Radioactive Waste Management and Decommissioning
NEA/RWM/R(2020)3
June 2021
www.oecd-nea.org

Multifactor Optimisation of Predisposal Management of Radioactive Waste

Proceedings of the NEA Joint Workshop
10-14 February 2020
OECD Conference Centre
Paris

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NEA/RWM/R(2020)3

Unclassified **English text only**

23 June 2021

NUCLEAR ENERGY AGENCY

Radioactive Waste Management Committee

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Please note that this document is available in PDF format only.

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JT03478699

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The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Foreword

The Nuclear Energy Agency (NEA) Workshop on the Multifactor Optimisation of Predisposal Management of Radioactive Waste, initiated and led by the Radioactive Waste Management Committee (RWMC), offered its 115 participants from 24 countries waste-focused sessions across a variety of disciplines with the goal of identifying methodologies and activities lending to holistic predisposal optimisation.

Held on 10-14 February 2020, the workshop fostered a rich exchange among participants that highlighted the broad spectrum of issues associated with predisposal management of radioactive waste. Attendees exchanged national experiences and examined factors that affect the development and optimisation of radioactive waste management programmes providing recommendations towards addressing the issues, as well as identifying potential collaboration among the existing international entities and organisations in the field.

The summarised discussions, conclusions and recommendations are intended to raise awareness, initiate activities and facilitate co-operation among countries in this context. Relevant organisations in all countries addressing and impacting nuclear waste are encouraged to take the results of this workshop into consideration.

Acknowledgements

The Nuclear Energy Agency (NEA) wishes to express its gratitude for the preparation of the report to all the members of the workshop Programme Committee, workshop support staff, session chairs, presenters and breakout group discussion leaders as well as the workshop participants.

Special thanks are owed to the reviewers of this document, listed below, as well as to Mike Garamszeghy (Consultant, Canada) who acted as the rapporteur for the workshop and was primarily responsible for the compilation of the session summaries and preparation of the initial draft of this report.

Hiroyuki UMEKI	**RWMC and Workshop Chair**
Walter BLOMMAERT	RF Chair
Boris BRENDEBACH	CDLM Bureau and CDLM Session Chair
Christine GEORGES	CDLM Session Chair
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Ioannis KAISSAS	CRPPH Session Chair
Cécile EVANS	Contribution to NDC Session
Ximena VASQUEZ-MAIGNAN	NEA OLC
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Finally, we would also like to recognise Amanda Costa (Consultant, United States) and our colleagues in NEA Publications for their efforts in finalising this report.

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Executive summary

The Nuclear Energy Agency (NEA) Workshop on the Multifactor Optimisation of Predisposal Management of Radioactive Waste (10-14 February 2020) was initiated and led by the NEA Radioactive Waste Management Committee (RWMC). It was organised in close co-operation with other NEA standing technical committees (STCs) assisted by a crossover collaboration of all responsible NEA divisions. The workshop was organised to discuss optimisation of predisposal aspects of national radioactive waste management (RWM) programmes from various points of view, employing the holistic approach for radioactive waste management. A clear distinction in the predisposal framework is made between waste and materials with further use, while the focus of predisposal waste management is solemnly on the waste. The workshop also involved other relevant international organisations, such as the International Atomic Energy Agency (IAEA) and the European Commission (EC).

The objectives of the workshop, attended by 115 registered participants from 24 countries, were to foster discussions among the audience, which represented a cross-section of all parties interested in holistic development and optimisation of the RWM programme (regulators, operators, policymakers, waste producers, decommissioning entities, etc.). Participants were invited to discuss a tentative list of the main methodological aspects of holistic optimisation by:

- exchanging existing national experience/opinions and examining factors that affect the development and optimisation of national RWM programmes as a whole (holistically);
- collecting inputs for the future work of the NEA and their STCs (especially the RWMC) in areas related to predisposal management of radioactive waste;
- trying to reach an understanding of how either partial or total optimisation was pursued (if at all) in the predisposal of radioactive waste management under review (what were the factors under consideration and what was the methodology used – attributes, expert judgement, etc.);
- identifying and documenting similarities and differences between the programmes in member countries;
- considering possible activities (including joint co-operation between STCs) to support the optimisation of predisposal national programmes.

During the workshop, a number of key messages were identified. These include:

- The issue of optimising predisposal waste management is complex and largely unexplored (in a holistic context), especially at a national or international level.
- There is no universal solution for optimal predisposal waste management applicable to all countries, due to various country-specific technical and non-technical factors

and since the optimised approach is not necessarily the preferred nor expected approach by all stakeholders.

- More than ever, the governance of predisposal radioactive waste management must be based on the involvement of an informed and vigilant civil society.
- *Waste management begins before waste production*. Integrated waste management needs to consider the whole life cycle of all nuclear facilities, from the design to decommissioning stages.
- For the purpose of predisposal waste management optimisation, the issue must be highly visible in organisations and the field.
- The observation that the success of holistic predisposal optimisation is determined by:
  - a high degree of willingness from all involved to co-operate as well as to sometimes compromise;
  - the ability to understand others in their own organisation as well as authorities and public perspective;
  - the identification of a solution that is acceptable to everyone.

The overall conclusions of the workshop participants were:

- The workshop provided a unique opportunity for the STCs and their related body members to discuss cross-cutting issues related to predisposal management of radioactive waste.
- The workshop successfully met its stated objectives, and the participants were well engaged.
- The workshop should be repeated in a few years' time, with an emphasis on sharing experience on cross-cutting issues and perspectives.

In addition, a number of areas was identified for closer collaboration between the STCs as well as with other international organisations, including:

- creating a consistent terminology around optimisation of predisposal waste management for better communication among internal and external stakeholders;
- increasing the level of communication and cross-incentivising among the various NEA bodies, as well as with other relevant international organisations;
- considering the incorporation of guidance on sustainability, optimisation, non-radiation risks and the "holistic approach" into all STC work programmes;
- considering the co-ordination and cost sharing of future international projects.

List of abbreviations and acronyms

ADS	Accelerator-driven system
ALARA	As low as reasonably achievable
Andra	French National Agency for Radioactive Waste Management
ASARA	As safe as reasonably achievable (all factors taken into account)
ASN	French Nuclear Safety Authority
BU	Burn-up
CDLM	Committee on Decommissioning of Nuclear Installations and Legacy Management (NEA)
CNRA	Committee on Nuclear Regulatory Activities (NEA)
CPE	Collective protective equipment
CRE	Collective radiation exposure
CRPPH	Committee on Radiological Protection and Public Health (NEA)
CSNI	Committee on the Safety of Nuclear Installations (NEA)
CT	Cooling time
DALY	Disability-adjusted life year
DB	Data Bank (NEA)
DCF	Discounted cash flow
DGR	Deep geologic repository
DNSH	Do no significant harm
EC	European Commission
EFIT	European Facility for Industrial Transmutation
EGCUL	Expert Group on Characterisation Methodology of Unconventional and Legacy Waste (NEA)
EPRI	Electric Power Research Institute
EU	European Union
EVC	Evaporator concentrate
FP	Fission product
FR	Fission reactor
HALEU	High-assay low-enriched uranium
HAW	High-level radioactive waste (German acronym)
HLW	High-level waste
HoD	Head of Division
IA	Intergovernmental agreement
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IE	Initial enrichment
ILW	Intermediate-level waste
IMF	Inert matrix fuel
IXR	Ion-exchanger resins
JEFF	Joint Evaluated Fission and Fusion Nuclear Data Library
LCOE	Levelised cost of energy
LEU	Low-enriched uranium
LILW	Low- and intermediate-level waste
LLW	Low-level waste
LWR	Light water reactor
MOX	Mixed oxide

NDC	Nuclear Development Committee (NEA)
NEA	Nuclear Energy Agency
NLC	Nuclear Law Committee (NEA)
NPV	Net present value
NSC	Nuclear Science Committee (NEA)
NTE	Division of Nuclear Technology Development and Economics (NEA)
NSDF	Near surface disposal facility
OLC	Office of Legal Council (NEA)
PC	Paris Convention
PCB	Polychlorinated biphenyl
PPE	Personal protective equipment
R&D	Research and development
REE	Rare earth elements
RF	Regulators' Forum
RP	Radiological protection
RW	Radioactive waste
RWM	Radioactive waste management
RWMC	Radioactive Waste Management Committee (NEA)
RWMD	Division of Radioactive Waste Management and Decommissioning (NEA)
SCI	Division of Nuclear Science (NEA)
SF	Spent fuel
SFCOMPO	International Database of Open Experimental Radiochemical Assay Data for Spent Nuclear Fuel
SL	Short-lived
SLW	Secondary liquid waste
SMR	Small modular reactor
SNF	Spent nuclear fuel
STC	Standing technical committee
TAF-ID	Thermodynamics of Advanced Fuels – International Database
TDB	Thermodynamic Database
UNECE	United Nations Economic Commission for Europe
UQ	Uncertainty quantification
URL	Underground research laboratory
VLLW	Very low-level waste
V&V	Verification and validation
VVER	Water-water energetic reactor
WAC	Waste acceptance criteria
WM	Waste management
WMO	Waste management organisation
WNA	World Nuclear Association

Background

The Nuclear Energy Agency (NEA) organised a joint workshop on 10-14 February 2020 to discuss optimisation of predisposal management of national radioactive waste management (RWM) programmes from various points of view, incorporating a holistic approach for RWM.[1] A clear distinction in the predisposal framework is made between waste and materials with further use, while the focus of predisposal waste management is solemnly on the waste designated for disposal. The workshop was initiated and led by the NEA Radioactive Waste Management Committee (RWMC), which invited other NEA standing technical committees (STCs) to be co-organisers of the event. The request was to hold individual sessions during the workshop and allow discussion of issues related to management of radioactive waste (RW) predisposal, in their areas of competency. Responding to this invitation, the following NEA bodies organised individual sessions within the workshop: the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM), the Committee on Radiological Protection and Public Health (CRPPH), the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC), the Data Bank (DB), the Nuclear Law Committee (NLC), the Nuclear Science Committee (NSC) and the Regulators' Forum (RF). In addition, the NEA invited other international organisations to participate and contribute to the workshop, which resulted in International Atomic Energy Agency (IAEA) and European Commission (EC) involvement.

