conventional risks to workers may arise. The risks associated with the use of heavy machinery used in excavations and transport of waste and clean backfill are likely to be considerably greater than the risks to members of the public associated with contamination left on site at depths where disturbance by construction activities or intrusion by plant roots is unlikely. A balance between 'no danger' from radioactivity and the risks associated with remediation activities is therefore needed. This could be achieved through a more flexible regulatory approach to site delicensing, which could have the added benefits of large cost savings with regard to site remediation and avoid large volumes of radioactive waste being generated. Work is ongoing to amend the regulations in order to move away from an overall no danger criterion to a more flexible approach that considers human intrusion scenarios and provides a greater possibility for optimization.

4.9 Status of Oak Ridge, Tennessee Gaseous Diffusion Plant decommissioning and reutilization

David Adler (U.S. DOE) presented.

Facilities were constructed on the Oak Ridge reservation in the 1940's as part of the U.S. Manhatten project, requiring the removal of around 125,000 residents. Three facilities were constructed:

→ Oak Ridge National Laboratory, where the first graphite reactor was formed and technology for plutonium extraction was developed;

→ Y-12 National Security Complex, used for uranium enrichment; and,

→ East Tennessee Technology Park, previously the K-25 gaseous diffusion plant.

A two-year process of stakeholder engagement has been undertaken by the U.S. DOE to agree on end-states for the site. The Oak Ridge reservation is divided into a number of watersheds and end-state planning is watershed-based. The overall intention for the East Tennessee Technology Park was to defederalize the site and transfer back to the local community for primarily industrial reuse.

Around 15,000 people had lived at the site prior to the construction of the gaseous diffusion plant, which was the largest plant ever constructed at that time. Gaseous diffusion at the site ceased in the late 1980's. Nothing was done to purge the system following cessation of activities whilst the facility was still in a workable condition, leaving in place a challenging clean-up requirement. The current status of decommissioning activities at technology park is illustrated in Figure 12. The buildings shown in green in Figure 12 have been removed. Light blue buildings, where early centrifuge technologies were developed, are in the early stages of being decommissioned. Full site remediation is planned by the end of 2020 with the site being cleaned to conditions compatible with industrial reuse. This will involve the removal of all facilities and soils, to a depth of 10 ft to ensure contamination will not be an issue with the excavation of new facilities. Groundwater clean-up is not covered in the decommissioning plans for the Park.

The entire clean-up program is reliant on the availability of a single on-site disposal facility for wastes generated by clean-up activities. The facility is located close to the Y-12 National Security Complex and has an area of around 200 hectares. The facility has been engineered to meet all NRC requirements for uranium-mill tailings and hazardous waste disposal associated with clean-up activities. The disposal capacity is around 2 million m^3. Liners and leachate collection are in place to prevent contaminant migration. A network of roads has been constructed to enable waste transport to be achieved whilst avoiding the use of public roads. The facility will receive around 90% of the wastes volume generated across the reservation, but the majority of radioactivity will be routed for disposal in a facility for higher activity wastes elsewhere.

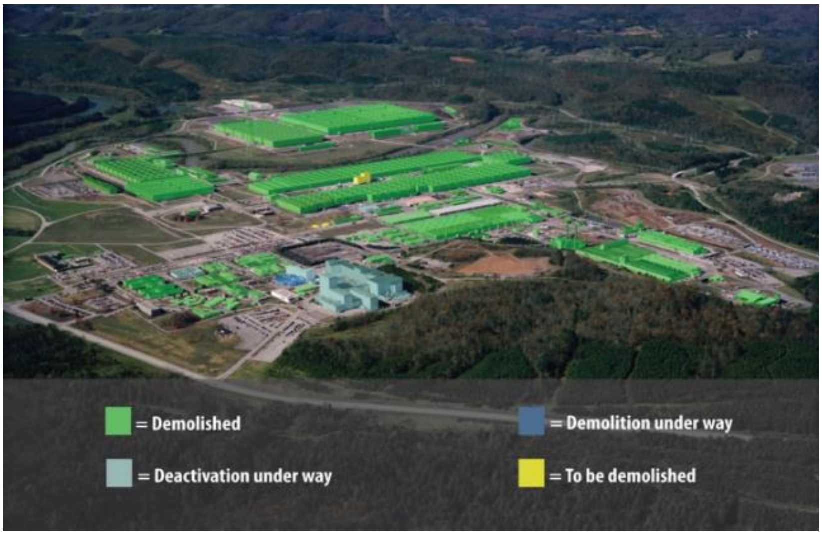

Figure 12: Progress and current status in decommissioning of the East Tennessee Technology Park.

The local community wants land to be returned as soon as possible. The majority of the land is hilly, whereas that associated with the Technology Park is flat and has a range of facilities, such as barge access and power that make it desirable for industrial reuse. The process for transferring land to a private entity takes around 2 years following clean up. Documents have to be prepared by the U.S. DOE for approval that demonstrate that the site has met clean-up standards. There are a series of review stages. Initial review is by the U.S. EPA and Tennessee Department of Environment and Conservation activities. After the U.S. DOE then revises the documents in line with initial review findings, the document then goes for public review. The approval and transfer process then continue until final approval by Congress. The process is illustrated in Figure 13.

To date, a large proportion of the site has been transferred. A radiopharmaceutical company has purchased one area and an airport authority plans to develop a small airport on another area. A national historic preservation area has also been proposed that will cover the history of the area, including the Manhattan project. Other areas, not suitable for economic development will be recreation or conservation areas that will be jointly owned by the National Park Authority and U.S. DOE. Two areas will remain under U.S. DOE control. These are old waste burial grounds. Whilst not particularly hazardous, the burial grounds do contain some items with classification issues and, hence, need to be retained under U.S. DOE ownership.

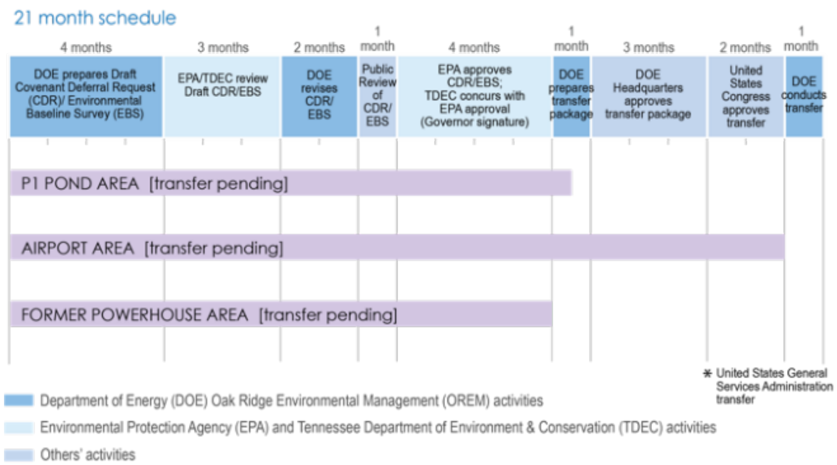

Figure 13: General transfer process timeline and progress for areas of the East Tennessee Technology Park.

The process has benefitted considerably by the U.S. DOE working in partnership with the not-for-profit sector on the industrial park development. Land has been transferred to partners at no cost with the partners then marketing the land. Land sales then provide revenue that is reinvested in infrastructure development. For land that has no clear economic development potential, U.S. DOE has worked alongside the state of Tennessee to develop conservation areas.

To date, around 200 private sector jobs have been created (excluding the clean-up workforce), 20 companies have been established in the area and around 1,300 acres of land have been transferred. A further 3,400 acres have been designated as conservation or greenspace areas.

In terms of lessons learned:

→ It was helpful to have a broad early definition of site end states and clean-up criteria. The need to be able to adapt was also learned. It took around 30 years to clean up the facility that had been created initially in just 18 months. In that time, new ideas arose that led to new options and clean up requirements. For example, it was initially thought that buildings on the site would hold some value as warehouses. However, the buildings had been built for specific purposes and were not readily adapted and were not fit for reuse as they were. The land the buildings occupied was found to be more valuable than the buildings themselves.

→ The land had to be provided for free to end users. There remained concern that there could be potential contamination remaining and new owners of the land did not want the liability. Some financial indemnification was therefore required. This involved providing guarantees that, if regulations pertaining to clean up criteria changed into the future, new owners would not be responsible for any additional clean-up costs. The indemnification does not, however, cover any loss of profit.

→ A partnership approach to cleaning up the site and releasing for reuse drove progress and was highly beneficial.

Work with regard to groundwater remediation is still under discussion. There are prescriptive requirements in place with regard to groundwater and the current expectation is to restore groundwater below the site to the same standard as required by the Safe Drinking Water Act. This, however, is an expensive proposition and is technically very challenging. The issue and approach to remedying are under discussion.

5 Scientific, technical and social aspects of legacy management

5.1 Science support for decommissioning and legacy management

Ole Christian Lind (Centre for Environmental Radioactivity, CERAD) presented.

The focus of the presentation was on models used for environmental risk assessment and to support decision-making for contaminated sites. Such models are simplified representations of reality and the uncertainties associated with the models are often large. Research is needed to reduce the uncertainties.

CERAD is a centre of excellence that aims to provide new scientific knowledge and tools to support better protection of people and the environment from the harmful effects of radiation. In essence, the Centre aims to significantly reduce overall uncertainties in impact and risk assessments associated with radiation (ionizing and ultraviolet (UV)), both in isolation and in combination with other stressors. Everything from sources, through transport in the environment, to consequences in terms of effects and risks are considered, along with ethics. In 2019 the Centre had a budget of €5 million, a staff of around 70 scientists although many are part-time, and 10 post-doctorate and 30 PhD students. A key objective is the training of scientists.

CERAD is a consortium of several Norwegian organizations, including thee Norwegian University of Life Sciences (NMBU) and DSA and has an extensive research infrastructure, including:

→ A climate-controlled gamma radiation facility;

→ A temperature-controlled isotope ‘fish’ laboratory;

→ A climate chamber for UV and gamma exposure;

→ A national outdoor gamma and UV-network for modelling purposes; and,

→ A state-of-the-art inorganic chemistry laboratory.

Wide-ranging international collaboration also provides CERAD with access to contaminated sites in many countries.

There are four broad research areas aimed at reducing overall uncertainties in modelling impacts and risks associated with radioactivity in the environment: source term and release scenarios; dynamic ecosystem transport; biological responses, and risk assessments (consequences and uncertainties).

Real and hypothetical case studies have led to a number of conclusions around sources of uncertainties in model predictions. Local and regional input data are needed as input to models to reduce uncertainties. Model codes that address speciation and dynamics are also required. There are also a number of ongoing EU projects, such as TERRITORIES, that consider model uncertainties.

It is useful to discuss the types of uncertainties associated with environmental risk assessments. Some of the key factors that have been identified as causing large uncertainties in assessments include: exclusion of radionuclide speciation and particle size distribution; ignoring system dynamics and kinetics; use of extrapolations from acute to chronic effects and from one species to another; ignoring sensitive life stages; and, either overly simplistic treatment or total disregard of multiple stressor effects.

In terms of requirements for models, simple models are most useful so long as the uncertainties are acceptable. Any improvement to models should focus on reducing uncertainties. Model results are only valid within the boundaries of the overall uncertainties and uncertainties should therefore be estimated, communicated and understood. Where models can be improved, this can help avoid undue restrictions/actions caused by poor model results since decisions are often reliant on model output. Norway is currently decommissioning its research reactors and CERAD is looking at how to contribute through provision of advice and research such as how model chains can be applied in support of decommissioning and associated waste disposal. Preparatory work has begun.

Radioecology is striving to link releases of radioactive species from different sources, via environmental transport, to dose and risk under different climate conditions. These are complex systems with many different stressors present and varied conditions (e.g. antioxidant conditions) that can influence the sensitivity and vulnerability of systems. Decision making relies on doses from models from both short- and long-term risk assessments. If doses are below applicable screening assessments then no action is likely needed or alternative measures can be applied, such as dose-saved or cost.

Risk assessments for ionizing radiation consider a source term in Bq, but this needs to be framed in terms of the source and how release occurs as well as what is released since the release scenario will have large implications for risk assessments. For example, the source material (volatiles, particulates etc.) and mechanism of release (e.g. explosions, fire, authorized discharge) will affect environmental behaviour and the scope for exposure. Corrosion processes could also lead to releases with effects on determinands such as pH and redox conditions that influence radionuclide behavior in the environment.

Sources may include particles, colloids or nanoparticles or low molecular mass species. The latter are the readily bioavailable fraction although colloids, nanoparticles and particles could also be taken up into biological systems through processes such as inhalation or cause effects as a result of skin contact. A source term given in terms of a bulk activity concentration does not provide information on the form or the relevant processes affecting radionuclide species. Whether or not the form of the source term matters was illustrated through a case study involving radionuclide particles from soils downstream from Krasnoyarsk-26. A 100 g soil sample was found to have a specific activity of 4.5 MBq/kg. The sample was split to remove an active particle. The bulk soil minus the particle had a count rate of around 40 cps. The activity concentration associated with the isolated particle was 436,000 Bq Cs-137. Such hot spots can be a real issue for the representativeness of samples and particle leaching can lead to analytical issues. Overall, such particles can significantly add to overall uncertainties, particularly with regards to exposure and biological effects. There is evidence that particles can be retained in biota. For example, particles from Chernobyl have been found retained in the gastrointestinal tracts of goat and Dounreay particles added to algal food for mussels resulted in the retention of around 37% of the particles within the mussels for extended periods, resulting in non-targeted effects damage to epithelial tissues.

Palomares in Spain has radionuclide contamination in the form of radioactive particles as a result of a nuclear weapon accident in 1966. Even following clean-up, lots of particles remain. The site therefore provides a natural laboratory for studying the environmental effects associated with radioactive particles. Snails ingesting soils in the area were studied and the concentration ratio (CR) for Pu studied. The range in CR was extremely high, reflecting the heterogeneity in particle contamination of soils. Lots of particles have been detected in snail faeces, but particles have also been found within the snails themselves, most likely embedded in the shell of the snail.

The presence of particles will have implications for measurements and for risk assessments, challenging the conceptual understanding of the links between source term, ecosystem transport, uptake and effects. Particles may have different deposition rates and ecosystem transfers with delayed transfers potentially occurring once particles have broken down over time. Effects may not, however, be delayed since point source effects through contact may be of concern. Concentration radios may also be affected through retention in biota. For ecosystem transfer, dynamics need to be taken into account. Systems are seldom in equilibrium and environmental factors such as pH and redox conditions can affect speciation and, therefore, the appropriateness of assessment parameters such as Kd and CR that assume equilibrium conditions. This was illustrated through a marine modelling example on the transport of Cs following a hypothetical accident in western Norway. Models were compared that either did or did not account for speciation. The range in output from the models was around a factor of 1000.

Environmental risk assessments therefore involve complex source terms, involve many processes that influence ecosystem transfer and are affected by the presence of multiple stressors that influence the biological responses in exposed organisms at different sensitive history life-stages. Risk assessments are affected as a result of variability, assumptions, knowledge gaps and model structure etc., all of which contribute to uncertainties and decisions around safety. Research efforts should therefore be prioritized to address key uncertainties relating to variables, parameters, processes and model structure. Sensitivity analyses are important in this regard in helping to identify, for any assessment, the key factors contributing to the overall uncertainties. Reviewing past assessments where the output was not sufficient to support decision-making could also identify key issues that could be addressed through further research effort. It is also important to ensure the models used in assessments are validated.

5.2 Application potential of existing methodologies to compare options and establish acceptance criteria of combined hazards and risks through stakeholder engagement

Ari Ikonen (EnviroCase) presented.