Workshop objectives

The overall objectives of the workshop were to:

- foster discussions among participants (e.g. regulators, operators, policymakers, waste producers, decommissioning entities) from different backgrounds to promote a holistic development and optimisation of predisposal RWM programmes;
- understand the overall RW path from generation to disposal of waste (acknowledging the inclusion of regulatory and licensing processes as well as safe operation);
- promote the understanding of the impact of various factors (legal, technical, economic, societal, etc) on the fuel cycle system for optimisation of RW management.
- identify topics for continuing and extending RWMC predisposal work, identify potential collaborations with relevant STCs, and potential areas for joint projects and collaboration with other international organisations (the IAEA and the EC, among others).

1. The RWMC stated its plan to apply a holistic, sustainable approach in organising its future activities in the RWMC Statement [NEA/RWM(2019)2]. Please note that this is an internal official document not available to the general public.

The expected outcomes of the meeting were to:

- identify members' needs and challenges considering the support that NEA STCs can provide according to their programmes of work, mandates and terms of reference;
- identify possible activities (including joint projects) to support the multifactor optimisation of the fuel cycle system;
- assist with prioritisation of the programme of work for the RWMC and other STCs.

Workshop format

The workshop was organised in nine sessions over a five-day period and was held at the OECD Conference Centre in Paris. The NEA invited all interested parties and international organisations (i.e. RW management experts, members of the RWMC, CDLM, and other NEA STCs, and other stakeholders) to discuss a range of issues relevant to predisposal management of RW and their effects on optimisation on final disposal. The workshop organisation accommodated to provide an opportunity for the participants to discuss various aspects of predisposal management of RW to identify both gaps and means of global optimisation, using a holistic radioactive waste management approach.

The invited representatives included a range of national stakeholders: RWM implementers and decommissioning operators, research organisations, regulators, decision-makers, responsible government ministries, environmental organisations and the broader public. International organisations were also invited.

Table 1: Programme Committee

Committee	Representative	Secretariat
RWMC RF (RWMC session) CDLM CDLM	Hiroyuki UMEKI Walter BLOMMAERT Boris BRENDEBACH Christine GEORGES	Rebecca TADESSE (HoD) Vladimir LEBEDEV Martin BRANDAUER
NSC + DB NSC + DB	Andreas PAUTZ Marcus ALTMAIER	Tatiana IVANOVA (HoD) Kenya SUYAMA (HoD) Stéphanie CORNET Maria-Eleni RAGOUSSI Davide COSTA
NLC NLC	Roland DUSSART-DESART Nuria PRIETO SERRANO	Ximena VASQUEZ-MAIGNAN (HoD)
CRPPH	Ioannis KAISSAS	Edward LAZO
NDC	Bill MCCAUGHEY	Sama BILBAO Y LEON (HoD) Michel BERTHELEMY

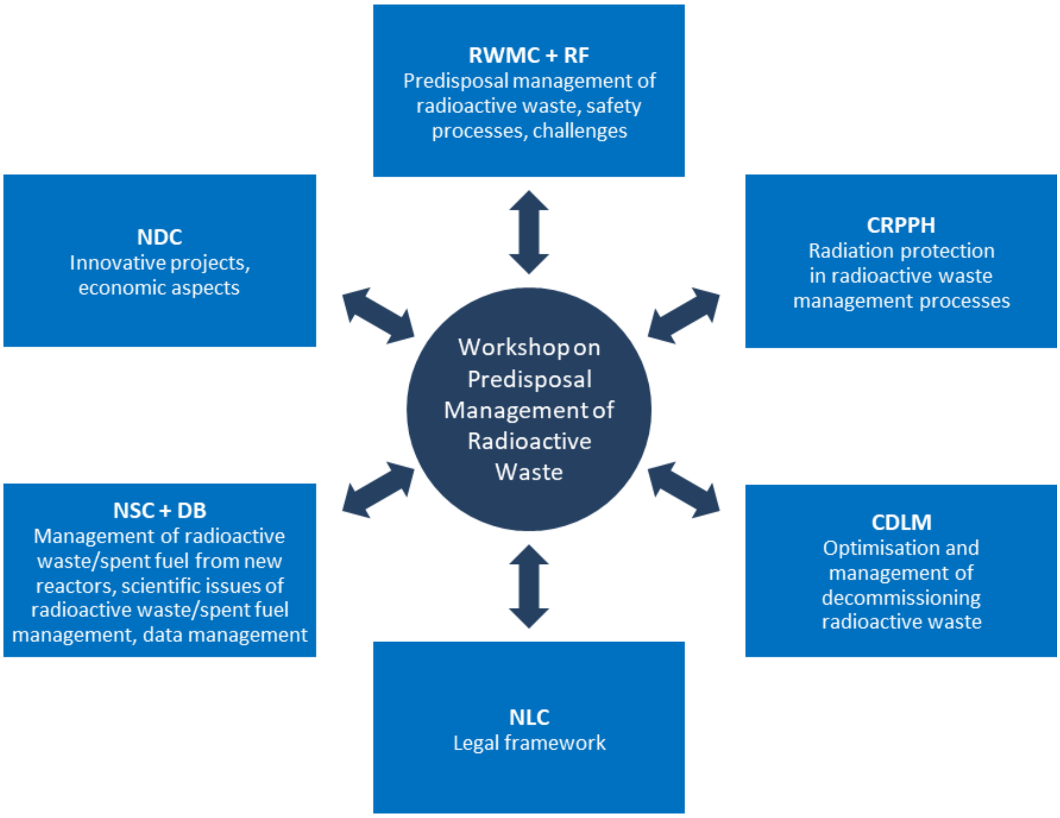
For the development of the workshop programme, the NEA convened a Programme Committee consisting of representatives from each NEA STC and representatives of relevant NEA divisions (Table 1). The RWMC asked each NEA STC to organise and hold an individual session within the workshop to discuss predisposal management of RW within the sphere of their work and activities, as shown in Figure 1.

All participating STCs developed agendas for their individual sessions. The individual agendas considered the entire RWM system, from prior to the moment of waste arising (e.g. design) to the moment it is sent to disposal (predisposal management), and included country-specific examples where appropriate. It should be noted that the focus is based on the waste requiring disposal; while in some member countries spent fuel is disposed of as high-level waste (HLW), it can also be considered as used fuel with a reprocessing path and thus does not entirely qualify as waste as pertains to the concept of predisposal.

After the workshop, participants were invited to a closing session to discuss the results of each individual session and compile overall conclusions.

The workshop programme consists of the STC sessions as shown in the agenda (see Appendix A).

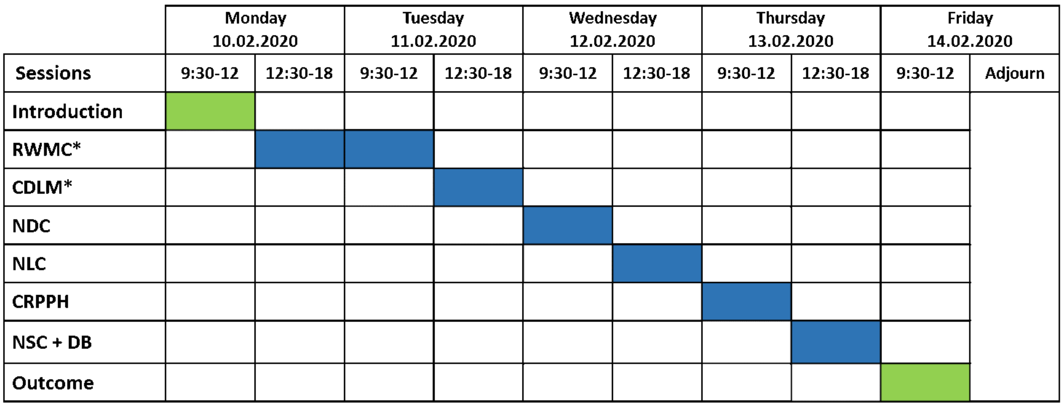
Figure 1: Contribution of each NEA STC to the workshop programme



Session summaries

The workshop was organised in nine sessions over four and a half days, including two breakout sessions (related to the RWM and decommissioning perspectives of predisposal optimisation with proposed questions, see Appendix B) with small group discussions. The workshop structure is shown in Figure 2.

Figure 2: Workshop structure



*including Breakout Sessions

The key messages and main conclusions from each of the sessions are given in the following. Key messages from each individual presentation are available in a document in the password-protected section of the NEA website related to the workshop.

Introductory session

This session included background presentations on the overall concept for the workshop along with summaries of key activities by the EC, IAEA and NEA in predisposal management of RW. The session was used to set the context for the remainder of the workshop and to provide a summary of international requirements and activities in predisposal management.

The key messages from the session were:

- All of the major international organisations concerning the application of nuclear energy (EC, IAEA and NEA among others) have programmes related to radioactive waste and spent fuel management.
- These programmes involve safety aspects, socio-political, economic and technical aspects. The organisations may have different objectives, but the programmes are often overlapping in scope.