Stakeholder involvement is beneficial in progressing and enhancing acceptance of projects, but there are many challenges. For example, a holistic approach is needed that considers both ecological risk and human health risks. There is a lot of literature available on the topic of environmental risk assessment, but it is difficult to draw a clear picture of what are the most important factors. There is also a lack of common metrics across different risk factors (e.g. chemical versus radiological risks versus more conventional risks such as noise and dust) and it is difficult to quantify risks in a way that allows direct numerical balancing of the different risks. Being comprehensive and transparent can help gain confidence, but this can be difficult to achieve in reality unless a structured approach is implemented and followed. It is also important that all reasonable alternatives are considered with regard to choices, preferences and premises. Even experts can disagree on terminology and this can make communication difficult. Whilst similar issues are faced by ‘conventional industry’, the public’s perception of radiation risk creates an extra challenge.

A Pathway Evaluation Process (PEP) ‘serious’ boardgame has been developed under the European Sustainable network for Independent Technical EXpertise of radioactive waste disposal – Interactions and Implementation (SITEX II) research project with the aim of supporting pluralistic dialogue between stakeholders. The boardgame involves identifying, structuring and discussing issues that would really matter to different groups of stakeholders from the current radioactive waste situation through to the safe conclusion or terminus. Different timelines and waste types are outlined and play cards used to present different conditions and events, such as operational failures or decision-making challenges. An additional set of cards provides questions on evaluation criteria, such as the values and ethics behind decisions. The game is not intended as a predictive instrument or tool to select best options or reach consensus, but aims to promote discussion and can help in making implicit choices more explicit. In order to play the game, agreement is needed that reaching a safe terminus is a common goal. There are different game modes that broadly relate to different waste management strategies, such as:

- A driven approach where the focus is on effort and resources to reach a safe terminus quickly with a chosen technical option.
- An oriented approach that involves a step by step examination of the technical option in light of alternatives.

→ An open approach where both the path and technical options are developed along the way.

It is also possible to combine elements, depending on the participants of the game. Work on the development of the game is continuing.

NUSAP is an alternative method supporting the management and communication of uncertainty, based on categories for qualitatively characterizing any quantitative statement: Numerical, Unit, Spread, Assessment and Pedigree. It was originally developed in the Netherlands where there had been a loss of faith in the authorities as a result of a chemical legacy, but there has been widespread application within, for example, climate change research and policy development, as well in the radiological assessment field. For example, the method provided the basis for knowledge quality assessment (KQA) in Posiva's biosphere assessment for a geological disposal facility for SF. The KQA was based on NUSAP but was more focused toward modelling and input data rather than stakeholder involvement. KQA was also applied in a BIOPROTA project relating to uncertainties in biota dose assessments (Smith et al, 2010). Currently, Posiva is extending KQA to their overall safety case, alongside stringent data clearance procedures. There have been comments that the NUSAP/KQA approach can be too laborious, but it needs to be adapted to needs, being best applied in a stepwise approach with an increasing level of focus through iterative or phased implementation, to help decide on whether or not there is sufficient confidence to make decisions on the next step. Other similar methods have been applied, with various degrees of stakeholder engagement, with respect contaminated land management, environmental policy and pharmacology etc.

There is a long list of what should be evaluated and ideally be decided upon in consultation with stakeholders. First, the problem should be framed in terms of assessment purpose, regulatory regime and other boundary conditions (noting what can and cannot be changed), the roles of stakeholders in the process, and the endpoints and acceptance criteria. The assessment strategy and main assumptions, including potential for alternative choices, should then be considered, along with data sources and their main uncertainties. Comprehensiveness is important and can be supported through tools such as lists of features, events and processes. The meaning of key assumptions, uncertainties and limitations should be considered, which can be supported by sensitivity, uncertainty and scenario analyses, together with non-numerical audits/reviews (e.g. peer review and/or stakeholder dialogue). There should be iteration within and across all steps.

There are tools available that support KQA, such as pedigree scoring that provides a semi-quantitative scoring approach aimed at evaluating the degree of consensus around assumptions. The approach involves the identification and categorization of the main assumptions to which 'strength scoring' can then be applied in terms of plausibility, subjectivity, availability of alternative choices, and influence of situational limitations. The mapping of strength scores versus results of sensitivity analyses can then be used to identify key uncertainties, i.e. those aspects of assessments that are most uncertain and influence model results. Uncertainty matrices can also be useful.

There is a need for thorough stakeholder engagement to help identify key issues for projects and applicable methods are available that are flexible enough to allow customization to particular topics/issues. Nonetheless, further application experience and subsequent development would be useful.

5.3 ALARA for decommissioning and site remediation: Lessons learnt from a European ALARA workshop

Ludovic Vaillant (Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire) presented.

The European ALARA Network (EAN) was created in 1996 by the European Commission with the following aims:

- Promoting the implementation of the ALARA principle for the protection of workers, public and patient exposures in all situations;
- Engaging stakeholders with different backgrounds on how to implement ALARA and providing a focus and a mechanism for the exchange and dissemination of information, knowledge and practical experience; and,
- Identifying and investigating topical issues of common interest to further improve the implementation of ALARA.

The EAN gathers representatives from 19 European organizations, consisting primarily of regulatory representatives. A workshop is held approximately every 18 months to facilitate the exchange of practical experience and knowledge with respect to the implementation of ALARA. The 18th EAN Workshop 'ALARA for Decommissioning and Site remediation' was held from 11th to 13th March 2019 at Marcoule, France, which is the site of the French Atomic Energy Commission. The workshop was attended by 50 participants. There were 25 presentations as well as group discussions on the topics of ALARA for workers, holistic approaches for risk management, and wastes management. Key highlights from the workshop presentations were presented.

- **Decommissioning of research installations at Ciemat in Madrid, Spain**. This was a remediation project where workers were considered to be occupationally exposed. There was therefore a lot of focus on monitoring, including internal monitoring. Internal monitoring can be difficult and, whilst optimization for external exposure of workers is quite common, optimization for internal exposure tends not to be considered to such an extent. Waste management was a driving factor behind the project and ALARA was applied to waste management for optimization and dose reduction to the public. A saving of €6 million from storage costs was achieved. ALARA should not focus only on workers – it is not only about dose: optimization applies to the whole remediation process.
- **Asbestos remediation in the decommissioning of a low flux reactor in the Netherlands**. Old buildings tend to have asbestos present, which can be a particular challenge in controlled buildings. Key lessons learned were that conventional safety is equal to radiation safety and work shouldn't start until all critical parameters are known, but projects should not be delayed until all details are known. It is important to find a balance and remain flexible to allow new information gained throughout the process to be taken into account.
- **Remediation of a former gas mantle factory contaminated with thorium-232 in England**. This was a former industrial site used for the manufacture of thorium gas mantles for which past practices were not appropriately regulated that was to be remediated for residential use. A dose constraint of 300 μSv/y was applied. Optimization was required below the dose constraint. Remediation workers were considered as occupationally exposed workers. Several radiological and mechanical incidents were reported during remediation works and the key lesson learned in this case was that, by going beyond ALARA, the exposure to significant conventional risks was increased.
- **Mixed alpha emitters and asbestos risk management at EdF in France**. This presented an interesting case where there were competing risk mitigation requirements. To mitigate risks associated with asbestos, water is required. However, in a controlled area, water use would lead to the creation of radioactive effluents and increase operator exposure risks. The use of water would also constrain alpha contamination monitoring through shielding. Regulators therefore had to discuss the approach to addressing the issue.
- **Radium Action Plan in Switzerland**. The relevant authority instigated a 4-year project to address radium legacies that included a buildings sub-project to identify buildings potentially contaminated with Ra-226 as a result of historical activities and to undertake diagnostic measurements in the buildings and remediate where the dose limit of 1 mSv/y was exceeded. Around 20% of cases showed a need for remediation, equating to 1,000 properties, which was far more than had been anticipated and a 3-year extension to the project will be required in order to achieve the plan. Risk communication

issues were encountered in properties where contamination was close to the dose limit but where no remediation was to take place. A pragmatic approach was taken that took account of building use (i.e. schools versus industry). A second sub-project looked at landfills that may have received radium wastes and for which risk-based radiation protection measures may be warranted over the long-term.

From the workshop it was concluded that a holistic approach for risk management is required for decommissioning and remediation that includes inputs and views from licensees, authorities and the public, with public views having the potential to influence the remediation process. It is also important to recognize that adjustments may be needed in how end-states are achieved and a Stop, Think, Act, Review (STAR) approach should be adopted. A graded approach to mitigate the most important risks should be applied, requiring a means for hazard ranking, recognizing that radiation may not pose the greatest risk. Stakeholder views are particularly important in this regard. In terms of waste management, having available a range of options is beneficial in terms of the application of ALARA, providing flexibility in the process to meet the optimal end-state. Finally, in setting out criteria to support the decision-making process, weighting factors should be clarified and discussed with stakeholders.

5.4 Using a starting case for pragmatic optimization of the end state for decommissioning: Example of a UK nuclear power reactor site

Daniel Galson (Galson Sciences Ltd) presented on behalf of Hugh Richards (Magnox Ltd) and Roger Wilmot (Galson Sciences Ltd).

The Nuclear Decommissioning Authority (NDA) has ownership of 17 of the UK's nuclear sites, including their assets and liabilities. The sites include 11 power plants with 26 Magnox-type reactors that are in the process of being decommissioned. The Trawsfynydd site in North Wales (operated by Magnox Ltd on behalf of the NDA) has been used as an example site to illustrate the approach taken to address new regulatory requirements relevant to the end states of decommissioning and release of sites from regulatory control. The new regulatory guidance has led Magnox Ltd to conclude that if large volumes of low-activity radioactive structures and/or contaminated ground are present on a site, the optimized end state of decommissioning may include some radioactivity remaining on-site unless there are overriding considerations requiring a 'clean' end state, where 'clean' means levels below the 'out-of-scope' criteria defined for UK Radioactive Substances Regulation.

A 'Starting Case' End State (SCES) can be used as a basis for comparison with delivering a 'clean' end state and/or as a starting point for optimization if the envisaged end state is to include some radioactivity remaining on site. The use of a SCES helps to make the process of optimization systematic, transparent, comprehensive and no more complex than necessary, which are all characteristics that are important in gaining approval from regulators and other stakeholders, as well as being characteristics of a good method. A two-stage approach is applied. In the first stage, the question is asked as to whether it is preferable to leave any radioactivity on-site at the final end state in the form of large volume, low-activity materials. It should be noted that, even if this is assessed as radiologically acceptable, there may be overriding concerns not to do so. However, if the answer is yes, the second stage is to consider the optimal approach for leaving some radioactivity on-site. It is for this second stage that a SCES is most useful, although the first stage can also be usefully informed by comparison of a SCES with a 'clean' end state. It is recognized that the term 'SCES' may have the potential to cause confusion when used in the first stage, especially if the starting point is an existing end state strategy with a 'clean' end state. An alternative phrase such as 'base case end state' might be used instead of 'SCES'.

The Magnox Ltd definition of a SCES (focusing on the second stage) is "*A starting point for optimization of the End State of a site or zone, defining a conceptual End State configuration that includes radioactive features considered to be credible candidates for remaining after release from regulation.*" A guiding principle in defining a SCES is to minimize the volume of solid waste (but not the amount of radioactivity) transferred off-site. This is in recognition of the detriments associated with off-site disposal of waste, including safety, environmental and financial costs, as well as limitations in national centralized disposal capacity. There are also avoidable risks to workers on-site associated with the removal of sub-surface radioactive features that could potentially remain in situ.

The regulatory "*Guidance on Requirements for Release of nuclear sites from Radioactive Substances Regulation"* (the GRR) is a helpful joint initiative from the environment agencies for England, Wales and Scotland. It was developed over several years, with the 2018 issued guidance incorporating learning from trial applications of a 2016 draft version at three sites, including the Trawsfynydd site. Magnox Ltd has developed an approach to addressing the issued guidance that has been reviewed by the environment agencies and has also been subject to peer review.

A staged/iterative approach is enshrined in the GRR. The first requirement (GRR Requirement R1) is for optimization of waste management options; this covers all radioactive wastes but implicitly includes a strategic decision (involving stakeholder input) as to whether or not the end state could or should include leaving radioactive material on site. This decision (or at least a provisional indication of its outcome) can usefully be informed by quantitative assessment of the hypothetical radiological and other impacts of implementing the SCES as well as the impacts of implementing a 'clean' end state.

If the provisional initial strategic preference is to leave some radioactive material on site, then a more detailed process should be undertaken to optimize envisaged on-site disposals (GRR Requirement R13). In Magnox Ltd's approach, this optimization process is informed by assessments of the radiological impacts of the SCES (without mitigations) and of variant end states in which radiological mitigations of various types are added to the SCES. This process can then be repeated as uncertainties in the radioactive inventory of key features of the SCES are reduced and the design of envisaged on-site disposals is refined.

Even if hypothetical radiological impacts of implementing the SCES are not consistent with regulatory guidance, there can be agreement to move forward with the optimization process rather than adopting a 'clean' end state, because the adoption of mitigation measures may allow for acceptable on-site disposals. On the other hand, there may be features or zones of the site, for which a 'clean' end state may be preferable to pursuing potentially costly mitigation measures. Hence the overall optimization process (including both the R1 and R13 stages) is iterative, rather than 'once through'.

The Trawsfynydd site is located within a national park in North Wales. The site, which generated electricity between 1965 and 1991, has two Magnox-type gas cooled reactors with a separate fuel cooling ponds and waste vaults complex. The site is undergoing decommissioning, and the current strategy is for a 'clean' final end state to be reached by 2083. However, the optimization requirements in the new regulatory guidance have called this end state strategy into question. Consideration is now being given to an alternative end state strategy, leaving in place lightly contaminated sub-surface structures, including reactor bioshields and cooling pond structures, if shown to be acceptable. In March 2019 the NDA directed Magnox Ltd to start to develop detailed decommissioning strategy proposals for the site that would involve demolition of the ponds complex structures within the next decade or so, leaving some radioactive contamination permanently on site. To do this requires assumptions to be made about all the major radioactive features of the site, in which context a similar strategy is envisaged for the reactor bioshields as for the ponds complex.

The major sub-surface structures and associated below-ground void spaces on the site are illustrated in Figure 14.

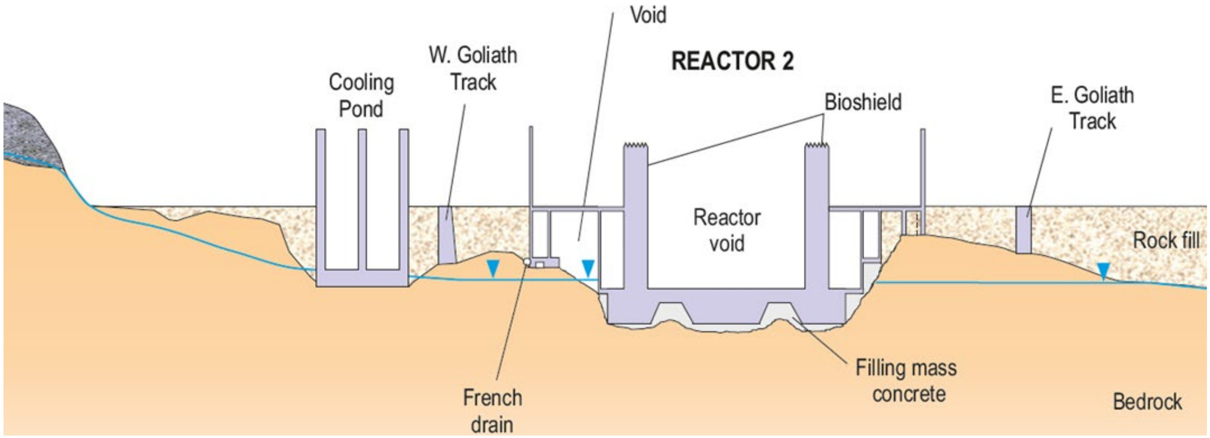

Figure 14: Schematic illustration of sub-surface structures and void spaces at the Trawsfynydd site (x2 vertical exaggeration)

The concrete reactor bioshields are large structures, with floors about 5 m below ground level. They are about 3 m thick and have a combined intact volume of around 22,000 m^3, a substantial proportion of which is activated. Additional radioactive concrete is associated with the cooling pond structures. Historical seepage from the ponds has also resulted in sub-surface contaminated ground that adds to the overall volume of waste that would be generated to create a 'clean' site.

The SCES defined for the site excludes any features for which on-site disposal is not credible, such as higher activity wastes, hazardous components (e.g. asbestos) and readily removable metallic components. It includes the bioshields, cooling ponds complex structures and sub-surface contaminated ground, and assumes that radioactive concrete from demolition of above-ground structures would be used as infill for unwanted sub-surface voids. The assumed SCES configuration is illustrated schematically in Figure 15.

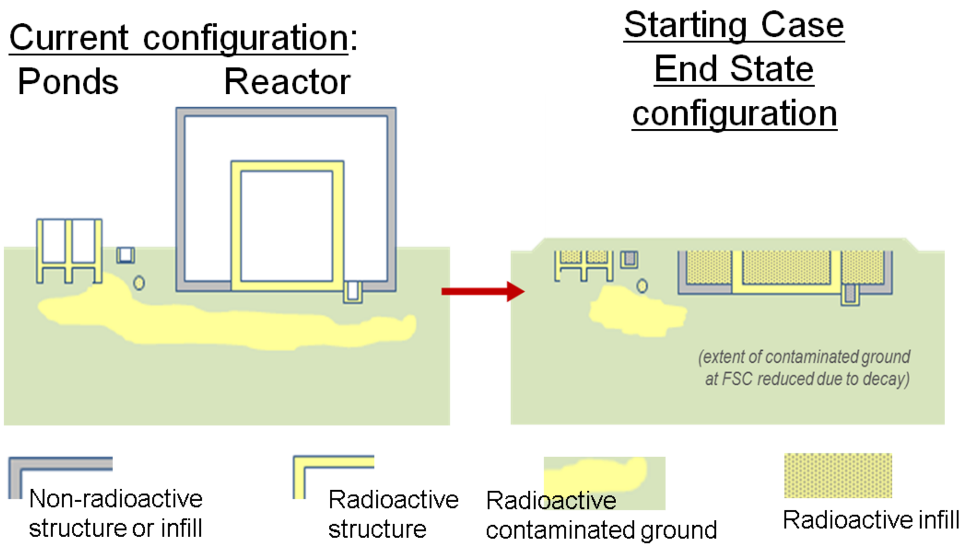

Figure 15: Schematic of assumed SCES configuration illustrating in-situ disposal of below-ground structures and void infill.

The initial radiological assessment was performed for the above SCES, which includes a 1-m thick layer of non-engineered clean cover over the buried structures. The purpose of the initial assessments was two-fold:

→ to inform the strategic decision on whether the site's final end state could include radioactivity (as on-site disposals and/or residual contaminated ground), and

→ to provide a base case for comparison with variant end states incorporating feasible mitigation measures.

The initial assessments were required to be realistic in order to inform optimization, because overly cautious assessments are unlikely to help in identifying appropriate physical mitigations. The assessments included groundwater release pathways and human intrusion scenarios (gaseous pathways and natural disruptive events were assessed qualitatively).

To inform the more detailed optimization stage, various site-wide and feature-specific mitigations of radiological impacts were identified and subject to radiological assessment. These were in the following main categories: targeted decontamination of particular features, conditioning of wastes for emplacement as void infill, in-ground engineering interventions and extending the period of control to allow radioactive decay before release of the site from radioactive substances regulation.

Typical results are illustrated qualitatively in Figure 16 (but note that these are not a complete summary, but are provided in somewhat 'fictionalized' form to illustrate the methodology). The results as shown would indicate that some mitigation would be essential, such as enhanced decontamination of certain ponds complex structures and the deposition of bioshield concrete as infill for sub-surface voids in the form of cut blocks rather than crushed material, in order to reduce the surface area of radioactive material potentially in contact with groundwater. Other mitigation measures could contribute to optimization and demonstration of ALARA, such as blocking fast pathways (e.g. redundant groundwater drains), but high cost mitigation measures that would deliver little radiological benefit (such as grouting contaminated ground in situ) would not be included in an envisaged optimized end state. The potential option to extend the period of control beyond that needed for validation monitoring purposes would confer some radiological benefit, but at present no attempt has been made to assess the costs of this (including hypothetical opportunity costs of not releasing land for beneficial next use).

Feature group	Pathway	Potential mitigation	Radiological impact		Magnitude of net cost of mitigation	Include mitigation?
			Starting case	With mitigation		
Bio-Shields	Groundwater	Cut into blocks, not crushed			High	Yes
Bio-Shields	Human intrusion	Blocks face down			Very low	Yes
Ponds complex	Groundwater	Enhanced decontamination			Medium	Yes
Ponds complex	Human intrusion	Enhanced decontamination			Medium	Yes
Contaminated ground	Groundwater	Grout in situ			High	No
Whole site	Groundwater	Block fast pathways			Low	Yes
Whole site	Human intrusion	Extend period of control			Uncertain	?

Key

	Assessed impact greater than regulatory guidance level
	Assessed impact consistent with regulatory guidance level
	Assessed impact well below regulatory guidance level

Figure 16: Deriving an optimized end state for on-site disposals through assessment of mitigation measures.

Magnox Ltd considers that the approach it has developed and applied for the Trawsfynydd site should meet the regulatory requirements for the process of end state optimization in a manner that is systematic, transparent, comprehensive and as simple as possible. In particular, it minimizes the unnecessary evaluation of options and potential mitigations that are either unrealistic or not sufficiently distinct from other options. This approach should allow the basis of any proposals to be clearly presented to regulators and other stakeholders.

5.5 The role of risk communication and stakeholder involvement in decommissioning and legacy management

Yevgeniya Tomkiv (Centre for Environmental Radioactivity, CERAD) presented.

The role of societal aspects in decommissioning and legacy management is increasingly recognized but requires risk communication. There are various definitions of risk communication. At one end of the scale there is the technical ideal where experts inform and persuade the public of the results of risk analyses and the decisions taken by risk managers. At the other end of the scale is the democratic ideal where risk communication is a rule-governed process where all affected parties are guaranteed maximum participation and power in decisions on risk management. The range is therefore from providing information and aiming to persuade and influence behavior through to empowerment and building mutual understanding. Risk communication in practice tends to fall more toward the technical ideal but there is a shift occurring toward a more democratic approach.

Stakeholder engagement is the process by which an organization involves people that may be affected by its decisions or can influence the implementation of its decisions. The motivations for stakeholder engagement could be instrumental (securing the endpoint), substantive (achieving better decisions) or normative (the right thing to do). It can be highly detrimental to the relationship if stakeholder involvement is considered as a public relations activity rather than active engagement in the process. A more middle-ground approach tends to be taken, i.e. aiming to identify issues that help achieve more informed and, therefore better, decisions.

There are over 100 methods for stakeholder involvement that allow for tailored approaches to each particular case. However, it is not just the method that needs to be thought about. The quality of the overall process is also very important. Stakeholder engagement processes have been analyzed to see what can be learned around the structure of the process, how to address democratic values and how to engage with uninterested stakeholders etc. Lack of impact in historical engagement programs can drive stakeholders toward being uninterested in future engagement programs. This can be addressed by ensuring that stakeholders understand they are not being invited to a ‘box ticking’ exercise but, rather, the objective is to derive better decisions through collaboration and mutual learning; learning is a two-way process and decision-makers should learn from stakeholders as well as providing information.

The quality of the stakeholder process can help build trust. Trust is, however, a complex issue. It can be achieved through listening and caring, demonstrating competence, expertise, knowledge, objectivity and fairness and by being honest, open, transparent and responsive, but is also influenced by the degree of ambivalence, powerlessness and dependency that people feel towards the experts and institutions that manage risks. It is much easier to lose trust than to build it. Decision-makers should therefore reflect internally on how they are worthy of trust such that people should feel confident in placing their trust in them. Communication is an important part of the relationship. It is too often the case that communication is limited to particular events or campaigns whereas continuity of engagement can help generate a long-term trusting relationship. Transparency and openness are key aspects of any communication strategy, but there should be awareness that being more open can lead to greater skepticism as people may be informed of issues they had not been aware of previously. This is not a reason to avoid being transparent, but it is a reason to reflect on it.

Overall, there is a need for institutional change. Current practices should be reviewed to evaluate whether or not societal aspects are being appropriately taken into account and to ensure there are good communication and involvement strategies in place. Institutions are continuously evolving, and it is important that their stakeholder engagement programs also grow and evolve. Overall, listening tends to be under-rated. Focus should be on the relationships and social networks that communication should support, recognizing that social aspects are no less important than any other aspect of decision making.

The development of interdisciplinary projects that integrate social aspects with technical and safety analyses and political feasibility would help in moving this forward and would also help in bringing social aspects of optimization to the forefront and address the issues being discussed. Where interdisciplinary projects have been established in the past, there is a tendency for social aspects to be considered as separate work areas. More interconnection would be useful with social aspects being incorporated within other work packages to ensure appropriate linkages and further the development of a more coherent system.

5.6 Site characterization in Nordic environments: Supporting optimization of siting, remediation and legacy programs by using site data, site understanding and site analogues

Tobias Lindborg (Blackthorn Science) presented.

The site concept is an essential part of radioactive waste disposal programs. Site understanding relies on long-term site development, with site analogues being potentially useful as a tool to developing understanding of the processes that could affect sites under, for example, different climate conditions, whether those sites are generic or specific. Site understanding should couple issues of importance ranging from gathering the information required to support risk calculations though to communication with the local population and authorities. Demonstrating site understanding also supports confidence building. The development of site understanding has been a key aspect of the Swedish geological repository program, with local organizations being involved as part of site investigations to help inform the assessment program and to aid in the overall communication program. Site understanding and ecosystem modelling are important inputs to the modelling of dose and risk and a useful strategy is to 'follow the radionuclide', i.e. consider the transport of radionuclides from source throughout the entire system to identify the different system domains of relevance that feed into dose modelling as well as informing on site characterization. A holistic and iterative approach is key to developing system understanding. There is no conceptual difference between the site understanding for disposal programs and management of surface-based legacy sites, although there may be a change in focus on the parts of the natural system and in the timeframes applied in safety assessments.

There are three major topics for which site information and understanding are required:

- In order to calculate risk, a good understanding of the properties and processes related to the transport of pollutants is required, including any possible time-dependent changes.
- Construction or remediation methods need to be undertaken in a way that does not adversely affect the long-term safety functions of the natural system. Site information supports the development of appropriate methods and supports the appropriate selection of approaches to follow-up safety function monitoring.
- Site information and understanding are also important inputs to environmental impact assessments used to demonstrate compliance with regulations.

A stepwise approach is needed from initial site generic stages, through the site selection process through to the development of a facility and, ultimately, closure application. The level of ambition is important and should be defined by the expected risk as well as societal expectations in order to gain trust for acceptance; if societal questions are not addressed there is a risk that the program will not succeed.

From conceptual through to site-specific stages of programs, it the 'follow the radionuclide' method is applied it is possible to end up with different models that describe the system, depending on the domains identified (e.g. mires, lakes, terrestrial domains). The use of such an approach provides the means by which data needs from site characterization programs can be identified. In an iterative assessment program, where new data and improved site understanding do not affect results in terms of safety functions, a decision can be made to move to the next step. If new data and understanding continue to alter the understanding of safety functions then further site characterization and iteration may be needed.

The SKB SR-Site conceptual site descriptive model for Forsmark in Sweden (Andersson et al., 2013) was presented as an example. The model includes a succession in landscape objects to account for landscape development and integrates the interface between the geosphere and biosphere. The representation of the biosphere was linked to site data needs.

It is possible to tell stories depending on the type of future conditions that are expected, informed by the physical constraints of the system. Various processes can affect a site and impact on the actual properties and processes at the site that is being described. There can be 'switches' for example between terrestrial and marine domains as a result of shoreline displacement. International experience in the treatment of site evolution in the context of waste disposal has been reported on in IAEA TECDOC 1799 (IAEA, 2016). Such methods can be applied to a site to describe changes in state (e.g. progression from marine to terrestrial systems) and may be relevant to the long-term management of legacy sites.

Once different climate narratives are developed for a site, site analogues can be useful in informing on processes and providing data relevant to different climate conditions. For example, to inform on how the Forsmark site could look and function under periglacial conditions, SKB started the Greenland Analogue Surface Project (GRASP). The Forsmark site is subject to a temperate climate, has a positive water balance and is subject to shoreline displacement, having been previously submerged following the last glaciation. Sea, lake and land ecosystems are present. The analogue site selected, Two Boat Lake, is subject to a periglacial climate such that there is permafrost present. The site is therefore subject to periglacial processes. It is a semi-arid system with both lake and land ecosystems present. Both sites are illustrated in Figure 17.

The objective of GRASP was to provide answers to two primary questions:

- → How does hydrology and the terrestrial and aquatic ecosystems behave in periglacial environments compared to other climate conditions?
- → Can climate-specific features and processes be identified that are important when calculating future effects in environmental assessments?

Various processes were studied within the Two Boat Lake catchment, including transport of matter (including wind drift) and accumulation processes and the different processes governing element transport were compared with those under temperate conditions. The hydrology of the catchment was also studied in detail to develop understanding around how the hydrology of the system functions under periglacial conditions and what might happen in terms of discharges from a repository if taliks were present, creating very different flow paths compared with that which might occur under temperate conditions. The investigations produced a wide range of site data. Decision-makers and modellers were involved in the process of deciding what site data were to be derived. Over 20 scientific papers relating to the studies have been published so far. The site research has also underpinned the development of a mass-balance model for carbon that will be used to inform the development of a dose model for the Forsmark site under periglacial conditions.

For any program concerning the siting of a new facility or legacy site remediation, the availability of site data and development of site understanding are key to informing decisions. Thorough planning of information needs should take place early in the process with iteration throughout the program. Site understanding is a multidisciplinary task with many different end-users and a holistic approach is needed to optimize the program. It is not necessary to have a site for planning to begin; thinking on processes can begin prior to a site being available, being informed by the use of site analogues to inform program development. Site analogues are therefore useful at various stages in a program. When the understanding of the systems safety functions does not change, the next steps in the program can be taken.

Figure 17: The current day Forsmark site (top) and its periglacial climate analogue, Two Boat Lake in Greenland (bottom).

5.7 Fukushima Daiichi "on-site" decommissioning and remediation experience from operator TSO

Kazuyaki Kato (Nuclear Damage Compensation and Decommissioning Facilitation Corporation, NDF) presented.

The first priority for decommissioning and remediation following the Fukushima accident was to quickly reduce the radioactive risks that had not existed at the nuclear power station prior to the accident. In the mid- to long-term, a roadmap and strategic plan for decommissioning the site, including associated waste management was needed. The strategic plan was made in 2015. TEPCO is involved in the engineering aspects of decommissioning. A managed decommissioning fund was established in 2017 to ensure continued progress in decommissioning work, with TEPCO receiving annual funds to progress on-site work, engineering and technological developments in support of decommissioning of the site.