- Optimising predisposal management of RW is a complex issue, with many technical and non-technical (e.g. socio-political and economic) factors to consider. The relative importance of the factors is different in different countries.
- There is no universally optimum solution for RWM applicable to all countries.
- Safety is a must for any optimal integrated solution.
- Optimisation of waste management needs to be systematically addressed through national policies and strategies, safety requirements and guides, technical rules and the management system applied to the available technical options.
- The optimal strategy should be determined by comparison of the advantages and disadvantages of each strategy option (multi-attribute analysis).
- Typically, issues related to different processing technologies, their interdependences, synergies and relation to different disposal systems should be considered. It should also be ensured that the chosen strategy can be implemented in the individual country based on sufficient financial and technical resources, taking into consideration political, social or legal aspects without impairing safety.
- Unlike the present, dispersed system for disposal of individual waste streams, a holistic waste management approach is required for the entire life cycle, including the "front end" of fuel production as well as reactor design/operation.
- Collaboration of the various nuclear disciplines and relevant organisations is key to tackling cross-cutting issues.

RWMC + Regulators' Forum session

The NEA Radioactive Waste Management Committee (RWMC), created in 1975, is an international committee that consists of senior representatives from regulatory authorities, radioactive waste management and decommissioning organisations, policy-making bodies and research and development (R&D) institutions from the NEA member countries. The International Atomic Energy Agency (IAEA) participates in the work of the RWMC as an observer, and the European Commission (EC) is a full member.

The RWMC supports members in the development of safe and economically efficient management of all types of radioactive waste including spent fuel, where appropriate.[2] It provides a neutral forum where policymakers, regulators and implementing organisations can discuss issues of common interest and develop best practices and feasible solutions that meet the diverse needs of its participants.

The RWMC is the lead NEA committee on topics related to predisposal management of radioactive waste and spent nuclear fuel, as well as disposal aspects.

Associated with the RWMC (as well as to the CDLM), the Regulators' Forum (RF) is composed of regulators, and focuses on radioactive waste management, decommissioning and legacy management activities. With its important role in the NEA, the RF contributed to this RWMC + RF session and also provided individual feedback in the Outcomes session.

This session presented various projects, reports and other works supported by the RWMC related to radioactive waste management. Please refer to details in the agenda provided in

2. In some member countries used fuel is recycled and is therefore not primarily considered as waste.

Appendix A. It is noted that this session also included an RWMC breakout session, and the summary of these discussions are given, along with that of the CDLM breakout session, in the subsection below titled "Breakout sessions".

The key messages and conclusions of the session were:

- The issue of optimising predisposal waste management is complex and largely unexplored (in a holistic context).
- There is very little technical or methodological literature on optimisation of the system as a whole. There is some literature available related to optimisation on parts of the system (e.g. fuel management).
- Optimisation methodologies have been developed for many issues in other areas and can be an aid for unbiased decision-making. However, any effective decisions will probably need to incorporate other inputs (socio-political, economic, etc.).
- One of the key inputs for any optimisation process is to identify what, exactly, is to be optimised and for whom. (The optimised process or solution is not necessarily the preferred, nor expected, one for all stakeholders.)
- Because a waste management system must be optimised as a whole, strong co-ordination is needed among all players. A limited number of players could be an advantage.
- Generally, waste is considered from the point of generation.[3] However, some characteristics are influenced or determined by choices made well upstream of generation; this should also be integrated into the optimisation process.
- Regulating back-end activities needs to use a graded and holistic approach that seeks an optimal balance between required levels of safety and economic aspects.
- There are numerous challenges associated with regulating and operating a waste management programme over long time scales, such as funding availability, knowledge retention and personnel training, changes in regulations, changes in societal expectations, etc.
- Stepwise decision-making can help ease some of the challenges related to changes in technologies and regulations.

CDLM session

The Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) assists members countries in managing a broad range of decommissioning issues, including waste and legacy site management. The committee provides a forum for experts representing national agencies with policy and programme responsibilities related to decommissioning, regulatory authorities, policy-making bodies, research institutes and other interested stakeholders, to facilitate the exchange of experience and information on policies and practices in these areas. In addition, the committee also aims at advancing the state of the art on environmental, financial and societal aspects. Broadly, the topics of interest of the CDLM include the development of practical guidance on regulating and managing:

3. In the context of materials requiring disposal.

- the decommissioning and dismantling of various nuclear facilities: all reactor types, front-end and back-end facilities, radioactive waste and spent fuel treatment and storage facilities, etc.;
- the retrieval and conditioning of legacy waste, the remediation and release of sites, and resolving legacies (i.e. complex sites with different levels of uncertainty).

These operations include predisposal RW management on sites or can lead to predisposal operations in dedicated waste centralised facilities. Decommissioning will generally result in significant quantities of waste. And efficient, quick and cost-effective characterisation is needed, including in situ (i.e. before removal of embedded elements) to allow choosing optimised routes for the waste. Once the waste is produced and the routes are available, waste characterisation is needed to triage waste to the appropriate treatment, storage or disposal facility. Material handling and transportation systems are also of vital importance to keeping projects on schedule.

After the safety priority to decrease nuclear risks on sites by removing mobilisable source term, cost is usually the main driver in decommissioning programmes. Time is money when seeking to decrease operating and maintenance costs as quickly as possible.

As much as possible, proven technologies should be chosen when they exist: segmentation, decontamination, etc. When they don't exist (e.g. conditioning of high activity powdery waste in back-end tanks, treatment of organic waste, treatment of some reactive metallic waste), R&D should be put into place as fast as possible to provide solutions towards disposal and avoid costs associated with storage and delay. This generally leads to the selection of technologies with a proven record of success rather than innovative or speculative technologies, even if such methods have cost-saving potential.

This session presented mainly practical experience in various French, German, Russian and Swedish decommissioning projects. Please refer to Appendix A for specific topics.

The key messages and conclusions of the session were:

- Decommissioning projects are very much schedule-driven. Therefore, efficient and proven waste management practices are a key to project success.
- Proper waste characterisation is a key aspect of decommissioning and legacy site remediation projects. It allows the wastes to be properly segregated and treated as well as directing them to the most cost-effective disposal solution.
- Characterisation extends over the entire life cycle of the project, from preparing the initial plans and cost estimates to the final end-state site surveys.
- The specific requirements for characterisation depend on a number of factors, such as the step within the project, the waste source and expected end point, waste acceptance criteria, nuclides and/or chemicals of interest, available technologies, etc.
- Characterisation needs to include non-radiological (e.g. chemical) aspects as well as radiological.
- Computer modelling can be important where direct measurements are not practical (e.g. scaling factors for difficult-to-measure radionuclides, neutron activation calculations for in-core materials).
- A variety of proven dismantling technologies have been employed worldwide for nuclear decommissioning projects (e.g. various cutting methods for concrete and large equipment, remote handling methods, characterisation techniques).

Breakout sessions

The workshop included breakout sessions after each of the RWMC and CDLM presentations. This allowed the participants to discuss the issues in smaller groups. Each group had an assigned leader, supported by a note-taker.

The breakout session questions, common to both breakout sessions, are listed, along with group members, in Appendix B. The six small groups, with membership pre-assigned by the NEA Secretariat, resulted in lively discussions, with the key findings described below. Many of the findings were similarly described by more than one group. Detailed findings from each group are provided in the Addendum.

RWMC breakout session

The RWMC breakout session allowed participants to discuss their thoughts and ideas on the material that had been presented in the session and how this might be considered in or influence future RWMC and NEA bodies' work programmes. The key findings of the RWMC breakout groups were:

- Optimisation has many drivers and objectives (reduce costs, doses, waste amounts, project times, increase in confidence, etc.). Clear, holistic drivers and/or objectives would help the development and implementation of optimisation for predisposal management. It is noted that drivers may be different in different countries.
- Information and knowledge of the basic issues are, in general, known and available. However, in many cases their inter-relationships and cross-cutting implications to specific situations are not well understood.
- There are often multiple parties involved in the waste management and related optimisation processes. Therefore, a clear definition of responsibilities and hand-offs is required (e.g. through a formal hand-off arrangement).
- A general methodology is difficult to create (one size does not fit all countries or situations). However, there is a need for the development of guidance on how to define the objectives for an optimisation programme and choose those that are relevant. Guidance might also be useful to support implementing RWM optimisation (in particular sharing experience for newcomer countries).
- Typical considerations for developing and optimising a waste management programme are to:
    - define the safety, economic and other key objectives, scale and scope (e.g. local versus global) for the optimisation;
    - establish the national policy for RWM (responsibilities, funding, etc.);
    - identify and characterise the waste streams, including non-radiological properties (e.g. quantities, chemical and biological hazards);
    - identify the details of treatment and disposal pathways, missing disposal routes and the timing for their implementation;
    - identify how to proceed with optimisation without having a final disposal site (e.g. no site-specific waste acceptance criteria [WAC]);
    - consistency and stability of solutions/decisions for long-term implementation of RWM.

- The practicality of implementing the programme is a key factor. Therefore, it is important to involve the regulators as early as possible to help guide implementers.
- Knowledge retention and ongoing education are essential for programmes that may last many decades.
- In many cases, there are ongoing R&D challenges:
    - long-term interim storage:
        - waste conditioning;
        - spent fuel (high burn-up, damaged fuel, etc.);
        - material behaviour (concrete, casks, etc.);
    - problematic waste (i.e. wastes without a defined disposal route/solution, such as irradiated graphite, tritium);
    - long-term behaviour of wastes and materials in different environments;
    - characterisation technologies;
    - waste reduction technologies (e.g. for waste treatment);
    - simultaneous consideration of societal and technical aspects;
    - scalable solutions with demonstrable benefits (practicality of the R&D).
- There is a need to look at a holistic approach from cradle to grave, which means:
    - finding a balance of risk and costs/economy supported by the society (including entertaining options such as creation and use of international or inter-regional disposal hubs and considering the possible economic value of waste[4] as a recovered product [e.g. recycling of certain materials, recovery of precious metals, isotope recovery]);
    - stepwise decision-making processes (taking into account environmental, economic and societal aspects);
    - focusing on the end point (e.g. disposal) and having a roadmap including status/state-of-the-art technologies and the goals that need to be reached;
    - having an overall driver and process to facilitate the holistic approach;
    - performing regular reviews and rigorous examination to make sure all elements and parts of the system have been considered;
    - establishing meaningful dialogue among all parties, with stakeholders being involved from the early stages;
    - covering not only radiological but also non-radiological hazards;
    - reducing overall waste generation production as well as solving any missing disposal path.