The strategy and roadmap for decommissioning of the site have been subject to review and new milestones set (Figure 18). Spent nuclear fuel removal from the reactor units is an important milestone with removal from unit 3 progressing. Removal of spent nuclear fuel from unit 4 is complete whereas removal from units 1 and 2 is currently planned to begin in 2023. Fuel debris removal is also an important task and a strategic plan for debris retrieval from unit 1 has been proposed to the Government. Retrieval from unit 2 is planned to start in 2021. The process and disposal method and necessary technology for waste management requires clarification to ensure safety and is due to be progressed by 2021.

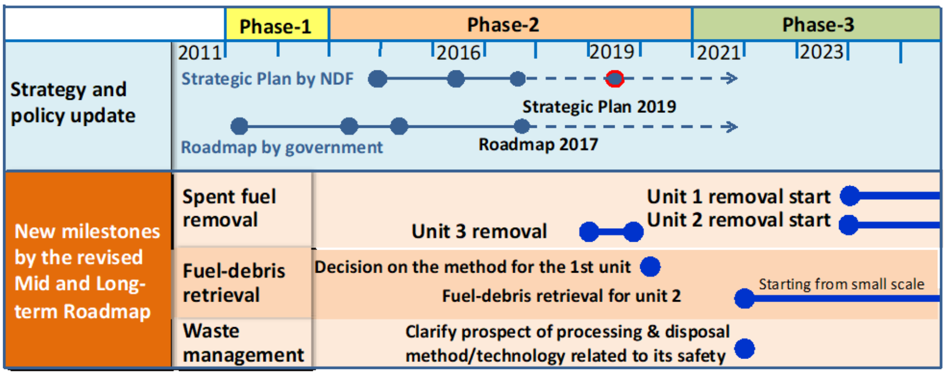

Figure 18: Mid- and long-term roadmap detailing key milestones for decommissioning and remediation activities at the Fukushima Daiichi NPP.

It has been recommended within the Government roadmap that a first priority for TEPCO is the development and implementation of a waste management plan that includes waste prevention, volume reduction and monitoring. The plan is required to be periodically updated in terms of the volume of solid waste estimated to be generated over the following ten years. A large volume of waste with various characteristics will be generated through the decommissioning and remediation works. A flexible approach is therefore required, along with improved analysis capabilities for waste characterization. A study on integrated countermeasures from characterization to processing and disposal will inform on the prospects for a processing and disposal method for solid wastes and the technological strategy for safe waste management. The waste management plan will be developed in line with policies relating to safe storage:

→ The fundamentals of managing solid waste are to contain not to scatter or leak.

→ Wastes should be kept isolated and managed appropriately by monitoring, etc.

→ It is important to raise awareness on reducing the volume of solid waste to be generated.

The prospects of a processing and disposal method and the technology related to its safety is to be made clear by the 2021 financial year. The research and development targets are as follows:

1. Establish safe/rational disposal concept based on processing technology applicable to solid waste and develop safety assessment method reflecting features of the disposal concept.
2. Clarify radiological analysis and evaluation method for characterization.
3. Clarify processing technology that would be expected to introduce actual equipment for stabilization and immobilization considering disposal.
4. Establish method of rationally selecting preceding processing method.
5. Have prospect of setting processing/disposal measure for solid waste of which the processing technology considering disposal is not clarified, using a series of method to be developed by 2021.
6. Clarify issues and measures concerning storage of solid waste before conditioning.

The flow of research and development targets relative to the establishment of a processing and disposal method for solid radioactive wastes is illustrated in Figure 19. There is only one facility for the disposal of LLW in Japan, but the accident wastes are different and so a different waste disposal concept is needed. Waste acceptance criteria also need to be developed, along with pre-disposal treatment technologies. Many of the higher activity wastes will require safe storage, which must also be considered.

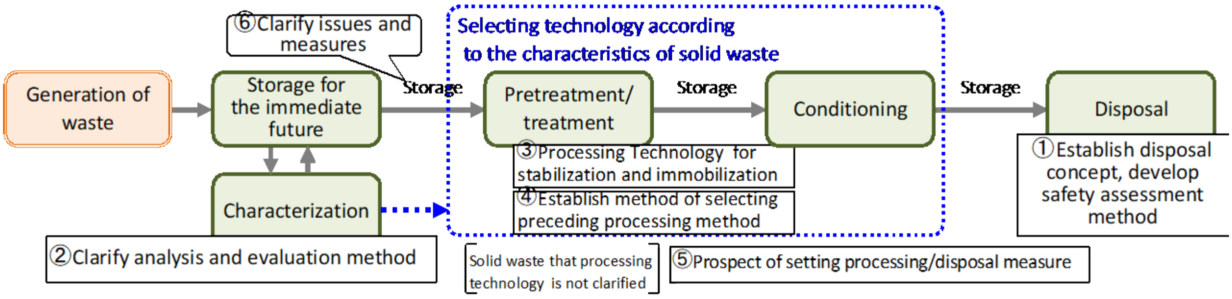

Figure 19: Flow of research and development targets for establishing a processing and disposal method for solid radioactive wastes.

Characterization of wastes will be important, and a research center is due to open in 2020 that will aim to improve the accuracy of models to obtain evaluation data based on the necessarily limited radiological analysis data that can support the setting and revision of the radioactive inventory. A system and facilities / equipment and technologies necessary for improved characterization of solid wastes will be established by the end of the 2020 financial year, taking account of international experience (NEA, 2016).

The schedule for the action plan for the next milestone (around financial year 2021) is given in Figure 20.

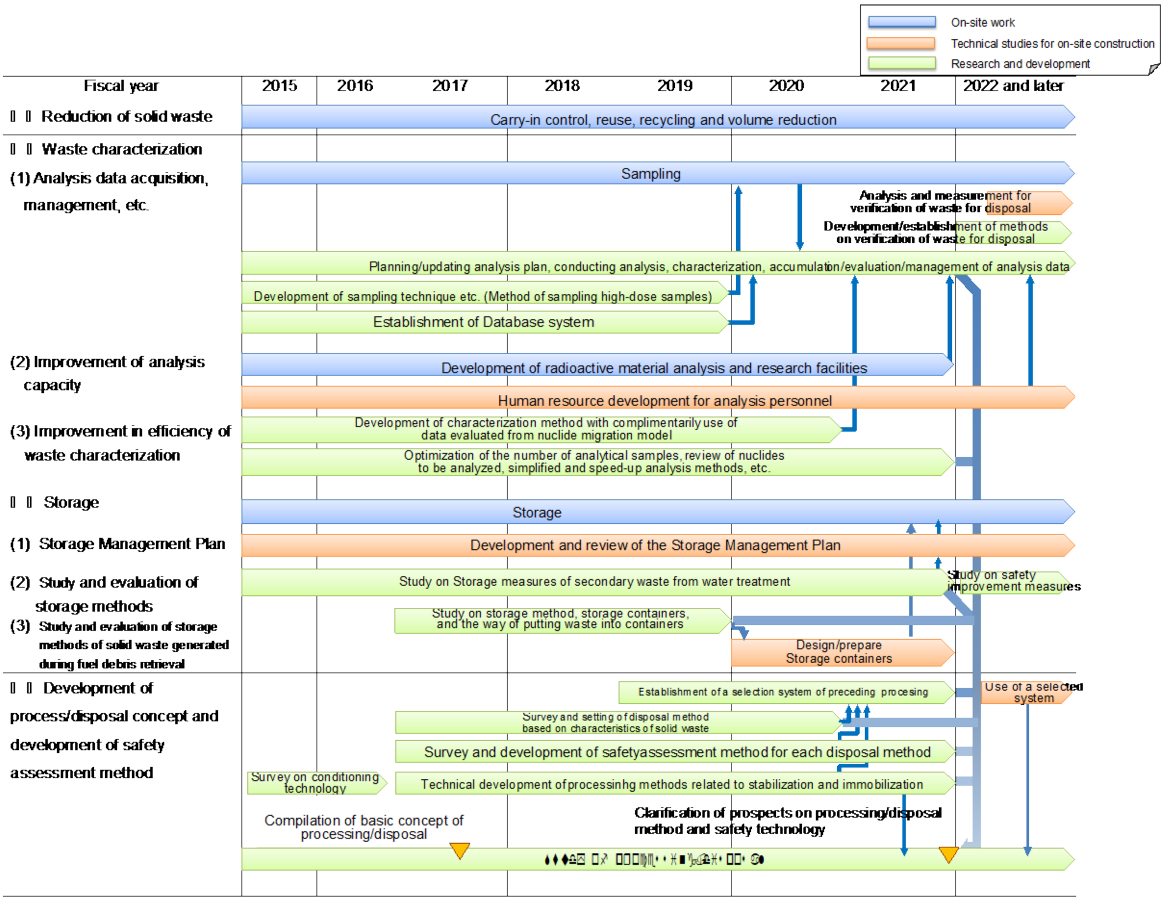

Figure 20: Waste management action plan for the next milestone.

For normal operating nuclear power stations, around 3% of the whole plant would be decommissioning waste. The Fukushima accident, however, resulted in a lot more building contamination and, as such, a greater volume of waste is expected. The accident also led to a large volume of rubble, spread over a wide area as well as felled trees and soils that were contaminated. The treatment of contaminated water also gives rise to secondary waste materials requiring disposal. There is also a lot of high activity waste present, including fuel debris. Characterization of the different materials will be important for the future.

Temporary storage capacity for the large volume of wastes being generated is limited and TEPCO has therefore developed a strategy. Under the strategy, rubble is categorized in terms of surface dose rate to inform on the storage strategy that minimizes worker exposure. At dose rates below 0.1 mSv/h, rubble can be stored outdoors, below 1mSv/h outdoor covered storage is required whereas outdoor container storage that provides greater shielding is required for rubble with dose rates of 10 mSv/h or less. Wastes with dose rates of 30mSv or less are routed to either temporary storage tents or soil covered temporary storage facilities. Any wastes associated with dose rates above 30 mSv/h are routed to a solid waste storage building. Felled trees and used protective clothing are incinerated.

Secondary wastes from water treatment are also considered in the storage strategy. Sludges, associated with high dose rates, are stored in indoor sludge storage facilities whereas concentrated waste liquid is stored in outdoor storage tanks. Used vessels are stored in one of four facilities within an outdoor temporary storage area. The choice of facility depends on the characteristics of the waste and shielding requirements.

Since storage area is limited and waste processing methods have not yet been determined, volume reduction is currently the main priority of the storage management plan. In the first 10 years, 770,000 m^3 of waste is expected to be generated. The use of metal cutters and concrete shredders will help with volume reduction, but many storage facilities will be required. The current plan is for six facilities to be installed in the near future, including an additional incineration facility and incinerator pre-treatment system, a volume reduction facility system, additional solid waste and large waste storage facilities, and a dedicated storage facility for contaminated soil. A miscellaneous solid waste incineration facility was installed in 2016.

Optimization is needed across the whole process of predisposal management and disposal. Each waste stream may have a different optimization point. Wastes will be stored for the interim and be subject to characterization that will then inform on the optimized disposal approach, including predisposal management. Higher activity wastes are likely to require deeper disposal solutions. A range of different technologies are being considered both in terms of waste volume reduction and pre-disposal management.

5.8 The human factor problem in spent nuclear fuel and radioactive waste management: Ways to solve the problem and implementation practice

Victor Shcheblanov and Aleksandr Bobrov (Federal Medical Biophysical Center, FMBC) presented.

Regulations for the protection of workers usually fall under occupational safety, but issues relating to human factors affecting safety tend to be excluded. However, up to 80% of incidents registered at spent nuclear fuel and radioactive waste management facilities are human induced. Human mistakes can be serious and attention to human factors is therefore increasing.

The human factor is a complex of psychological, psycho-physiological and physiological characteristics of human behavior in the work environment. The human factor effect is manifested in the following areas:

- → The reliability of the worker in connection with the requirement to ensure safe and economical work, which leads to the need to identify these features.
- → Monitoring of human cognitive functions manifested in the processing of information and decision-making in normal and emergency situations.
- → Expanding the potential range and increasing the possibilities of improving the human-machine interface, which requires the advanced methods and knowledge that would allow problems to be identified and adequate decisions to be made.

Following the Fukushima accident, a lot of the initial response depended on human actions. The mentality of responders was important which was, in part, driven by human traditions and cultural factors play a role. Human vulnerability is an important component of human safety, affecting the ability to perform tasks without failures. The study of cognitive factors under both normal and emergency situations can help improve the human-machine interface and this has been a topic of study within FMBC.

Developments at FMBC have taken account of international experience from the IAEA and NRC. Various documents, including TECDOC and NUREG series reports, were studied thoroughly to identify relevant input on regulatory decisions, research results, results of emergency investigations and other technical and administrative information. The facilities being dealt with by the FMBC are relatively small compared with what has been looked at internationally, but many of the issues relating to spent nuclear fuel and radioactive waste management are relevant.

International experiments have been run with the aim of improving understanding around human risk assessment studies, and to try to expand the potential range and increase the possibilities for improving the human-machine interface. A key challenge for studies is how to assess human vulnerability. Recently, human cognitive factors and issues of training have been the focus of research. Most methods and models for human factor analysis take into account various conditions during task execution to help determine the probability of system failure. However, the models do not cover all aspects of an operator's activities that could affect the reliability of the human-machine interface. Furthermore, inconsistent implementation by analysts can lead to variation in human factor analysis results.

An international empirical study involving 5 countries has been undertaken to compare human risk analysis forecasts from various analysts and methods with performance data of crews at the Halden Reactor in Norway in training classes. This proved to be a good simulator for playing out different situations and to test new approaches. Strengths and weaknesses of the most widely used in practice of various methods aimed at assessing human reliability in complex systems were identified. It was concluded that human risk analysis methods could be enhanced by improvement to the qualitative analyses carried out by the methods. The effectiveness of various methods has also been investigated in the United States. Method forecasts were compared with actual crew characteristics in simulated accident scenarios conducted on a nuclear power plant simulator. There was significant agreement in the findings with the previous international study in terms of strengths and weaknesses of the methods. Results are well documented in NUREG-2156 (U.S. NRC, 2016).

Traditional safety analysis is based on the mathematics and principles of the classic theory of reliability, for which there are a number of indicators, such as time between failures and failure rate. Probabilistic safety analysis methods are often applied, but there are many influencing factors that affect vulnerability. Human factor analysis is defined mainly as a synthesis of systems engineering and behavioral sciences by phenomenological and deterministic methods, which is against a direct application of probabilistic safety analysis methods for assessing the contribution of human factors to the safety of hazardous facilities. Furthermore, whilst inclusion of human factors in risk analysis is an advantage of probabilistic safety analysis, limitations must be taken into account. For example, calculations tend to be based around an event tree, but the sequential chain is only valid if all elements of the tree equally affect safety which prevents optimization of certain aspects.

Human factor interest areas include individual attitudes to safety culture, professional training, team psychological incompatibility, and unsatisfactory current functional state. Safety culture tends to be the domain of top management since they set the overall safety culture for an organization, but individual safety culture is just as important. Professional training should not just be with regard to regular operations but should also consider the psychological, psycho-physiological and physiological price of maintaining the required level of safety. Biological feedback, the ability of people to learn how to handle themselves in stressful situations, is an important consideration. A key question is how it is possible to monitor a person’s functional state, preventing possible incidents and accidents due to the human factor in advance, since this can greatly affect safety and this was the focus of the FMBC human factor project.