4. With the clear distinction of used fuel which already considers recycling options.

The result is that a new paradigm is emerging. It needs to be recognised that:

- Waste management begins before waste production (i.e. waste anticipation).
  - The Nuclear Innovation 2050 (NI2050)[5] project provides the opportunity to build in waste management considerations right from the start.
  - While considering the overall economic impact of the nuclear programme, keep in mind that waste management cost is only a small part (typically a few per cent of the life cycle costs).
- Overall "quality" of the waste management solution is the important driver (e.g. not focused only on cost, among other specific issues).

CDLM breakout session

The CDLM breakout session groups had different memberships than the RWMC groups, thus resulting in a different mix of opinions (see Appendix B). The questions under discussion were the same as those used in the RWMC breakouts. However, the focus of the discussions was related to how decommissioning activities and wastes differed from "routine" nuclear operations.

Some of the main differences between routine operational waste management and decommissioning waste management are related to the drivers and challenges. Compared to routine waste management, decommissioning waste management:

- has increased waste quantities, often with a wider variety of materials and more complex characterisation needs;
- needs more immediate availability of waste management (WM) routes, cutting technologies, robotics, remote handling, rapid waste characterisation, etc.;
- is typically schedule driven, therefore removal of waste as it is produced is necessary so as not to create a backlog that delays the project;
- has an increased need for identification of reclassification opportunities due to larger waste volumes;
- has more emphasis on not creating wastes you cannot manage, e.g. oversized or overweight packages (note the current challenges associated with having to retrieve and recondition historic wastes in storage);
- has a greater need to understand the uncertainties, e.g. lack of good waste characterisation data, conventional hazards (physical, chemical, biological);
- has a shift in safety focus (safety assessments during licensing procedures focus on release of radioactive substances and resulting exposure to the public, but during decommissioning safety of the workforce is very important, including conventional health and safety issues);
- has an increased need to rely on the continuity and maintenance of knowledge and experience.

5. See www.oecd-nea.org/jcms/pl_21829/nuclear-innovation-2050-ni2050.

Some of the additional elements to consider include:

- Provision of a good plan that is integrated, flexible, comprehensive and credible.
- Establishment of a baseline plan with consideration of divergence over time on:
  - complete documentation prepared at the beginning of the project;
  - operational history, materials of construction, provenance;
  - iterative improvement, subject to regular review.
- Identification and early engagement of stakeholders. During decommissioning it is important that the nuclear regulator and the conventional health and safety regulator clearly define their respective responsibilities and co-ordinate their regulatory interactions.
- Anticipation of the risk of sudden political decisions to phase out nuclear energy production, thereby creating challenges for infrastructure (service providers, suppliers, etc.) and human resource needs at short notice. Combined with a number of parallel running decommissioning projects and shortened project timelines, this could lead to a reluctance of new people/ companies to enter the field and thus lead to a shortage of experienced personnel.
- Establishment of an efficient process to characterise, categorise, triage, handle, transport and store on site or treat (decontaminate, incinerate, condition in matrices, etc.) as waste management is often on the critical path for a decommissioning schedule.

There is also a need to further share experiences and best practices in decommissioning even if this is sometimes difficult due to commercial sensitivities around technologies.

NDC session

The Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle, known as the Nuclear Development Committee (NDC), was established in 1977, initially with the aim of analysing the resources that would be needed for future exploitation of nuclear energy. The objectives of its work programme are to:

- analyse the economics of nuclear power across the nuclear fuel cycle in the context of changes in electricity markets, social acceptance and technological advances, and to assist member countries in evaluating the role of nuclear energy in their energy policies;
- promote international co-operation on the development of innovative nuclear energy systems;
- review the role of nuclear power in the broader perspective of climate change and sustainable development;
- assess the availability of nuclear fuel and infrastructure required for the deployment of existing and future nuclear power and to identify the eventual gaps;
- assist member countries, upon request, in addressing emerging concerns related to nuclear technology and radioactive materials, including medical radioisotopes;
- establish a communication network within and outside the OECD framework aiming to provide factual information on nuclear issues;

- review the role of research and development in new nuclear technologies and their impact on energy generation and non-power applications.

The NDC is responsible for the study of advanced fuel cycles and reactor systems and their impact on nuclear energy programmes and the associated costs. Such activities typically involve various spent fuel processing and recycling schemes. This interacts with predisposal waste management in two main areas: management of nuclear materials and wastes resulting from processing and recycling of used fuel. An additional issue is handling of operational and decommissioning wastes from advanced reactor concepts.

Based on the discussions and presentations (see Appendix A) in the NDC session of this workshop, key messages and conclusions were:

- Funding of back-end activities is an emerging issue for the NDC, for which close collaboration is required with RWMC.
- One of the basic guiding principles for establishing an effective waste management system is to allocate responsibilities to the parties best equipped to handle them:
  - The responsibility for financing decommissioning and radioactive waste management will ultimately need to be allocated to those parties that are best equipped to manage the underlying costs and risks.
  - This does not imply that the original creators of decommissioning and waste liabilities, primarily electric utilities and their customers, are released from their obligations.
  - Any transfer of responsibilities will need to be accompanied by concomitant transfers of accrued funds and the rights to future revenue streams as well as by appropriate additional payments.
- The historical approaches to the costs of different fuel cycle strategies (i.e. “levelised costs” approach) may need to be complemented by new methods to better reflect the role of risks and uncertainties in long-term costs and financing.
- There are three categories of fuel cycle options: open cycle, mono- and multi-recycle.
- There are challenges, opportunities and risks that are shared by all fuel cycle options. They are not discriminators between the different options. For example:
  - deep geologic disposal;
  - financial challenges;
  - social acceptance;
  - proliferation, security, worker safety, public and environmental impacts.
- Some challenges, opportunities and risks are, however, significantly different among the fuel cycle options. For example:
  - ^{nat}U required at the front end (highest in open cycle, lowest in multi-recycle);
  - characteristics of the material that requires disposal, e.g. thermal output, volume of waste, nature of radionuclides (note that radiotoxicity is not necessarily a good indicator of risk – most actinides are immobile in repository conditions);
  - high technical challenges with the potential for greater long-term economic development opportunities (e.g. for multi-recycling).

- All countries need to be actively implementing a strategy for the back end of the fuel cycle. Prolonged delays in making and implementing decisions often result in increased costs and probability of failure.
- Decision-making in the back end of the fuel cycle and/or predisposal management demands more advanced assessment methodologies representative for:
  - dynamic multi-stakeholder decisional environment;
  - uncertain futures where the ability for a given scenario to create more flexibility in the decision-making process can be of significant value for all stakeholders;
  - complex systems demanding representation from the physical/technological level to socio-political objectives.
- Used fuel interim storage solutions are needed independent of the overall fuel cycle strategy.
- All used fuel management schemes require a handling and transport programme and implementation or access to geological disposal capacity.
- Recycling is key to reducing risks and increasing flexibility and financial predictability. It offers more adaptable schemes providing flexibility and a road to multi-recycling in light water reactors and/or fast reactors.

NLC session

The Nuclear Law Committee (NLC) is a highly focused group of specialists designated by the NEA member countries, comprising lawyers, policymakers, academics and occasionally technical experts. Its terms of reference centre upon the interpretation, implementation, improvement and modernisation of the international nuclear liability regimes. It also provides a forum for discussions concerning the development and harmonisation of legislation on other aspects of nuclear law.

The objectives of the NLC are:

- to assist member countries in the development, strengthening and harmonisation of nuclear legislation that is based upon internationally accepted principles for the safe and peaceful use of nuclear energy;
- to contribute to the modernisation of the international nuclear liability regimes and encourage the strengthening of treaty relations between interested countries to address liability and compensation for nuclear damage;
- to collect, analyse and disseminate information on nuclear law generally and on topical nuclear law issues.

Radioactive waste management is a highly regulated field, nationally and internationally. This national and international governance must be considered when planning, executing and optimising a predisposal management programme for RW and spent nuclear fuel.

In order to cover the broad scope of the legal and regulatory frameworks[6] for radioactive waste management, the NLC session was divided into three parts: international legal

6. There is a difference between legal and regulatory frameworks. Legal aspects are governed by laws adopted by the relevant authority (usually parliament) and regulatory aspects are governed by regulations that can be adopted by ministries, relevant governmental bodies or regulators.

framework, nuclear third-party liability and transboundary aspects. Each session is addressed individually in the following.

International legal framework relating to radioactive waste management

A number of binding[7] and non-binding[8] international instruments are applicable to radioactive waste and spent fuel management. They are generally under the auspices of the IAEA, the NEA, the EU and the United Nations Economic Commission for Europe (UNECE).

The main messages and conclusions from the session were:

- International treaties and conventions place requirements and constraints on many aspects of radioactive waste and spent fuel management.
- They are especially important for transboundary movements of radioactive materials and expressly forbid certain activities (e.g. dumping radioactive waste at sea or sending radioactive waste to another country for disposal without a bilateral agreement between the concerned countries).
- Some treaties and conventions (e.g. the IAEA Joint Convention and the EU Radioactive Waste Directive) entail reporting obligations. These obligations require a signatory country to identify its policies and strategies for all its radioactive waste and spent fuel and to develop plans for implementation. This encourages countries to think about their waste management and spent fuel management programmes in a holistic fashion.
- Some countries have had difficulties implementing some of the reporting requirements, largely due to the magnitude of the task of collecting the relevant information and presenting it in the expected format.
- Some countries encountered difficulties implementing the binding[7] and non-binding[8] international instruments into their national system.
- Nuclear phase-out plans in some countries contribute to major rearrangements of the utilities and the whole energy generation market. This raises issues with respect to securing the necessary financing to manage the waste, for which the operators of nuclear installations are responsible.