Overall, the reliability of human operators is due to three main factors:

- The correlation between the psycho-physiological capabilities of the operator to the engineering and psychological requirements imposed by the technical elements of the operation for a person to solve the problems faced.
- The level of qualification, training and commitment of the operator to the safety culture to perform tasks.
- The operator’s psycho-physiological characteristics, in particular, features of the central and autonomic nervous system, thresholds of sensitivity, health status, and psychological characteristics of the operator’s personality.

The reliability of an operator is therefore a function of not only the tasks arising and the technical conditions in which they are solved, but also of the individual qualities of the operator. The interaction between these three main components will determine the reliability of a human operator.

Therefore, the provision of medical, psychological, psycho-physiological and physiological support for workers is key to professional reliability, ensuring safe operations by reducing man-made risks, and preserving the health and professional longevity of personnel. This involves medical monitoring, but also periodic psychological, psycho-physiological and physiological monitoring to ensure appropriate mentality for undertaking high stress operations. Mandatory monitoring has therefore been introduced across radiation and nuclear hazardous facilities to ensure workers are ready to carry out the tasks required of them. Forecasts are made for a person working under the necessary conditions for a year and to assess whether the requirements of the job are too high for an individual. A number of deliverables have been achieved as a result of the projects undertaken, including the following developments:

- a prototype of an expert diagnostic information system for monitoring the risk of professional reliability violation of workers involved in the management of SF and RW;
- a methodology for assessing the safety culture of the SevRAO facilities;
- a prototype of a hardware-software training complex based on interactive simulation training games with biological feedback in a virtual environment; and,
- a hardware-software complex and guidelines for pre-shift monitoring of the psycho-physiological state of workers involved in the management of SF and radioactive waste.

A proactive approach to increasing worker reliability is proposed that includes:

- periodic and pre-shift psycho-physiological examination of the personnel in order to identify persons with reduced psycho-physiological adaptation;
- improving the quality of professional training of operational personnel, using adequate information training models, which helps to reduce psycho-physiological price and uncovers reserves of the body, increases its stress resistance, and maintains and develops professional forms of activity of the worker; and,
- the introduction of progressive forms of management through a safety culture, providing for its quantitative assessment at the individual level and at the level of facility management.

The projects coincided with the fact that, at a Federal level, it became clear that human factor issues were important and, as such, a law was passed making it mandatory for human factor studies to be undertaken for high-stress risky jobs. This provided the framework for different innovations to be carried out.

The next step was the use of Vibra technology has been a valuable input, allowing emotional reference lines to be established and data to be obtained for comparison against the baseline. Pre-shift examination can be conducted in a very short space of time with cameras detecting minor fluctuations in the human head and face. The detection is as reliable as other medical diagnostics, such as electrocardiograms etc. The system has been finely tuned such that boundaries for good performance can be set and any deviation outwith these individual bounds detected from day to day.

Virtual simulators have also been developed for high risk operations such as the removal of nuclear fuel assemblies, allowing research ideas to be tested and operators to be trained. The work to remove assemblies was achieve in a matter of weeks, but with a year of preparatory work beforehand. Vibra technology was again employed for people using the simulator where two cameras were used to determine the psychological and physiological price of working under stressful situations. It is not just the face that reacts to emotional or hormonal changes; it is the whole body. Hence two cameras are used, one on the face and another for the body. The technology was employed for normal, or background, operations and for stressful operations to assess behavioral responses using vibra-image parameters. The difference in responses is illustrated in Figure 21.

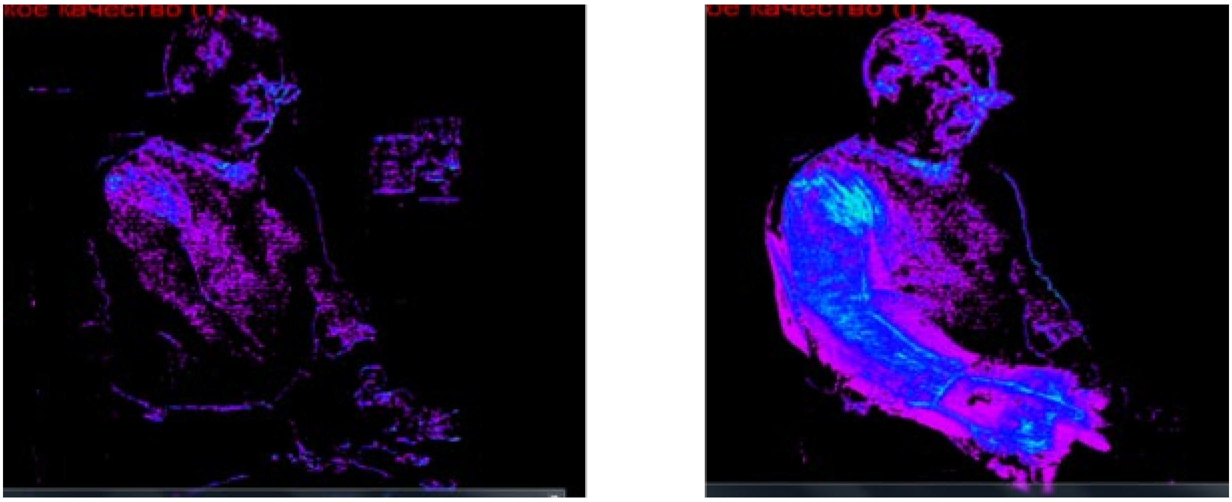

Figure 21: Vibra-image detection for 'normal' operations (left) and 'stressed' operations (right).

The developments from the projects undertaken allow qualitative surveys to be made of the safety culture at sites. Four sites in Russia, including Andreeva Bay were studied. Results indicated that the safety culture at Andreeva Bay was the best between the sites. This is due to continued efforts to improve the safety culture situation at this site. The application of the human factor analysis software in this way helps to identify where greater effort should be placed in order to improve the overall safety culture.

Thus, the application of the developed methodological, hardware-software and information support tools for the analysis of the human factor helps to determine where more effort should be made to improve the overall safety culture, which includes, in a broad sense, the professional reliability of the nuclear industry worker.

5.9 Topographical classification of dose distributions: Implications for control of worker exposure.

Konstantin Chizhov (FMBC) presented.

An indicator of radiation safety for workers under emergency and/or occupational exposure situations is the distribution of individual doses of personnel for the time period of interest. The form of the distribution provides a means by which the effectiveness of any work restrictions can be gauged which can, in turn, provide a feedback mechanism to inform on further restrictions. Types of dose distribution can be represented using KQ diagrams. An example is given in Figure 22. The antikurtosis (Q) scale is always between 0 (Cauchy distribution) and 1 (discrete 2-digit distribution) and the entropy coefficient (K) scale is always in the range from 0 to 2.66. The lognormal dose distribution with any parameters corresponds to point D (coordinates Q = 0.577 and K = 2.066) in Figure 22. The distance between image points on the diagram is a measure of the difference between the two distributions.

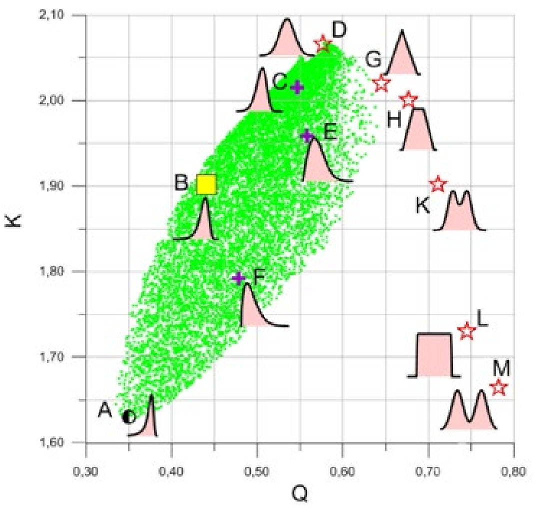

Figure 22: Example of a KQ-diagram to represent types of dose distribution.

Relative errors in determining the antikurtosis, Q, and entropy coefficient, K, can be visualized using Monte Carlo analysis applied to sample sizes for different distribution types (Figure 23).

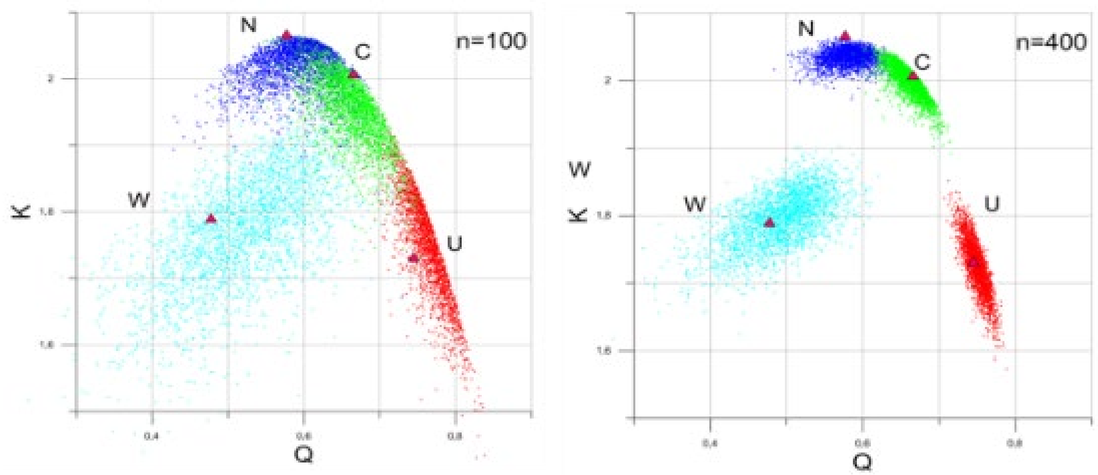

Figure 23: Scatterplots of K-Q coordinates for sample sizes of 100 (left) and 400 (right) for Weibull (W), Normal (N), Uniform (U) and Chapeau-type (C) distributions.

Emergency dose distributions for Chernobyl nuclear power plant liquidators have been plotted, based on a database of doses for emergency responders. Dose distributions close to lognormal indicate an absence of dose management. However, to the right of this zone, bimodal distributions occur, indicating dose management (Figure 24).

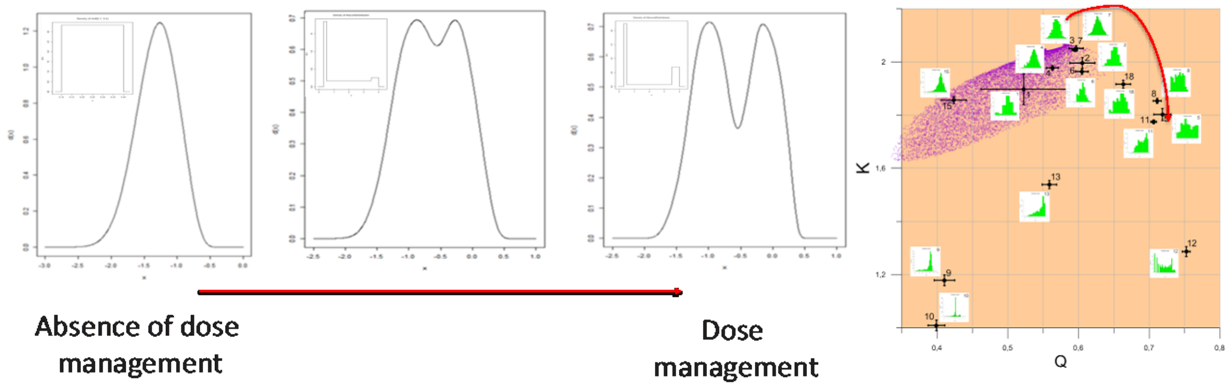

Figure 24: Use of KQ diagrams to identify dose management.

A similar approach was applied to occupational dose distributions from Rosatom facilities on the Kola Peninsula for the period between 2008 and 2017. Not all distributions were lognormal; some Chapeau-type distributions were evident. Similarly, for nuclear power plant staff and contractors working on the Fukushima site post-accident, two peaks were evident[4]. Transformation of the normal distribution into a chapeau-type distribution allows the average individual and, therefore, collective dose, to be increased; the more pronounced bimodality, the higher the result. The maximum effect is achieved in the case of a discrete two-digit distribution, when all emergency workers or personnel involved in radiation hazardous work will have individual doses equal to the maximum permissible dose of exposure of personnel or emergency workers. This enables dose optimization; e.g. in cases where exposures are close to the limit, it may be possible to minimize the number of workers.

In future work, the aim will be to identify optimum dose functions that can be used in protective dose services, with the model helping to identify how many personnel to use and when personnel should be moved away from contaminated areas.

In conclusion, the QK-diagram of the distributions of logarithms of dose is a compact form of representing information on the forms of dose distributions. When considering the final distributions of individual doses in the case of both emergency and occupational exposure situations, as well as daily doses to the personnel involved in the aftermath and routine work, however, it has been shown that in all cases there are three types of distributions of the logarithms of individual doses: normal, Weibull and the Chapeau-types. However, the lognormal distribution is not able to satisfactorily describe a significant part of the dose distributions both in case of emergency work and in the case of occupational exposure under normal conditions. The position of the image point of a certain dose distribution on the QK-diagram reflects the degree of control over the process of accumulation of individual doses of workers. The absence of control over the process of accumulation of individual doses on the QK diagram corresponds to a point with coordinates (0.577; 2.066). The further the depicting point of the analyzed distribution of the logarithms of the individual doses of a certain contingent of workers deviates from the point corresponding to the lognormal distribution, the greater the intervention in the process of accumulating individual doses.

[4] See further discussion in Bragin et al (in press)

6 Breakout discussion sessions

In order to elicit input and views from as many workshop participants as reasonably achievable, session 4 of the workshop was dedicated to breakout discussion groups. The overall objective was for participants to develop views on key aspects, commonalities and differences, in terms of the regulation and implementation of optimization in waste, decommissioning and legacy management circumstances in relation to technological possibilities, scientific input and stakeholder involvement.

Participants were divided into three discussion groups, each with a facilitator. The groups were each asked to focus discussions around three set questions during two discussion sessions:

→ What does ‘optimization of protection’ mean in circumstances of decommissioning, legacy and waste management?

→ What common elements of ‘optimization of protection’ should be included in an overall ‘legislative / regulatory framework’ encompassing optimization of protection for any circumstance?

→ What elements of ‘optimization of protection’ are specific to the circumstances of decommissioning, legacy and waste management?

A summary of discussion group feedback is provided below, focusing on broad consensus areas from the three groups and identification of key issues and lessons. It may not represent the views of each group participant, nor their organizations. Full feedback from each discussion group is provided in Appendix B.

6.1 What does ‘optimization of protection’ mean in circumstances of decommissioning, legacy and waste management?

Optimization of protection is making the best use of available resources to achieve the best outcomes in protecting the health of people and the environment from all risks under the prevailing circumstances. The process needs to be balanced with regard to the different hazards present, which requires a realistic assessment of the risks associated with the various hazards present. It can be considered as optimization of choice rather than protection since the lowest dose is not always the right answer.

Optimization is an iterative process that considers all stakeholders’ values, input and feedback. Compromise will likely be necessary to allow the different views of stakeholders to be taken into account. The process can benefit from the development of stakeholder communication plans to encourage stakeholder dialogue at an early stage, including during the identification of strategic options, that will, in turn, help build trust amongst affected parties.