7. For example, under the auspices of the IAEA: the Convention on the Physical Protection of Nuclear Material (1980), the Convention on Early Notification of a Nuclear Accident (1986), the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986), the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter as amended (1994) and the Convention on Nuclear Safety (1994); under the auspices of UNECE: the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus Convention, 1998), the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention, 1991) and the Protocol on Strategic Environmental Assessment (Kiev Protocol, 2003); under the auspices of the Euratom Treaty, the Radioactive Waste Directive (2011/70/Euratom); as well as the nuclear third party liability conventions under the auspices of the IAEA and the NEA, and the treaties relating to safeguards and non-proliferation under the auspices of the IAEA.
8. For example, the IAEA Safety Standards.

Nuclear third-party liability as applicable to radioactive waste

To balance the benefits of nuclear energy with the potential risks incurred in case of a nuclear accident, a special liability regime was set up to ensure that victims receive adequate compensation for nuclear damage, while protecting nuclear plant investors and suppliers.[9]

The main messages and conclusions from the session were:

- Several international conventions deal with nuclear liability.[10]
- The conventions state that the operator shall be exclusively and strictly liable in case of "nuclear damage" caused by a "nuclear incident" occurring at a "nuclear installation" or in the course of transport of "nuclear substances" or "nuclear material" to or from such an installation.
- Radioactive waste and the nuclear installations containing such waste (whether storage or disposal facilities) are covered by the nuclear liability regimes established by the conventions. However, in some limited cases, radioactive waste or nuclear installations for the disposal of certain radioactive waste may be excluded from these special regimes.[11]

Transboundary aspects of predisposal management

Transboundary movement of radioactive waste or spent fuel is necessary when sending such material to another country for processing or for the return of resulting waste products to the country of origin. Shipments are generally made by sea or land (road or rail) or some combination of the two. Shipments have also been made by air, although less frequently.

9. The basic principles that are set forth in all nuclear liability conventions are the following: the operator is strictly liable (i.e. the victims need not prove fault or negligence, but will have to prove the causal link); the operator is exclusively liable (i.e. only the operator will be considered liable and no other law than nuclear liability law shall apply to compensate the victims); in principle the operator's liability will be capped (certain countries, such as Germany, Japan and Switzerland provide for unlimited liability); the operator will have to cover its liability up to an amount determined by law, either with private insurance (the usual option) or any other means approved by the relevant national authority; a prescription period will apply.
10. Under the auspices of the IAEA: the 1963 Vienna Convention on Civil Liability for Nuclear Damage, the 1997 Protocol amending the Vienna Convention on Civil Liability for Nuclear Damage, the 1997 Convention on Supplementary Compensation for Nuclear Damage; under the auspices of the NEA: the 1960 Paris Convention on Nuclear Third Party Liability and the 2004 Protocol amending the Paris Convention on Nuclear Third Party Liability.
11. Exclusions relating to the Paris Convention: 1977 Decision on the Exclusion of Certain Kinds of Nuclear Substances [NE/M(77)2], 2016 Decision on the Exclusion of Small Quantities of Nuclear Substances outside a Nuclear Installation [NEA/NE(2016)8/FINAL], 2014 Decision and Recommendation on the Exclusion of Nuclear Installations in the Process of Being Decommissioned [NEA/SUM(2014)2], 2016 Decision and Recommendation on the Exclusion of Nuclear Installations for the Disposal of Certain Types of Low-level Radioactive Waste [NEA/NE(2016)7/FINAL]. Exclusion relating to the Vienna Conventions and the CSC: 2014 IAEA Board of Governors Resolution on the Establishment of Maximum Limits for the Exclusion of Small Quantities of Nuclear Material [GOV/2014)63]. Please note that the aforementioned NEA documents are located in a restricted area of the NEA website and are therefore not accessible to the public.

In addition to the IAEA SSR-6 transportation regulations,[12] some of the treaties mentioned above also apply in case of transboundary movements,[13] and intergovernmental agreements may also be agreed.

The main messages and conclusions from the session were:

- Countries in which radioactive waste treatment or spent fuel processing companies offer services to foreign clients usually prohibit the disposal in their territory of the foreign waste concerned. In principle, all treated foreign waste must be returned to the country of origin, usually within a specified period. However, in some instances, the waste resulting from the processing [mainly high-level waste (HLW) generated by spent fuel processing] remains in temporary storage in the receiving country due to unavailability of suitable storage or disposal facilities in the sending country.
- Only operators from France and Russia are currently offering commercial spent fuel processing services to operators from other countries.
- Operators from France, Sweden and the United States are also offering commercial services to other countries for the treatment of low-level waste (LLW).
- Many types of spent fuel and radioactive waste have been successfully transported to and treated at these facilities with the resulting waste returned to the country of origin.
- A treatability review of the waste or spent fuel is important prior to the first shipment to ensure that it can be properly treated at the receiving facility.
- Some countries prohibit the export of their own waste or spent fuel to other countries for treatment or storage.
- Formal intergovernmental agreements are required between the countries involved as well as commercial contracts between the sending and receiving operators.
- Transboundary movements may involve more than just the sending and receiving countries when the carriage needs to transit through the territory of other countries. This can complicate the logistics (e.g. circuitous routes to avoid non-agreeing countries, or multiple handovers between transport operators), including the legal aspects relating to such carriage.
- Slovenia and Croatia have a unique situation whereby a nuclear power plant located in one country (Slovenia) is shared between the two countries with joint responsibility for waste and spent fuel management.

CRPPH session

The NEA's Committee on Radiological Protection and Public Health (CRPPH) is made up of regulators and radiological protection experts, with the broad mission to provide timely identification of new and emerging issues, to analyse their possible implications and to recommend or take action to address these issues to further enhance radiological protection

12. IAEA (2018), *Regulations for the Safe Transport of Radioactive Material, IAEA Safety Standards Series No. SSR-6 (Rev.1)*, IAEA, Vienna. Available at: www.iaea.org/publications/12288/regulations-for-the-safe-transport-of-radioactive-material (Accessed on 20 April 2021).
13. IAEA (n.d.) Transport, www.iaea.org/topics/transport (Accessed on 20 April 2021).

regulation and implementation. The regulatory and operational consensus developed by the CRPPH on these emerging issues supports policy and regulation development in member countries and disseminates good practice.

The CRPPH works in close co-operation with the Radioactive Waste Management Committee (RWMC), the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM), the Nuclear Development Committee (NDC), the Committee on Nuclear Regulatory Activities (CNRA), the Committee on the Safety of Nuclear Installations (CSNI) and with other NEA committees as appropriate.

Radiological protection of workers and the public is one of the aspects that must be considered in the optimisation of predisposal management. Many of the steps involve worker contact with the raw wastes and/or final waste packages, such as characterisation, handling, sorting, treatment, etc. Therefore, the CRPPH can provide important guidance in the optimisation process of such contacts in terms of radiological protection.

The main messages and conclusions from the session were:

- The term "optimisation" has a specific meaning in radiological protection terms, which is different than the context generally used in radioactive waste management.
- The principle of optimisation of protection: the likelihood of incurring exposures, the number of people exposed and the magnitude of their individual doses should all be kept as low as reasonably achievable (ALARA), taking into account economic and societal factors.
- Optimisation of protection is not minimisation of dose. Optimised protection is the result of an evaluation, which carefully balances the detriment from the exposure and the resources available for the protection of individuals. Thus, with respect to the dose limitation principle, the best option is not necessarily that with the lowest dose.
- Radiological protection is often considered in isolation from other hazards (physical, chemical, biological, etc.). Therefore, optimisation of radiological protection is not necessarily optimisation of the overall protection of workers and the public.
- Taking into account all the hazards, the ALARA principle can be expanded into the concept of "as safe as reasonably achievable" (ASARA):
  - The ability to balance different risk based on a common metric should provide input to the decision-making process and allow focusing on actual risk (low, medium and high risk). There are existing decision-making tools, which can be fed with the connections and convolutions of the different risks and thus keep the risk assessment simple and user friendly.
  - The development of a common metric to assess risks associated with various substances and exposure pathways would be essential for the development and practice of the ASARA concept in RWM.
- Non-radiological hazards (e.g. handling of toxic materials, carrying excessive personal protective equipment [PPE]) should be taken into consideration, especially in decommissioning procedures of nuclear facilities wastes.
- Risk communication is ineffective where there is no trust. Clear and understandable stakeholder participation is a trust-building initiative. Communicating risk is based on trust and credibility that is built during the risk assessment process.
- Past experience show that stakeholder involvement in risk assessment associated with a remediation project is (even if time and resource consuming) an effective way to:
  - understand their concerns and provide relevant information;
  - improve risk assessment;
  - improve radiological protection culture;
  - build trust in the decision-making process;
  - reach a sustainable decision.
- Protection against alpha contamination can be vital for decommissioning projects.
- In countries where "clearance" is allowed, it should be used to minimise the amount of waste sent to a RW disposal facility. This is especially vital for decommissioning projects, where large quantities of waste are non-radioactive or minimally

contaminated. In such cases, thorough calculation of the doses delivered to the public and the biota can be proof of the minimal environmental imprint.

NSC and Data Bank session

The NEA nuclear science programme is developed and executed by the Nuclear Science Committee (NSC), comprising high-level scientific experts from all NEA member countries. The Division of Nuclear Science provides secretarial support to the NSC. Close co-operation with the Data Bank is maintained, primarily because of the potential for mutual benefit to be gained between the programme of work of the Data Bank (DB) and the type of activities pursued within the nuclear science programme. The main areas of work are: reactor physics and radiation shielding, fuel cycle physics and chemistry, criticality safety, material science, nuclear data, experimental needs and nuclear knowledge management.