The optimization process requires stepwise, decision-making and licensing processes that allow for flexibility and leave room for adaptation in specific cases. A balance is needed between regulatory flexibility that allows unplanned or unexpected situations to be addressed and prescription that can be more helpfully precise on how to achieve combinations of protection objectives. There should be early dialogue between relevant authorities to gather necessary competencies, to streamline the process, and avoid / address conflicting regulatory requirements. Throughout the different stages, clear allocation of responsibilities is needed. There can be value in the early identification of those parameters and factors that are flexible and available for optimization, such as flexibility in the end state or the time available to achieve the end state.

Optimization of protection requires a holistic approach that takes into account all prevailing circumstances and that addresses all relevant issues that can impact on decisions and inform on remediation options, including the application of the principles of waste minimization, stakeholder engagement and avoiding placing an undue burden on future generations. Site specific solutions are required that are sustainable. Therefore, a 'global' view should be taken to optimization that encompasses all aspects, including waste management, to avoid the creation of new legacies. The process needs a clear starting point (e.g. an agreed end state) but should include clear stages to allow new knowledge and/or technologies, as well as changes in stakeholder views, to be incorporated over time.

A number of issues were identified within the break-out discussion groups with regard to achieving optimization of protection:

- Optimization for radiation protection may not be fully consistent with optimization of conventional and/or chemical hazards and consideration needs to be given as to how radiation risk and risks from other hazards can be balanced when the endpoints for risk evaluation differ (e.g. dose versus concentration). Risk perception can also be an issue with radiation risks often being perceived as a greater threat than risks associated with other hazards, irrespective of the actual risks posed. In addition to recognizing the need to try to align perceived risks with the best scientific information, there is the issue that fear itself carries its own detriment.
- It can be difficult to know how to prioritize decisions on risk mitigation, for example whether to prioritize reduction of the area affected, or the number of people at risk, or to reduce peak individual risks. Time and other pressures can impact on the ability to make good decisions.
- There will always be differences in opinion and, therefore, what is seen as 'best' by one person may be different to 'best' for another. It can also be difficult to balance between getting things done and engaging with affected stakeholders. The identification of relevant stakeholders and knowing how and when to engage with them to good effect can also be challenging.
- Human factors that affect performance reliability should be taken into account to mitigate risks of human error during high stress / hazardous activities. Such errors could impact not only on workers but also the public and the environment.
- There is a dependency of decommissioning and legacy remediation activities on the availability of waste disposal routes. This can be a particular challenge where there are mixed hazard wastes requiring disposal, such as radioactively contaminated asbestos or where large volumes of waste are generated, e.g. as a result of wide are land and mining remediation activities.

Optimization is a challenge in its own right and one of the key challenges is knowing when optimization has been achieved. There was broad consensus between the groups that there would be benefit in systematizing the approach to optimization of protection to provide a defined process and guidance on its application, recognizing that this process and guidance must be flexible to accommodate differing perspectives and circumstances.

6.2 What common elements of 'optimization of protection' should be included in an overall 'legislative / regulatory framework' encompassing optimization of protection for any circumstance?

A number of common elements that should be included in an overall legislative or regulatory framework encompassing optimization of protection were identified in the discussion groups. For example:

- Stakeholder engagement is necessary. Stakeholders should be engaged at an early stage to build trust and allow stakeholder input to the decision-making process.
- The waste hierarchy should be applied while avoiding undue burdens on future generations.

- → A graded and iterative approach is needed that allows for transparent and traceable decisions to be made. Tools and experience are available that can support the improvement of decision-making processes.
- → Flexibility and room for adaptation of procedures is required to allow new information and technologies to be taken into account and to achieve a sustainable solution. There is also a need to consider all options from the outset to avoid pre-judging the outcome.
- → Integrated management strategies are required to maintain competencies and provide a strong and robust management system to manage uncertainties and support decision-making. Knowledge management strategies are also required to avoid the risk of new legacies being created in the future.

6.3 What elements of 'optimization of protection' are specific to the circumstances of decommissioning, legacy and waste management?

Several elements of optimization of protection can be specific to the circumstances of decommissioning, legacy management or radioactive waste management. Elements that were identified across the break-out groups include:

- → **Timeframe.** The timeframe of interest can vary considerably for decommissioning, legacy and waste management. For example, a time period of hundreds of years is likely to be the focus for decommissioning programs, whereas for waste management the timeframe can be thousands of years or even longer. In the case of legacy management, urgent action to characterize and address risks may be an important factor. Where urgency is a factor, this can influence decisions and hence the outcome of the optimization process.
- → **Knowledge base**. A key differentiator between legacies and decommissioning is that legacies tend to be significantly less well characterized. This can lead to large uncertainties that impair decision-making. Some sites present complex mixtures of legacy and decommissioning circumstances and there is not a clear distinction between these two.
- → **Waste inventory and spatial scale**. Linked with the previous point, legacy waste inventories are often unknown and may be distributed over wide areas, whereas areas of interest for decommissioning sites and waste management are more likely to be delineated (e.g. within or close to nuclear licensed site boundaries. Considerable site characterization for often mixed hazards is therefore often required, over potentially large areas, for legacy sites. The scale of waste disposal requirements can also differ significantly, with remediation potentially giving rise to considerable volumes of waste requiring treatment and/or disposal.
- → **Funding and liability**. Key challenges for legacy sites can be identifying who is responsible, who is providing and allocating resources.
- → **Setting protection criteria**. Decommissioning and waste management activities fall within the category of planned exposure situations for which dose constraints and limits apply. Legacies however typically fall within the category of existing exposure situations for which reference levels should be selected and applied[5]. The use of reference levels provides flexibility in addressing prevailing circumstances that is not available for planned exposures.
- → It is not possible to plan in advance for all eventualities and, therefore, for legacies, there tends to be a greater degree of interaction between authorities and government required in order to develop appropriate strategies in light of the hazards present.

[5] Note, doses to remediation workers of a legacy may be considered as a planned exposure situation, leading to the possibility for workers to be protected to higher standards than the public at the site being remediated.

7 Discussion of lessons, key issues and recommendations

This section summarizes points raised during overall discussions, particularly with regard to lessons learned and key issues that need to be addressed. Recommendations to support the development of a coherent and practical framework for optimization of decommissioning, legacy site and waste management are also set out.

7.1 Discussion of lessons and key issues

Presentations and discussions during the workshop provided a wide range of perspectives on different prevailing circumstances, including international perspectives on optimization, regulatory and operator challenges and scientific, technical and social aspects. Together these identified a range of interesting lessons and key issues, summarized as follows.

- There are significant commonalties in addressing decommissioning of old facilities and in legacy management. In particular, both activities need to be jointly coordinated with radioactive waste management programs. However, the optimum way forward at a particular site will depend on the prevailing circumstances.
- It is clear that, when thinking about optimization, it is important to take an encompassing view and avoid focusing on issues in isolation. It is not just about reducing radiation doses.
- There may be a need for review and revision of regulatory and/or related procedures and guidance to address decommissioning of old facilities in an optimum manner, even when they have been constantly under close regulatory supervision.
- Performance assessment can be a useful input to finding optimal solutions to decommissioning and radioactive waste disposal and there is opportunity to learn from such assessments, and supporting site characterization studies, to inform approaches for the long-term management and resolution of legacy sites.
- Many of the issues and challenges discussed during the workshop relate to existing exposure conditions at sites and, in moving forward, greater consideration is needed on how existing exposure situations can be addressed at a practical level. Innovation has been demonstrated at many sites to address site-specific needs and to mitigate risks to workers, for example the recent experience in addressing significant challenges at Andreeva Bay in the retrieval of spent nuclear fuel assemblies from legacy ponds within a highly contaminated and hazardous building. It is important to continue sharing and learning from experience via open and transparent discussion based on case studies, to properly understand the issues encountered and take advantage of lessons learned.
- There is a clear need for adaptive regulatory processes in the management of legacy sites and decommissioning of older facilities and associated waste management. Regulatory frameworks have been primarily designed for planned operations or emergencies and do not fully address the circumstances encountered in decommissioning and legacy management. There is a need to build on experience in the further development of regulatory frameworks and to link remediation and decommissioning with waste management programs. Care should be taken to avoid over-prescription to ensure the ability to consider and compare options without undue constraints that may generate operational conflicts in terms of risk management and mitigate against innovation.
- There tends to be a lack of cost-effective equipment and processes for decommissioning and to support waste characterization for clearance and other waste disposition. Continued sharing of experience, as noted above, can help demonstrate the benefits of innovation and help motivate

further improvements. Part of practical optimization thinking can come during the process that companies use to bid for remediation or decommissioning projects.

→ Stakeholder engagement is clearly recognized as important in the process of optimization of protection for decommissioning, legacy and waste management, but issues continue to be faced at a practical level. Clear communication is needed on the purpose of the engagement and what it is intended to achieve in terms of decision making. The stakeholder engagement process should be inclusive of those affected and be engaging rather than focusing on informing; it is important to listen to stakeholders and learn.

→ Radioactivity tends to be an emotive topic and concern around risks from radioactivity may dominate even when other hazards present greater risks. This may be an added dimension and uncertainty for legacy sites and situations where the site does not deliver any societal value. There would be advantage in developing common approaches to allow like for like comparison of hazards and risks, so as to allow identification and justified focus on priorities. There is also a need to develop common approaches to assessment of risks from different hazards and strategies for communicating those risks, including consensus around terminology.

One of the aims of the workshop was to develop input for building a more coherent and practically applicable framework for optimization of protection, that would generically cover all types of prevailing circumstances, and that could be practically adapted, within the framework's structure, to appropriately address specific circumstances from a multidisciplinary perspective. This was an ambitious objective, but the presentations and discussions during the workshop show that progress is being made and steps are being taken forward along the right path. The discussion and conclusions from the workshop parallel experience of the NEA EGLM (NEA, 2019), but add many more examples to support recommendations on holistic optimization, type of exposure situation and prescriptive and performance related regulations.

7.2 Recommendations

Whilst there has been significant progress since the last legacy workshop in 2017 (Sneve et al., 2018), it is clear that further international guidance on addressing nuclear legacy challenges would be beneficial. Aspects of that guidance are examined in the following recommendations, based on the above discussion and key lessons.

1. Further international guidance on addressing legacy sites and facilities should be developed, addressing aspects of decommissioning and the implications for radioactive waste management. The scope of the guidance should include holistic application of the process of optimization of protection, that is to say, addressing all hazards as well as a wide range of economic and social factors. The guidance should recognize that flexibility and adaptability can be helpful in reaching the optimum solution in different circumstances. Presentations and discussions during the workshop may be useful input to the development of such guidance, potentially providing the basis for prioritization of issues and needs. It may be appropriate to consider developing separate guidance for regulators and operators.

2. In developing the guidance, special consideration should be given to terminology, recognizing that countries differ in their legal definitions of key terms, and experts in different disciplines also sometimes use terms in specialist contexts. Descriptions of terms rather than strict definitions may therefore be preferable in international documents, to allow guidance to be readily adapted to national situations. A key objective will be to develop consensus around common understanding of terms across expert groups in the initial stages to avoid later confusion and conflicts. This approach will also aid communication and explanation of the guidance

3. The guidance should be illustrated with examples of best practice and lessons learned in the application of optimization of protection in different contexts. Such examples will demonstrate how different practices and approaches can deliver locally optimized solutions, according to the prevailing circumstances. Establishing databases on known legacy facilities could also be beneficial, aiding decision-making for newly recognized legacies and other complex existing exposure situations. Examples should include information on contractor processes, tools and technical solutions, which could support competitive procurement and help mitigate against non-optimal contractor behavior.

4. The effectiveness of stakeholder engagement techniques in different cultural and other contexts should be explored, bearing in mind that stakeholder engagement continues to be a challenge faced at a practical level. The results could then be used to better develop stakeholder processes in different complex site circumstances.

5. A framework should be developed by which different types of hazards, e.g. radiological, chemical and physical, can be ranked. This would support hazard reduction strategies and the implementation of a proportionate, graded and reasonable holistic approach to hazard management. In addition, it would also underpin the development of risk communication strategies to support stakeholder engagement.

6. The balanced integration of nuclear safety, security, protection from radiation and all other hazards is a key challenge. Much of the discussion and related suggestions within the workshop relate to balancing one factor against another, or several factors against several others. It is therefore recommended that the guidance examine how to achieve an appropriate balance among different attributes and the advantages and disadvantages of prescriptive and performance related approaches to regulation.

It is hoped that the results will support the further development of a coherent and practical framework for optimization of decommissioning, legacy site and waste management from a multidisciplinary perspective, and avoid creation of new legacies.

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Appendix A. List of Participants

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

Surname	First name	Organization	Country
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Tvaliashvili	Vladimer	LEPL Agency of Nuclear and Radiation Safety	Georgia
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Hashizume	Haru	Obayashi Corportation	Japan
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Umeki	Hiroyuki	Nuclear Waste Management Organization of Japan (NUMO)	Japan
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Appendix B. Feedback from Break-Out Discussion Groups

Feedback from each of the three break-out discussion groups is provided below.

Group 1 Feedback

Feedback was presented by the group 1 facilitator Andrew Fairhurst (Environment Agency, England).

Terminology

There was agreement that terms need to be context driven and can be difficult. It is possible, however, to describe terms and illustrate without defining. Definitions can then be given with regard to specific contexts.

Liabilities management may affect things differently compared with activities that generate revenue and this affects optimization. Optimization is connected with doing the best we can with the resources that we have.

What does "optimization of protection" mean in circumstances of decommissioning, legacy and waste management?

Optimization is a process aimed at arriving at the best solution. It is optimizing choice rather than radiation protection since the lowest dose is not always the right answer. A holistic approach is therefore required to ensure good decisions are made.

It is suggested that a high-level definition of optimization be used (e.g. a dictionary definition) such that there is common understanding with more people, although there should be awareness of the ICRP / IAEA definitions in the context of radiation protection. There would be benefit in systematizing the approach to provide a defined process for optimization.

Whether or not there is an 'ALARA' principle for chemicals was queried. In the absence of an ALARA principle for chemicals, thought needs to be given as to how to match chemical optimization with radioactivity optimization. This may involve optimizing for radioactivity at the same time as meeting thresholds for chemicals.

Example characteristics of a legacy were put forward:

- Legacies are not generating revenue
- There is generally limited information / data on the site and the contamination
- No mission
- There are immediate unmanaged safety concerns (as opposed to a managed risk)
- They tend to be old sites / facilities that have been neglected, are worn out, and have not been maintained properly
- They are abandoned (even on regulated sites)
- Often there is no owner
- They are unregulated or have not been regulated to modern standards

Urgency is a factor for legacies, and this may be related to safety or to other drivers, such as cultural restoration. The issues may be familiar to locals but present a hazard, or they may not have been previously recognized, becoming urgent after new realization of the dangers present.

What is one person's idea of 'best' in terms of optimization may not be the same as another's; there will always be differences in opinion. The attributes of "best" were therefore discussed in the context of doing the best we can with the resources available. The following list of attributes was presented:

- Minimizing things that can be measured, e.g.:
    - radiation dose (individual people, number of people exposed at different levels, environment, habitat, populations of species);
    - conventional hazards; and/or,
    - chemical hazards
- Maximizing well-being (mental and physical)
- All health hazards addressed and considered in combination
- Societal and cultural impacts, e.g. ancient farming practice
- Employment
- Public views
- Other land, water bodies and infrastructure use (i.e. end-state)
- Resources, such as:
    - groundwater at end-state;
    - decommissioning and remediation resources (raw materials, energy, [sustainability]); and/or,
    - site release or reuse with or without restrictions.
- Minimizing project cost
- Project risks and availability of funds/confidence to complete the project
- Waste generation/reduction
- Risk reduction
- Systematic understanding of the circumstances

Consideration of a combination of attributes may be appropriate in determining what is 'best'. For example, the minimization of risks and use of resources to ensure sustainability may need to be balanced against project costs. With regard to risk reduction, thought needs to be given to what are the risks and who is at risk.