The objectives of the NSC programme of work are to:

- help advance the existing scientific knowledge needed to enhance the performance and safety of current nuclear systems;
- contribute to building a solid scientific and technical basis for the development of future-generation nuclear systems;
- support the preservation of essential knowledge in the field of nuclear science.

The diverse NSC programme of work includes, but is not limited to, the following activities relating to the workshop topic:

- advanced fuel cycle scenarios for improving sustainability [multi-recycling scenarios, impact of starting reactors on used fuel and evaluation of low-enriched uranium (LEU), including waste reduction];[14]
- fuel recycling chemistry with separation technologies (including processing issues for different nuclear fuels and fuel cycles comprising aqueous, pyrochemical and hybrid-combination scenarios), assessment of treating and managing residual wastes, emissions and effluents arising from the recycling processes (including reduction of waste from structural materials);[14]
- evaluation of available experimental data, including critical integral experiments and spent nuclear fuel assay data of spent nuclear fuel;[15]
- study of criticality of used nuclear fuel (including investigations on degraded fuel, degraded poisons);[15]
- study of the reflector effect of silicon dioxide for criticality safety in the direct disposal of used nuclear fuel;[16]
- through database/joint projects:
  - Thermodynamics of Advanced Fuels – International Database (TAF-ID) allowing critical reviews of existing experimental data and models, calculated thermodynamic data and phase diagrams for complex multi-component systems (such as oxide fuels containing fission products, corium, etc.);

14. NEA Working Party on Scientific Issues of the Fuel Cycle.
15. NEA Working Party on Nuclear Criticality Safety.
16. NEA Expert Group on Criticality Analysis of Used Nuclear Fuel.

    - Spent Fuel Isotopic Composition (SFCOMPO) database of open experimental isotopic compositions of spent nuclear fuel, with +750 spent nuclear fuel samples from fuel irradiated in 44 reactors, 8 reactor types and 22 100 measurements.

The NEA Data Bank works under three main lines of activity relevant for this workshop:

- Thermochemical Database Project (joint project):
    - carries out literature reviews and assessment of thermodynamic data of interest to radioactive waste management;
    - provides high-quality thermodynamic data to support performance assessments of deep geological repositories;
    - provides state-of-the-art reports on topics of broad interest to describe systems related to geological disposal;
    - provides guidelines on data selection and assessment.
- Computer Programme Services (CPS):
    - collects and distributes nuclear data and codes;
    - disseminates know-how (e.g. training courses) on widely used computer codes.
- Nuclear Data Services (NDS):
    - co-ordinates the Joint Evaluated Fission and Fusion (JEFF) nuclear data library and compiles experimental nuclear data (EXFOR);
    - preserves knowledge in nuclear data evaluation and nuclear codes as well as develops tools (e.g. JANIS, NDEC).

Material data and computer modelling are very important for developing the safety cases for radioactive waste and spent fuel management. It is especially important for the very long timescales required to be considered for disposal programmes. In these situations, the prediction of changes in RW/spent fuel (SF) behaviour relies heavily on modelling and simulation that requires reliable experimental evidence for validation. In particular, the availability of high-quality data for the development and optimisation of waste forms, such as glasses for vitrification of HLW where many chemical species can coexist in the waste, is important. The NSC and its related working parties and expert groups, in co-operation with the Data Bank, collect and maintain various datasets. The NSC and DB rely on expressions of interest from the scientific communities for providing and collecting the data needed for predisposal.

There is an obvious link between predisposal and final disposal – although the scope and focus of NEA data is on deep geological repositories (DGRs), the data and principles can also be applied to near surface disposal, and as well as to many predisposal steps. There are many common aspects, such as nuclides of interest as well as waste form and engineered and natural barrier materials. Selection and prediction of appropriate material properties and modelling how they evolve over time is important for all phases of RWM.

In a disposal engineered barrier system, there are a number of simultaneous and interacting processes going on: dissolution, sorption, advection, diffusion, radionuclide decay, etc. The relative rates and net effect of these processes can be very different for different radionuclides, chemical species, barrier materials, groundwater chemistry, among others, as can how all of these interact over very long time periods with ever-changing conditions.

All this leads to a need for reliable computer models and data. Reliable prediction of radionuclide speciation and solubility requires:

- understanding of the main physic-chemical processes;
- availability of realistic chemical models;
- availability of reliable thermodynamic data.

The presentations in this session covered some of the recent work of the NSC and the Data Bank and how it is being applied in the key but diverse areas of long-term spent fuel and HLW storage; thermodynamic data needs and challenges in waste management; decay heat data and calculations; used fuel sampling and characterisation; and characteristics and impacts of advanced fuel cycles on geological disposal of SF and HLW. The main messages and conclusions from the session are summarised below, grouped in five categories.

Long-term storage issues

- HLW and spent fuel require long storage prior to disposal. Waste form and storage time need to be optimised to reduce storage and disposal costs.
- An important difference between predisposal and disposal is the timescale over which the evolution of the system occurs. For predisposal management, the timescale (even for extended storage) is of the scale of a few decades at most. For near-surface disposal, the time may extend to a few centuries or more, while for DGRs the timescale of interest is typically of the order of thousands up to a million years.
- Uncertainty quantification and sensitivity analysis in calculations and modelling are important:
  - reduce penalties/conservatism and increase safety margins for waste and cost optimisation;
  - understand the main uncertainty sources and their impacts.
- Fuel drying prior to dry storage is important for long-term storage to prevent degradation of the fuel and storage envelope, while proper and effective criteria need to be established.
- Spent fuel thermo-mechanics modelling is performed for fuel thermo-mechanical evolution from wet to dry to disposal. Modelling of the behaviour of hydrogen in zirconium alloys is important. The repartition of hydrogen, its precipitation and reorientation, and thus the mechanical properties of the cladding, are dependent on:
  - the temperature and its gradient;
  - mechanical stress/strain and its gradient;
  - the electrochemical potential gradient (change in materials, composition and microstructure);
  - hydrogen concentration gradient.

Thermodynamic data needs and challenges

- The thermodynamic database provides key data for geochemical modelling. The NEA TDB project has attained an important status as an international reference.

- Simulation of solubility and retention processes (radionuclide source terms and sorption) is a key aspect in geological disposal to assess long-term performance, taking into account:
  - o reliable prediction of radionuclide speciation and solubility;
  - o development of scientific process understanding;
  - o development of realistic chemical models;
  - o collection of reliable thermodynamic data.
- Geochemical tools provide powerful insight into processes on a qualitative and quantitative level.
- Radioactive waste vitrification, with the chemical complexity (30+ elements) and metastability of glass, is difficult to model and predict due to solubility, crystallisation and phase separation. These phenomena depend on temperature (thermodynamic) and time (kinetic) parameters. One of the main challenges is finding the optimal compromise among:
  - o radioactive waste specifications (waste loading composition, quantity, activity);
  - o the best containment matrix (glass feasibility, quality, long-term behaviour);
  - o the best process (robustness, maintainability, best elaboration conditions, low corrosion, volatility).

Decay heat data and calculations

Decay heat is important in all parts of the back-end system:

- transportation;
- intermediate storage in both wet and dry systems;
- reprocessing, including the cost of storage;
- final geological repository due to:
  - o passive cooling by non-flowing processes in the rock;
  - o optimisation and design of canisters and repository, taking into account what fuels are encapsulated, the distance between canisters in the rock, etc.;
  - o strict temperature requirements on canister and bentonite (less than 100°C for the KBS-3 concept) as well as on the rock;
- accuracy of data and calculations of decay heat (uncertainty of the order of a few per cent), criticality (of the order of a few per cent), radiation doses (of the order of 10%) as well as contents of fuel amount of fissile material burn-up (BU), initial enrichment (IE), cooling time (CT), all with an intermediate accuracy;
- economical terms, as low uncertainties of the decay power parameters reduce costs required for safety.

Open questions remain on the realistic uncertainties, judging of conservatism, biases and required margins for decay power and thermal issues in the back end.

Spent fuel characterisation

- Fuel characterisation is a necessary step in all parts of the back end of the nuclear fuel cycle. International development in this field is growing and must be mature at the appropriate time for the various spent fuel management programmes in the world.
- It is important to well characterise HLW before disposal, because it will not be possible or reasonable to retrieve, characterise and repackage waste, especially after repository closure. It is noted that:
    - Over-design of a repository system to address uncertainties is expensive.
    - Decay heat is an important parameter for repository design, so accurate data is required.
    - There is a good opportunity for international collaboration to improve statistics.
- Assay data are based on datasets of measured nuclide concentrations of well characterised used nuclear fuel samples. Descriptions of samples' characteristics and operation histories are provided with adequate detail for potential use in benchmark models.

Characteristics and impacts of advanced fuel cycles on geological disposal

- Long-lived radionuclides, especially minor actinide alpha-emitters, are important for the long-term safety case for disposal of HLW.
- Advanced fuel cycles, including novel separation techniques, multi-component reactor systems, partitioning and transmutation, and advanced reactor designs can reduce the quantities of problematic radionuclides and the associated radiotoxicity of the wastes going to geological disposal.
- Transmutation requires a lot of fast neutrons (fission becomes dominant and minor actinides transform into fission products), and thus partitioning and transmutation:
    - changes the form of the waste (full fuel assembly vs. product streams);
    - reduces the number of minor actinides to be disposed;
    - increases the number of fission products and reprocessing waste to be disposed;
    - changes the time scale/size of the repository;
    - reduces the radiotoxicity of the waste.[17]
- New wastes from advanced reprocessing schemes and fuel cycles need to be compatible with planned disposal options.

Outcomes session

This session consisted of a presentation by Mike Garamszeghy, the workshop rapporteur, followed by a panel discussion of the session chairs and a roundtable discussion with all

17. "Radiotoxicity" is not necessarily a good safety indicator for a repository, as radionuclides are essentially immobile and do not cause significant radiological impact by entering the biosphere. However, their removal from the repository inventory can simplify the design process as well as increase public confidence in the reliability of the safety modelling.

participants. The workshop ended with a final wrap-up by workshop Chair Hiroyuki Umeki.

The rapporteur's presentation summarised key messages and potential areas for collaboration that were discussed over the course of the workshop, forming the basis of the following sections of this report. The presentation is included in the Addendum as an updated version including additions and edits made throughout the presentation and subsequent discussions. The panel discussions and roundtable are summarised below.

Figure 3: Outcomes session

RMWC wrap-up

The RWMC, workshop and RWMC session Chair, Hiroyuki Umeki, stated that the presentations and discussions at the workshop were both valuable and informative.

Nuclear energy expansion – and introduction of advanced fuel cycles – will face intense scrutiny and a fully integrated case must be made for its safety, security and sustainability. Unlike the present, dispersed RWM systems of individual waste streams, a holistic waste management approach is required for the entire life cycle, starting from the front end of fuel production and reactor design/operation. Optimisation is a key aspect of the holistic approach. The RWMC has adopted this approach and been developing its programme of work accordingly.

An important gap in the current RWMC work related to transportation was identified and needs to be considered for the future. Potential areas for collaboration between the RWMC and other STCs have emerged. For example, cost estimating methodology is an area for collaboration with the CDLM and the NDC. Transboundary issues and their international legal implications could be topics of collaboration with the NLC. Verification and validation of data and codes are important areas for collaboration for the NSC and Data Bank. Development of a methodology for balancing radiation and non-radiation risks is a potential area for collaboration with the CRPPH.

The current RWMC programme of work includes the areas of knowledge management (IDKM)[18] and robotics and remote handling system (EGRRS),[19] while the scope also allows interaction with the CDLM. These areas have been identified as important issues for the optimisation of predisposal management and can be further extended to incorporate topics of other STCs. Work is also ongoing in building stakeholder confidence under the activities of the Forum on Stakeholder Confidence (FSC)[20] as well as building regulatory competencies under RF programmes. This work could be also extended to all relevant processes of waste management.

A potential area for collaborative work is also identified to develop a general framework chart of all the steps involved in radioactive waste management, including the decision points and all relevant factors to promote discussion of an overall optimisation required to establish and maintain the programme.

CDLM wrap-up

The Chair of the CDLM session, Christine Georges, said that the workshop was a useful forum for discussion among the STCs. She suggested that the next meeting, however, should include more cross-cutting sessions.

The increasing collaboration between international groups (EC, EPRI, IAEA, NEA, WNA, etc.) was highlighted. Each has similar programmes and efforts are being allocated to avoid overlapping areas. Further co-ordination would lead to more efficient use of resources, since many experts are members of similar groups within each organisation.

Waste management and decommissioning are generally afterthoughts in the design and construction of a new nuclear facility. Therefore, there is a need for better co-ordination and collaboration between waste management/decommissioning groups and reactor/nuclear facility designers/operators at the outset of the design process so as to integrate “waste management and decommissioning by design”.

Similarly, there is often poor communication among different areas of waste management. For example, similar waste from operation and decommissioning may be handled differently mainly because there is often a different organisation responsible. Efficiencies can be gained by using similar methods for similar wastes.

NLC wrap-up

The NLC and session Chair, Roland Dussart-Desart, mentioned that the NLC pre-dates the NEA. It has a long history of collaboration with the other STCs. It currently collaborates with the RWMC in legal areas related to financing, stranded wastes, social acceptance, transparency and legal treaty obligations, among others. Future collaboration could include (though not be limited to) guidance on long-term liabilities, transportation and transboundary requirements.

NDC wrap-up

Michel Berthélemy, from the NEA Secretariat, indicated that nuclear waste management is a cross-cutting topic. There is a need to build new mechanisms for collaboration, not just

18. NEA Working Party on Information, Data and Knowledge Management (WP-IDKM).
19. NEA Expert Group on the Application of Robotics and Remote Systems in the Nuclear Back-end.
20. www.oecd-nea.org/jcms/pl_26865/forum-on-stakeholder-confidence-fsc.

within the NEA but also externally. The issues for addressing the back end of the nuclear fuel cycle, including predisposal, are primarily socio-political rather than technical. Thus, there is a need to inform policymakers in clear, actionable ways that provide both the right messages and right level of detail.

Costing and financing of different fuel cycle strategies are closely related and require more collaboration among the various STCs and working groups. Uncertainties in these areas abound, and there is a need to share related experience and best practices.

A particular remark was made concerning the importance of the predisposal framework considered in this workshop, requiring a clear distinction between nuclear materials (including used fuel) and radioactive waste (designated for disposal). In some countries used fuel is not considered as waste until it is transferred to a waste management organisation

(WMO) and it should be managed accordingly, including keeping recycling options open. Only when it is transferred to such a WMO does the possibility of considering it as a valuable material end.

CRPPH wrap-up

The Chair of the CRPPH session, Ioannis Kaissas, made clear that there is a need to protect workers from conventional safety issues as well as radiation issues, especially during decommissioning where conventional risks may not be readily apparent or may be difficult to quantify. The physical risks of dismantling as well as handling of materials such as asbestos, heavy/toxic metals, PCBs, etc. that may be present in some facilities (especially older ones) should be considered. Protection of the public is generally limited to radiation issues, although some residual chemical contamination may be present on legacy sites.

In some cases, there is conflict between radiological protection principles and conventional safety requirements (e.g. the use of extra PPE for chemical hazard work may result in awkward or restricted movement, increasing the job time and subsequently the worker dose). Consequently, there is a need to develop common metrics for risk assessments of different types. This convolution of risks may call for variations in the principles applied: depending on the circumstances, ALARA or ASARA might be appropriate.

Internal contamination, especially of alpha-emitters, creates elevated fear in workers and the public. Therefore, R&D on best practices for decontamination procedures to reduce the risk of internal contamination is important. The prior, accurate knowledge of the radioactive components of the materials to be decommissioned is essential for pre-emptive worker protection, also against alpha-emitters. Taking into account characterisation methods such as scaling factors for difficult-to-measure radionuclides and neutron activation calculations for in-core materials can guide the choice of appropriate PPE as well as the overall decommissioning procedure.

The aforementioned points reveal topics for close collaboration of the CRPPH with the RWMC and the CDLM in the reasonable practice of optimisation concerning the protection of exposed workers and the public.

NSC and Data Bank wrap-up

Reliable science is the key to underpin decision-making in matters of RWM mentioned by the Chairs of the NSC session, Andreas Pautz and Marcus Altmaier.

There are a number of data and modelling issues that are important for waste management related safety cases as well as process control. These include:

- verification and validation of codes and data, including reliability of data and quantification of uncertainties;
- improved and consistent data on spent fuel characterisation, including an understanding of what elements need to be treated in vitrification;
- accurate thermodynamic data for elements and materials of interest for disposal systems;
- reliable mathematical models;
- level of detail and accuracy needs for waste characterisation data;
- implications of advanced fuel cycles.

To facilitate this, it is necessary to bring experts on predisposal, disposal and sciences together to discuss their needs and understand the needs of others. The NEA can also seek expressions of interest from the scientific communities for providing and collecting the needed data. This will take better advantage of the existing tools and large experimental infrastructure.

Proposals were made as follows:

- The NEA provides a good framework to discuss topics of overarching interest and importance. Therefore, it is proposed to create an NEA body that would bring together experts on predisposal, disposal and sciences to discuss and understand the R&D needs in the area of predisposal and disposal.
- Collect expression of needs for experimental databases required for predisposal activities.
- Establish a new NEA joint project on advanced fuel cycles for waste minimisation.
- Establish international collaboration to improve decay heat data.

Regulators' Forum wrap-up

Walter Blommaert, Chair of the Regulators' Forum (RF), stated that the RF is a specialised group within the RMWC supporting both the RWMC and the CDLM, consisting of senior members from the nuclear and radiological protection regulatory agencies of NEA member countries. The RF has wide and active participation in many NEA committees and working groups. All have recognised the need for closer collaboration between regulators and implementers. More active collaboration is needed between the RF and other NEA groups, such as the Committee on the Safety of Nuclear Installations (CNSI), the Committee on Nuclear Regulatory Activities (CNRA), as well as with other international groups, such as the European Nuclear Safety Regulators Group (ENSREG) and the IAEA. More active collaboration and co-operation among multiple regulators within a country is also required (e.g. between the nuclear regulator and the conventional safety or environmental regulator).

Implementers need to engage with regulators early in the process. Both regulators and implementers need to communicate with all stakeholders and listen to their needs and concerns. Sustainability of decision-making is a concern to both regulators and implementers. Once taken, decisions should not change frequently, especially due to non-technical or safety-related factors (e.g. socio-political reasons). A stepwise decision-making process could assist in gaining stability.

The regulatory and supervisory regime in a country must ensure that all planned steps in waste management can actually be licensed and carried out. A stable and consistent framework for licensing must be in place to ensure that all required licences can be granted in a timely fashion as needed.

A move towards performance-based regulations would also be helpful, especially when assessing the very long-term (post-closure phase) for disposal facilities. This allows the implementers some flexibility in their choice of solutions leading to easier optimisation, rather than following a strictly prescribed path "because it is required by regulations".

In addition to competency management for implementers, there is a corresponding need for training, knowledge management and maintenance of competency for regulators as well. This is especially true for nuclear phase-out countries, where there is little incentive for new recruits to enter such a career.

The final point related to the need for updating the regulations around decommissioning of nuclear facilities in many countries. The RF already has a programme of work in this area after the extension of its mandate, covering both RWMC and CDLM issues, in 2019.