There are a number of broad principles that should be applied:

- waste generation should be minimized;
- no undue burden should be placed on future generations; and,
- there should be engagement with stakeholders.

Examples of means and issues to be considered in order to achieve an optimized outcome, include:

- Is the required technology available?

- → Is decision-making being done under time or other pressure that could affect the outcome?
- → Balancing between getting things done (i.e. making technical decisions) and engaging with affected stakeholders.
- → Development of communication plans (engaging early to avoid surprising people), including providing advice to the public on how they can contribute to decisions.
- → Knowledge management (records, skills, site experience, knowledge transfer and training).
- → Building trust with communities around the facilities, workers and all impacted stakeholders.
- → Balancing between strategy at country level verses at individual sites.
- → Regulatory interaction, on mixed hazards and other issues, to get balanced supervision.
- → Providing motivation and maintaining interest.
- → Optimization with people today is not necessarily the same as for future populations.
- → Multi-attribute Decision Analysis (MADA).
- → Agreeing on appropriate radiological criteria, i.e. reference levels or dose constraints and whether the exposure situation is existing or planned.
- → Whether or not compliance with the above criteria can be confirmed (i.e. can measurements to the appropriate level be made?).
- → Dose and risk assessment and overall risk management and supporting site characterization.
- → Workers with plant experience could be used to train new people.
- → Selection of endpoints / end state, recognizing that it is important to have a clear starting point.
- → Opportunity cost for the community (value for money at the community level), recognizing that there may be other funding priorities within communities other than complete clean-up.
- → Learn lessons.
- → How to identify the stakeholders? How to inform them? When to engage them?
- → Obtaining and managing limited finances.
- → Prioritization: reduce the area affected or reduce the peak risks?
- → Management systems (addressing project risks etc.).
- → Peer review.

Safety cases can be developed, and social licenses can be obtained, particularly if stakeholders are successfully engaged, but optimization cases are rarely required. Some regulators may call for optimization cases but international guidance on making such cases is limited. A big question to be addressed in such cases is to know whether or not optimization has been achieved. Whether or not optimization is required under national regulations is variable.

What common elements of "optimization of protection" should be included in an overall "legislative / regulatory framework" encompassing optimization of protection for any circumstance?

It is largely regulators that make the final decisions, but they may be 'called in' by the government or courts, particularly if decisions are challenged. There are tools available that can support the process of making decisions and supporting discussion with stakeholders, such as MADA tools. A guidance note on optimization could be developed within the context of the new NEA committee (CDLM), with input from the EGLM report and other material such as this workshop and available national guidance. Best practice in the field could be compiled, along with lessons learned in the application of optimization in different contexts, including examples of how different practices/approaches delivered optimization.

What elements of “optimization of protection” are specific to the circumstances of decommissioning, legacy and waste management?

The attributes listed previously are (almost) always relevant to all circumstances, but to significantly different degrees. For example:

- → At the stage of decommissioning you need to know the building status and what happened in it as well as operational knowledge and maintained motivation. It is unlikely such knowledge would be available for legacies.
- → End-states for decommissioning are not like those for disposal facilities.
- → For legacies there are greater difficulties with identifying the responsible parties.

There is an interdependence of decommissioning on disposal. Where disposal routes are not available, decommissioning may be delayed. There is a tendency for optimization to be site focused rather than being strategized at a national level such that optimization across a country may not be achieved. Furthermore, the different regulatory regimes that are often in place at a national level for radioactivity and chemicals and other hazards can lead to significant challenges in reaching an optimized solution.

The availability of sufficient effective equipment and processes for decontamination and to allow for clearance and other waste disposition can also affect whether or not an end state can be reached. It is important to ensure that there is a common goal set and agreement at the start. Without this, it is unlikely that an optimized situation will be achieved.

Management and technology change over time so regular review of best available techniques (BAT) is important. However, BAT and research on new technologies might be driven down because there is less incentive to try new technology due to strict interpretation of BAT. Human reliability is a big factor in risk management.

Radiologically contaminated asbestos was identified as a particular challenge for decommissioning. The disposal of graphite can also be challenging.

Group 2 Feedback

Feedback was presented by the group 2 facilitator James Scott (ARPANSA).

What does “optimization of protection” mean in circumstances of decommissioning, legacy and waste management?

Optimization is making the best use of available resources to achieve the best outcomes in protecting the health of people and the environment from all risks under the prevailing circumstances. It is an iterative process which considers stakeholders’ values, input and feedback. The process requires compromise; there can be several regulators involved in the process and different regulations at play that may not be consistent. Arbitration may be required, and flexibility is needed.

Whether or not optimization should be at a site-specific level or be program based was discussed. A program level approach would provide for more consistency, but every site is unique and, therefore, a site-specific approach is most likely to be appropriate.

Optimization for radioactivity may not be fully consistent with optimization of conventional and chemical hazard. It can, therefore, be difficult to reach a balance.

A wide range of stakeholders could be engaged in projects and it was agreed that undertaking a stakeholder identification exercise at the outset can be very useful.

Legacy sites can present a unique problem as there may be no funding available to address the prevailing issues and there may be little information available on past practices at the site. An iterative approach to addressing legacy sites is needed with several iterations likely needed to achieve an optimized solution.

There is a lack of guidance on the practical application of optimization and this can be an issue. In developing guidance, it may be beneficial to target regulators and operators separately. The process should take account of stakeholder values.

What common elements of "optimization of protection" should be included in an overall "legislative / regulatory framework" encompassing optimization of protection for any circumstance?

The following points were put forward as being common elements of optimization of protection:

- Flexibility. Not being forced to make decisions that may not be optimal in the end.
- Consideration of all options from the beginning. Sometimes decisions are made, and optimization then occurs. However, the approach should be to look at all available options and then screen based on attributes such as financial cost, available technologies etc. The optimal outcome should not be pre-judged.
- Stakeholder engagement. People are emotive about radiation and radioactive waste and the timescales involved.
- Transparency and traceability. The justification for decisions should be available to all stakeholders. Communication plans should be developed for all situations / projects.
- Performance-based rather than prescriptive. There is a need to be flexible and allow performance-based output that can lead to better optimization.
- Nuclear and radiation risks versus other risks. A risk management approach should be considered carefully with regard to how risks associated with different hazards are to be communicated.
- Graded approach. An important principle for waste management.
- Regulatory cooperation and coordination and consistency between regulations. There can be multiple different regulations which can be challenging and may require a change in legislation to allow for consistency and avoid conflicts.
- Guidance. Guidance is not currently available but is needed. In developing guidance, care is needed to it does not lead to new legacies being created.
- Sustainability. An important component of the process. At the end of the process an end state will be reached. The need to revisit this in the future should be avoided.

What elements of "optimization of protection" are specific to the circumstances of decommissioning, legacy and waste management?

Elements specific to circumstances of decommissioning, legacy or waste management were identified as follows:

- Timeframes. The timeframes of interest will vary considerably depending on the case. For decommissioning, a timeframe of 100 years may be applicable, whereas the timeframe for waste management may be thousands to millions of years.

- Funding and liability considerations. Legacy sites in particular may not have any available funding and those responsible for the legacy might not be known.
- End state. The end state is very important and can be very different between decommissioning sites, legacies and waste management.
- Stakeholder identification. The relevant stakeholders will be specific to each case. The focus should be on identifying affected stakeholders, particularly for legacies.
- Managing uncertainties for different circumstances. Legacies in particular can have large uncertainties associated with the waste inventory and the area affected. A process is needed that allows uncertainties to be analyzed and to consider the sensitivity of decisions to these potentially large uncertainties.
- Broad risk management approach. There are often hazards other than radioactivity present at legacy sites, so risk management approaches are needed that take account of these different factors.
- Historical data. There may be a lack of data, particularly for legacies, on past practices etc. that can impair decision-making.
- Acceptability of approach. The acceptability of approach can vary between stakeholders and particularly regulators.
- Different knowledge management requirements. Decommissioning situations have a workforce with knowledge, which is different from legacies where no workforce may be present. Keeping the memory of decisions is important in terms of traceability and avoiding future legacies.

A balance is needed between regulatory flexibility to allow unplanned or unexpected situations to be dealt with and prescription around what is required in a more performance-based approach. Countries tend to have different views on the appropriate balance between the two. When old facilities are being decommissioned or legacy sites remediated, there is a need to move toward a more performance-based approach. A level of prescription is therefore required but achieving an appropriate balance can be challenging.

Group 3 Feedback

Feedback was presented by the Group 3 rapporteur Karen Smith (RadEcol Consulting Ltd).

What does "optimization of protection" mean in circumstances of decommissioning, legacy and waste management?

The optimization process requires stepwise decision-making and licensing processes that allow for flexibility. There should be early dialogue between relevant authorities to gather necessary competencies, to streamline the process, and avoid conflicting requirements. There should be clear allocation of responsibilities throughout the different phases.

A graded and sequenced approach should be followed, ideally with a high level of engagement with stakeholders to identify strategic options. More technical optioneering with more focused engagement is likely appropriate at later stages in the process.

The optimization process needs to be holistic and balanced relative to the hazards present. It should be based on an agreement of the prevailing circumstances to be taken into account and a realistic assessment of the hazards. There are, however, difficulties in how to 'rank' different hazards. For example, dose is used in terms of radioactivity whereas concentration may be the endpoint for chemicals, and we are not, therefore, comparing like with like. Risk perception can be an additional challenge. The process needs to be sustainable and iterative such that it can develop over time with new knowledge.

The process of optimization should be informed by information on the inventory and its spatial distribution and site characterization. This calls for optimization of information management, including scientific and technical input. The process should address all relevant issues that can impact on decisions and inform on remediation, recognizing that decisions can create further legacies. Ideally, the aim should be to achieve holistic optimization such that optimization is achieved through the entire process from recognition to resolution. This requires:

- → optimization of involvement through the different stages,
- → optimization of information to address varied challenges; and
- → balancing science and technology advancements against cost and the effects of delay.

Other points raised with respect to optimization of protection were as follows:

- → Optimization should be recognized as a challenge in its own right.
- → Optimization is the responsibility of the designated operator, but the process needs to involve government, regulators and affected stakeholders.
- → Waste management strategies are needed that are flexible to allow for wastes from legacies. This includes unknown wastes from known legacies and unknown wastes from not yet discovered legacies.
- → There may be merit in establishing databases on known legacy facilities to aid decision-making on new legacies / complex existing exposure situations. This could include information around contractors, tools and technical solutions, which could support competitive procurement and help mitigate against non-optimal contractor behavior.
- → There is value in having early identification of the parameters and factors that are flexible and available for optimization, such as flexibility with regard to selecting a range of end state land uses and/or flexibility on timing (i.e. time to achieve the end state).
- → Human factors should be taken into account, including the personal features of the persons performing optimization. They should have wide knowledge and understanding of available technologies, an ability to communicate, use formalized methods of efficiency evaluation and use of optimization criteria, and respond to the safety culture.
- → The scoring of attributes and identification of priorities should be supported by weighting of criteria.

What common elements of "optimization of protection" should be included in an overall "legislative / regulatory framework" encompassing optimization of protection for any circumstance?

Common elements of optimization of protection include:

- → The need for a knowledge management policy to maintain knowledge and experience and to archive information and data for future use.
- → The need for a graded approach.
- → The need for an integrated management strategy to maintain competencies and provide a strong and robust management system to manage uncertainties and support decision-making.
- → Application of the waste hierarchy for waste reduction.

What elements of "optimization of protection" are specific to the circumstances of decommissioning, legacy and waste management?

Elements that are specific to legacies / complex existing exposure situations include:

- → the involvement of the government from the outset;

- → the setting of reference levels that provide the necessary flexibility to address the prevailing circumstances;
- → the characterization of mixed hazard wastes over varied spatial scales; and
- → the interaction of authorities to develop strategy in light of the hazards present.

Appendix C. Workshop Program

BACKGROUND AND PROGRAMME

Regulatory Framework of Decommissioning, Legacy Sites and Wastes from Recognition to Resolution

Building Optimization into the Process

Organised by the Norwegian Radiation and Nuclear Safety Authority and NEA in cooperation with the IAEA and ICRP and in association with the IUR

Framsenteret, Tromsø, Norway, 29 October – 1 November 2019

BACKGROUND

Decommissioning, legacy and waste management have become topics of great interest internationally. The management of decommissioning and legacy sites, and associated radioactive wastes is recognized as highly complex. Practical guidance is required to support their efficient and effective regulatory supervision based on direct experience in different prevailing circumstances. The value of international cooperation in this area is illustrated through the recent setting up of the NEA Committee on Decommissioning and Legacy Management (CDLM), and the case studies evaluated by the NEA Expert Group on Legacy Management (EGLM)[6]. Other important and related initiatives include the projects of IAEA: EuCAS, LeTrench and DERES, and ICRP Task Groups concerned with the application of Commission recommendations in existing exposure situations.

Knowledge and experience gained through different international activities has been shared through a series of workshops hosted by DSA in cooperation with NEA, ICRP and IAEA. Conclusions from a workshop, held in 2015, on the **"Regulatory Supervision of Legacy Sites: from Recognition to Resolution[7]"** emphasized the gap between theory and good practice and the need for further international guidance. A subsequent workshop, organized by the DSA in cooperation with the IAEA, NEA-OECD and ICRP, was held in Lillehammer in 2017 on the "**Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution**[8]" to promote expert discussions and support the continuing development of practical guidance.

Arrangement of a third workshop

Noting the above, a third workshop has been being organized, focusing on **building optimization into the process** of decommissioning, legacy sites and waste management and their regulation. The workshop is hosted by the DSA and jointly organized by the DSA and NEA in cooperation with the ICRP and IAEA, and in association with the IUR. The workshop will bring together experts in radiation protection, decommissioning, legacy management and radioactive waste management in order to share experiences in the applying optimization.

OBJECTIVES

The overall objective is to support development of a coherent and practical framework for optimization of decommissioning, legacy site and waste management from a multidisciplinary perspective. A preliminary framework and basis for discussion has been provided in the EGLM report *(in the publication process as NEA 7419)*. Given that:

- aspects considered to identify the optimum solution will vary significantly depending on the circumstances being considered;
- a coherent framework is needed to characterize optimization in any circumstance;
- there are emerging, practical regulatory and implementation questions coming from various existing circumstances in many countries; and
- radioactive waste management, decommissioning management, and legacy management are significant, practical issues in many countries;

the particular objectives of this workshop are to:

- identify practical optimization issues, arising from operational programmes, that are not clearly addressed by current regulation or guidance;
- identify approaches or paths forward to achieving accepted, sustainable protection solutions in radioactive waste management, decommissioning management, and legacy management circumstances;
- identify a path forward to use experience from the practical application of optimization as feedback for consideration in the evolution of guidance and regulation of optimization, and
- identify further recommendations for future international collaborative work on how to regulate and practically implement the optimization principle in these fields.

Topics of Interest

- Lessons learned from legacy site, decommissioning, and waste management experiences.
- Application of optimization in regulation and regulatory processes, coherently across decommissioning, waste management, and legacy management, and implications for a common framework for regulation and application of optimization, distinguishing the generic from the specific.

[6] NEA-OECD/CRPPH. Challenges in nuclear and radiological legacy management: Towards a common framework for the regulation of nuclear and radiological legacy sites and installations. Report of the Expert Group on Legacy Management. *In Publication process at NEA.*

[7] Sneve M K, Strand P. Regulatory Supervision of Legacy Sites from Recognition to Resolution. (in publication) Report of an international workshop. StrålevernRapport 2016:5. Østerås: Norwegian Radiation Protection Authority 2016. http://www.dsa.no/en/publications

[8] Sneve M K, Popic J M, Siegien-Iwaniuk K. Regulatory Supervision of Legacy Sites: The Process from Recognition to Resolution. Report of an international workshop, Lillehammer, 21-23 November2017. StrålevernRapport 2018:4. Østerås: Statens strålevern, 2018. http://www.dsa.no/en/publications

- Source term characterization linked to radioactivity and other hazards.
- Site characterization that supports analysis of options.
- Monitoring and measurement: objectives, techniques and use of results.
- Selection of reference levels, constraints and other criteria for control of risks to people and the environment.
- Radiological and other risk assessment methods that support proportionate management of different hazards and risks to workers, the public and the environment.
- Procedures for selection and achieving sustainable end-states.
- Challenges to implementation of a holistic / multi-risk / graded assessment approach to end-states for different types of sites and facilities.
- Stakeholder engagement in the optimization process that supports confidence in the decision-making process.
- Procedures for transparent and trace able analysis of risks and benefits associated with different options, in assessing the reasonableness of protection objectives, and for their communication, in support of overall options assessment and decision making.

Expected Output
This workshop aims to develop input for building a more coherent and practically applicable framework for optimization of protection, that will generically cover all types of prevailing circumstances, and that can be practically adapted, within the framework's structure, to appropriately address specific circumstances from a multidisciplinary perspective.

Participation
The workshop is intended for participation from international organizations, regulators, operators, technical support organizations and other stakeholders with an interest in nuclear and radiation legacy issues, decommissioning and waste management.

Dissemination of results
As with previous workshops, a report will be produced that will document presentations and discussions, subject to review by participants. In addition, a special issue of the **Journal of Radiological Protection** is planned for early 2020 on the topic of **"*Management and Regulatory Supervision of Nuclear Decommissioning, Legacy Sites and Radioactively Contaminated Land: Development of a Coherent and Proportionate Process from Recognition to Resolution*".** Presenters and participants will have the opportunity and are invited to put forward papers for this publication.

PROGRAMME

Monday, 28 October 2019

18:00-20:00		**Welcome Reception** Hosted beverages and tapas.	Clarion Hotel The Edge, Arbeidskontoret 2

Tuesday, 29 October 2019

08.30		**Morning coffee and registration** Registration in the will be open until 13.00	FRAM center lobby
09:30		**Workshop Openings:** – DSA Welcome: Per Strand – NEA Welcome: Rebecca Tadesse – IAEA Welcome: John Rowat – ICRP Welcome: Edward Lazo	Auditorium FRAM center
09:45		**Session I - Setting the Scene: Implementation and Regulatory Challenges in Application of Optimisation in Legacy, Decommissioning and Waste Management** The Workshop Chairs will explain the workshop objectives and outputs Session I Chairs: **Malgorzata Sneve (DSA, Norway)** and **Rebecca Tadesse (NEA)**	Auditorium FRAM center
10:00	1	**Main output from Lillehammer workshop and EGLM** This paper will present main discussion points and conclusions from the 2nd Workshop in Lillehammer and also main recommendations and results from EGLM as an input to the discussions in current workshop. Presenter: **Malgorzata Sneve, DSA, Norway**	
10:20	2	**Optimisation: Key Elements and Objectives for Decommissioning, Legacy and Radioactive Waste Management** This paper will give an overview of how the concept of "optimisation of protection" is regulated and applied in circumstances of decommissioning and legacy management, including the management of resulting LL and IL radioactive wastes. Aspects to consider, and qualification of optimisation objectives will be discussed. Presenter: **Walter Blommaert, NEA Regulators' Forum Chair, FANC**	Auditorium FRAM center
10:40	3	**Regulatory challenges and opportunities in the UK relating to the optimisation of nuclear site decommissioning and associated waste management practices** This paper will give an overview of challenges and opportunities related to UK decommissioning, focusing on development and implementation of Guidance on the Requirements for Release from Radioactive Substances Regulation, to facilitate more sustainable optimisation of radioactive waste management.	Auditorium FRAM center

		Presenters: **Steve Hardy and Andrew Fairhurst, Environment Agency, UK,**	
11:00		**Coffee break**	Auditorium FRAM center
11:20	4	**Practical experience of FMBA of Russia in radiation protection optimization at the legacy sites of the Russian Federation** This paper will give an overview of the current Russian Guidelines on optimization of radiation protection for the personnel; analysis of the optimization process at the legacy site, where SNF and RW are managing, and optimization perspectives will be given for the personnel, population and environment of this legacy site. Presenters: **Natalya Shandala and Renata Starinskaia, FMBC, Russian Federation**	
11:40	5	**National Regulations Addressing Optimisation in Decommissioning and Legacy management: Australian Experience** This paper will present Australian regulations addressing the optimisation of protection for sites in decommissioning, including discussion of end-state selection and verification, worker and public protection, and evolution from optimisation regulation for normal operation Presenter: **James Scott, ARPANSA, Australia**	Auditorium FRAM center
12:00	6	**National Regulations Addressing Optimisation in Waste Management: US DOE Experience** This paper will present US DOE approaches and regulations for the optimisation of radioactive waste management from nuclear installations either in decommissioning or sites considered as legacies as addressed in this workshop. Aspects addressed will include worker and public protection, and environmental considerations. Presenter: **Patricia Worthington, DOE, USA**	Auditorium FRAM center
12:20	7	**Cleaning up the UK's earliest nuclear sites: Building optimisation in to decision-making** This paper will introduce some of the key strategic decisions that shape decommissioning of the UK's earliest nuclear sites, and describe the challenges we face in building optimisation in to these decisions Presenter: **Anna Clark, NDA, UK**	Auditorium FRAM center
12:40		**Discussion** The Chair and presenters will hold a discussion with the audience of questions arising from presentations.	Auditorium FRAM center
13.00		**Lunch break**	Cafeteria FRAM center
14:30		**Session II - Existing International Optimisation Guidance and Implementation Aspects** This session will introduce the concept of optimisation from the standpoint of existing principles,	Auditorium FRAM center

		recommendations, requirements and regulations. Here is opportunity for international organisations and national experience to comment on their view of the challenges and the on-going activities how to address them. Chairs: **Patricia Worthington, DOE, USA** and **Per Strand, DSA, Norway**	
14:35	8	**The Global Nuclear Safety Regime and optimization for decommissioning, legacy sites and radioactive waste management** The Global Nuclear Safety Regime is the institutional, legal and technical framework for ensuring the safety of nuclear installations throughout the world. This talk will elaborate how optimization is achieved through the GNSR as it applies to decommissioning, legacy sites and radioactive waste management. Presenter: **John Rowat, IAEA**	Auditorium FRAM center
15:00	9	**The Evolution of Optimisation Regulation and Implementation: NEA Views** This paper will present the views of the NEA CDLM and the CRPPH/EGLM with regard to the regulatory and practical challenges associated with legacy and decommissioning sites Presenter: **Ted Lazo CRPPH, NEA**	Auditorium FRAM center
15:30		**Coffee break**	Lobby FRAM center
16:00	10	**SNF retrieval from the building 5 at Andreeva Bay, history, achievements, process optimization.** Presenter: **Igor Pavlov, STC, Russian Federation**	Auditorium FRAM center
16:20		**Discussion** The Chair and presenters will hold a discussion with the audience of questions arising from presentations.	Auditorium FRAM center
17:00		**End of Day 1**	
18.30		**Social event** Visit to "Villmarkssenter" and official dinner hosted by DSA (see additional information sheet) Note: Bus from the Clarion The Edge Hotel	
		Wednesday, 30 October 2019	Auditorium FRAM center
09:00		**Session III - Optimisation in Different Circumstances** This session will focus on the practical challenges under different circumstances when trying to identify the optimum protection choices. The goal of this session will be to identify common problems and propose solutions on strategy, procedures, and processes of optimization based on operational experience running from recognition to resolution.	Auditorium FRAM center

		Chairs: **Hiroyuki UMEKI (RWMC Chair at NEA), NUMO, Japan** and **Anna Clark, NDA, UK**	
09:05	11	**Optimisation of Radiological Protection and Existing Exposure Situations: Recommendations of ICRP** Presenter: **Ludovic Vaillant (ICRP Scientific Secretariat), CEPN, France**	Auditorium FRAM center
09.25	12	**Optimising the Management of Radiation Waste from Decommissioning and Legacy Management Situations: Regulatory Views** Presenter: **Jamal Chaouki, ASN France**	Auditorium FRAM center
09:45	13	**Review of Remediation Activities of the Territories of the Former Baku Iodine Plants Contaminated by Natural Radionuclides** Presenter: **Aysel Hasanova, State Agency on Nuclear and Radiological Activity Regulation of the Ministry of Emergency Situations, Azerbaijan**	Auditorium FRAM center
10:05	14	**Offsite Clean-up and Interim Storage at FDNPP Explosion – Complex Constraints to Optimize** Presenter: **Haru Hashizume, Obayashi Corporation, Japan**	Auditorium FRAM center
10:25		**Coffee break**	Lobby FRAM center
11:00	15	**Use of performance assessment in finding optimal solutions to decommissioning and radioactive waste disposal** Presenter: **Cynthia Barr, US NRC, USA**	Auditorium FRAM center
11:20	16	**Optimising the Regulatory Framework for Legacy Management Situations** Presenter: **Cornelia Virtopeanu, CNCAN, Romania**	Auditorium FRAM center
11:40	17	**Optimising the Management of Decommissioning: TSO Views** This paper will present Implementation of Graded Approach in Ensuring Safety of Emergency and Legacy RWM in Ukraine Presenter: **Kateryna Fuzik, SSTC NRS, Ukraine**	Auditorium FRAM center
12:00	18	**Delicensing of Nuclear Sites in the UK – Optimisation of the survey that leads in to Public Dose Assessment** Presenter: **Warren Bungay PHE, UK**	Auditorium FRAM center
12.20	19	**Transfer and reuse of facilities and areas at the former uranium enrichment facilities in Oak Ridge.** Presenter: **David Adler, US DOE, Oak Ridge, USA**	Auditorium FRAM center
12:40		**Discussion and Summary** The Chair and presenters will hold a discussion with the audience of practical optimisation questions arising in participants' countries in circumstances similar to those presented, or of other, unique and country-specific	Auditorium FRAM center

		circumstances that could contribute to the development of a coherent optimisation framework.	
13:15		**Lunch break**	Cafeteria FRAM center
14:30		**Session IV - Breakout Discussions** In order to facilitate eliciting input and views from as many participants as reasonably achievable, the workshop includes breakout discussion sessions. Based on the previous presentations, on how optimisation is approached in different prevailing circumstances, workshop participants will break into smaller groups in order to develop views on key aspects, commonalities and differences, in terms of the regulation and implementation of optimisation in waste, decommissioning and legacy management circumstances in relation to technologic possibilities, scientific input and stakeholder involvement. Facilitators and rapporteurs for each group: **Andrew Fairhurst, Walter Blommaert and James Scott**	Bjørnøya, Ny-Ålesund
14:45		**Breakout Sessions Begin**	
16:00		**Coffee break**	Lobby FRAM center
16:30		**Breakout Sessions Continue**	
18:00		**End of Day 2**	
		Thursday, 31 October 2019	
09:00		**Session V – Scientific, technical and social aspects of Legacy management** This session will include the presentations that have been submitted by participants, and will address both aspects of Optimisation of Decommissioning, Legacy Site and Waste Management and countries experience and challenges Chair: **Natalya Shandala, FMBC, Russian Federation** and **Ole Christian Lind**	
09:05	20	**Science support for Decommissioning and Legacy Management** Presenter: **Ole Christian Lind**, **Norwegian University of Life Sciences, CERAD CoE, Norway**	
09:25	21	**Application potential of existing methodologies to compare options and establish acceptance criteria [of combined hazards and risks through stakeholder engagement** Presenter: **Ari Ikonen, EnviroCase, Finland**	
09:45	22	**ALARA for Decommissioning and Site Remediation: lessons learnt from a European ALARA Workshop** Presenter: **Ludovic Vaillant, CEPN, France**	

10:05	23	**Using a Starting Case for Pragmatic Optimisation of the End State for Decommissioning: Example of a UK Nuclear Power Reactor Site** Presenter**: Daniel Galson, Galson Sciences, UK**	
10:25	24	**The Role of Risk Communication and Stakeholder Involvement in Decommissioning and Legacy Management** Presenter: **Yevgeniya Tomkiv, University of Life Sciences, CERAD CoE, Norway**	
10.45		**Coffee break**	Lobby FRAM center
11:15	26	**Site characterisation in Northern Environments** Presenter: **Tobias Lindborg, Blackthorn Science, Sweden**	
11:35	27	**Fukushima Daiichi decommissioning and remediation experience from operator TSO** Presenter: **Kazuyuki Kato, Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF), Japan**	
11.55	28	**The human factor problem in SNF and RW management: ways to solve the problem and implementation practice** Presenters: **Victor Shcheblanov** and **Aleksandr Bobrov, FMBC, Russian Federation**	
12:15	29	**Topographical Classification of Dose Distributions: Implications for Control of Worker Exposure** Presenter: **Konstantin Chizhov, FMBC, Russian Federation**	
12:35		**Discussion and Summary** The Chair and presenters will hold a discussion with the audience of issues that arose during the presentation sessions, and of how these add to the break-out discussions.	
13:15		**Lunch break**	Cafeteria FRAM center
14:30		**Breakout Sessions Continue**	
16:00		**Coffee break**	Lobby FRAM center
16:30		**Plenary Discussion of Breakout Results** Rapporteurs for each Breakout Group will present their Group's views on the three questions asked: 1. What does "optimisation of protection" mean in circumstances of decommissioning, legacy and waste management? 2. What common elements of "optimisation of protection" should be included in an overall "legislative / regulatory framework" encompassing optimisation of protection for any circumstance?	Bjørnøya, Ny-Ålesund (TBD)

3. What elements of “optimisation of protection” are specific to the circumstances of decommissioning, legacy and waste management?

18:00	**End of Day 3**	
	Friday, 01 November 2019	
09:00	**Session VI – Discussion of Lessons and Key Issues** Based on presentations and discussions, the Chairs along with participants will summarise discussion, the key conclusions of the workshop, including: • practical optimisation challenges, arising from operational programmes, that are not clearly addressed by current regulation or guidance; • approaches or paths forward to achieving accepted, sustainable optimised-protection solutions in radioactive waste management, decommissioning management, and legacy management circumstances; and • a path forward to use experience from the practical application of optimisation as feedback for consideration in the evolution of guidance and regulation of optimisation Moderator – **Malgorzata Sneve and Rebecca Tadesse**	
10:30	**Coffee break**	Lobby FRAM center
11:00	**Session VII – Recommendations and Path Forward** Based on presentations and discussions, the Chairs will present recommendations to support development of a coherent and practical framework for optimisation of decommissioning, legacy site and waste management from a multidisciplinary perspective. Proposals for papers to the special issue of the Journal of Radiological Protection will also be discussed. Chair – **Malgorzata Sneve and Rebecca Tadesse**	
13.00	**END OF WORKSHOP**	
	Lunch break	Cafeteria FRAM center

During the workshop participants visited the DSA’s Laboratory of the Section High North in Tromsø, located at the Fram Centre, and got acquainted with Section’s activities, laboratory as well as the DSA’s emergency preparedness and response capacities in the region.

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DSA

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