Roundtable discussion

The general opinion of the session chairs and the participants was that the workshop was useful and interesting. It was very helpful for understanding different perspectives and country-specific issues. The workshop was considered well-organised, with a good mix of presentations and discussions. It was a good opportunity to see the work of other NEA STCs, as well as other international organisations.

The workshop was a good beginning for the topic of optimisation. The challenge will be to continue. A future meeting should be held in several years' time, with more specific topics pertaining to radioactive waste, decommissioning and radiological protection (as it relates to the first two). The breakout sessions were particularly useful and more such sessions should be included in any future workshop. The shared experiences on good practices (and bad) as well as how countries have developed and applied some of the methodologies are also very helpful.

It is important to see all sides of the issue. The wide mix of participants was helpful to generate good discussions from different angles. A holistic view on waste management is integral to the future of the nuclear industry.

One common theme was that terminology is important – different groups had different interpretations of "optimisation" and other key terms (including predisposal). It is challenging to explain exactly what is meant by the term in an easily understandable way. Learning how other STCs understood the term was very helpful for all concerned. Further guidance is needed in this area, including societal, economic, environmental and technical aspects. The guidance must be usable for all levels of society, especially decision-makers.

"Optimisation" is a philosophy that should be applied across the board, from cradle to grave rather than only in selective, discreet areas.

Dealing with new technologies, such as radically different small modular reactor (SMR) designs, will also present some challenges. Waste management issues need to be addressed upfront, rather than left to some undefined point in the future. This will help to prevent the creation of new waste forms that may not be easily dealt with.

The field of optimisation and holistic waste management is new and needs to be further developed and promoted among the various nuclear industry stakeholders. Regulators have particular influence to direct the implementation of a radioactive waste management programme and how it is optimised.

Identified areas for collaboration

In the "tour de table" participants judged the workshop useful and expressed that the concept of optimisation in radioactive waste management should be further explored. As the NEA Director-General William D. Magwood, IV said in his opening address, "this topic is not an easy one and we might end up with more questions than answers".

A number of areas for potential collaboration among the NEA STCs were identified over the course of the workshop. These are addressed in this chapter, structured within six areas:

1. development of guidance/information material concerning the optimisation of predisposal RWM;
2. creation of a mechanism for collaboration between the NEA bodies, as well as IAEA, EC and other international entities;
3. identified collaboration opportunities for the individual STCs;
4. facilitation of co-ordinated research projects;
5. encouragement of knowledge preservation and transfer;
6. organisation of a follow-up workshop.

Development of guidance/information material concerning the optimisation of predisposal RWM

To provide a common understanding and drive stepwise decision-making as well as inform the general public, it was recognised that guiding documents would be a very useful tool to understand and develop actions for predisposal management. The collaborative viewpoint covering all aspects of the nuclear life cycle (technical, environmental, economic and societal aspects) allows addressing waste issues beyond the point of actual generation and thus raises awareness of the subject within the community and beyond. Proposals comprise the following aspects.

Create a consistent terminology

Discussions highlighted the fact that some terms have different meaning in different nuclear domains (e.g. the terms "predisposal" and "optimisation" are understood differently by members of different STCs). To allow proper discussion on the subject, a consistent terminology would be beneficial. There are a number of glossaries that could be used, but would need to be agreed upon.

Publish a document to introduce the concept of predisposal optimisation, so that different stakeholders, including the general public, can understand it clearly

This addresses two points, which could be tackled separately or in conjunction:

- guidance documentation to the nuclear community to allow waste minimisation beyond the actual point of generation, thus contributing to the holistic optimisation of radioactive waste management;
- an informative document (pamphlet) for the general public usable by all levels of society, including decision-makers, with the aim of raising awareness towards radioactive waste management optimisation opportunities.

The general opinion was that there is very little technical or methodological literature on optimisation of the radioactive waste management system as a whole. Generally, available literature addresses optimisation of parts of the system (e.g. fuel management).

Emphasis was placed on the need for global versus local optimisation, including societal, economic, environmental and technical aspects.

Develop a holistic RWM optimisation methodology

Based on the development of guidance for information purposes, it is suggested to construct a strategic methodology to address the stepwise optimisation of predisposal waste management. The aim is to, in a holistic way, avoid and reduce waste over the entire life cycle of nuclear facilities. This comprises waste beyond the point of production (e.g. in the design of facilities, fuel development), parts of the system which are not fully defined or developed (e.g. disposal as well as re-treatment of historical waste types created without a WAC or which no longer meet current WAC), as well as back-end issues such as site end state, discharge and clearance.

Highlighted areas are:

- A focus on decision-making regarding clearance and disposal has been emphasised. In member countries where it is allowed, clearance is an important tool for radioactive waste reduction and should be used as such. In addition, it was highlighted that clearance must consider non-radiological hazards as well (ASARA, taking all factors into account). Challenges exist especially for alpha contamination and other very low clearance level nuclides.
- Regarding new builds, especially SMRs, it is important to avoid technologies that have the potential to produce wastes incompatible with future storage or disposal options, especially if they are irreversible (e.g. liquid fuels, sodium-bonded fuels, different construction materials and others). However, this should not default to deferral of decision-making.

Creation of a mechanism for collaboration between the NEA bodies as well as the IAEA, EC and other international entities

It was recognised that there is a need for a mechanism to allow and/or facilitate collaboration between the NEA committees as well as associated bodies such as the IAEA, EC and other international entities (e.g. WNA, EPRI). The aim is to increase exchange, reduce duplication, focus co-ordinated efforts and evaluate cost sharing for future international projects needed in the waste management optimisation field. Existing programmes involve safety aspects, socio-political, economic and technical aspects. Proposals comprise the following aspects.

Increase communication among NEA bodies

In order to be optimised, waste management needs to be better integrated from design of nuclear facilities, operation, decommissioning and legacy management up to disposal or recycling of waste, taking into account all relevant aspects (safety, security, costs, legal, etc.). Suggestions include:

- Establish and increase mutual participation between STCs and their associated bodies. This can be in the form of attendance of meetings as invited observers (or full members) as well as collaborative topical sessions, webinars or similar information-sharing platforms.
- The STCs should consider the incorporation of guidance on sustainability, optimisation and the "holistic approach" into their work programmes.

Co-ordinate and share costs of future international projects

All of the major international organisations concerning nuclear energy (NEA, IAEA, EC, WNA, etc.) have programmes related to radioactive waste and spent fuel management. These programmes involve safety aspects, socio-political, economic and technical aspects. The organisations may have different objectives but the programmes are, to some extent, overlapping. It was suggested to create a mechanism of co-ordination and facilitation of cost sharing. Examples include research and innovation, knowledge management, training, methodology, guidance, standards, etc.

Identified collaboration opportunities for the individual STCs

Within the workshop, it was suggested that each of the NEA STCs should look for areas of potential collaboration with other STCs and international organisations in their current and future programme of work (e.g. include some overlapping representation among the various working groups). This would improve the work of the individual groups by bringing different perspectives to the work as well as facilitating better communication by keeping other STCs and groups informed about each other's ongoing work.

In general, each of the STCs should see if they can incorporate guidance on sustainability, optimisation and the "holistic approach" into their programme of work.

The following topics have been identified for further collaboration by the chairs of the individual sessions of the workshop.

RWMC

In addition to the general areas of collaboration identified at this workshop, the following topics have been identified as potential areas of work:

- Increase consideration of transportation in the RWMC programme of work as a vital aspect of predisposal management.
- Consider life cycle analysis of individual facilities (i.e. recognise their uniqueness: nuclear power plant, research reactors, fuel cycle facilities), developing a RWM life cycle in collaboration with the relevant STCs.
- Create a general framework chart of all steps involved in RWM, including decision points and relevant factors needed to establish and maintain the programme.

- Cost estimating methodology is a potential area of collaboration with the CDLM and the NDC.
- Transboundary issues and their international legal implications are potential areas of collaboration with the NLC.
- Verification and validation of data and codes are potential areas of collaboration with the NSC and Data Bank.
- Development of a methodology for balancing radiation and non-radiation risks is a potential area of collaboration with the CRPPH.

CDLM

- Enhanced co-ordination and collaboration among WM and decommissioning groups as well as reactor/nuclear facility designers/operators is suggested. The topic of "waste management and decommissioning by design" has been suggested as an area for further exploration.
- Cost estimating methodology, including associated risk and uncertainties, is a good area of collaboration with the NDC.
- Consider the sharing of lessons learnt/best practices/available solutions:
  - disseminate the decommissioning experience of certain types of facilities (e.g. VVER, MOX plants) including operators, regulators and WMOs;
  - share the data needed for decommissioning with current plant operators (e.g. characterisation);
  - apply safety case experience for predisposal management (e.g. long-term storage);
  - exchange lessons learnt, e.g. in the field of management of historical conditioned waste (characterisation methodology, etc.).

NDC

- Establishing a stable financial mechanism from beginning to end, including funding of final disposal, is an emerging issue for the NDC. Close collaboration with other STCs, especially the RWMC, is required.
- The historical method for calculating waste management and decommissioning liabilities (i.e. "levelised costs" approach) may need to be complemented with new methods to better reflect the role of risks and uncertainties in long-term costs and financing. This could be addressed in collaboration with the CDLM and the RWMC.
- Costing and financing are closely related and require more collaboration among the various STCs and working groups.

NLC

- Collaborations with the RWMC currently exist in legal areas related to financing, stranded wastes, social acceptance, transparency and legal treaty obligations.
- Future collaboration with the RWMC could include guidance on long-term liabilities, transportation and transboundary requirements.

CRPPH

- Non-radiological risk (physical and hazardous material such as asbestos, heavy/toxic metals, PCBs, etc.) is of great concern during decommissioning. Consequently, there is a need to develop common metrics for assessment of risks of different types, which could be done in collaboration with the RWMC and CDLM.
- Best practices for decontamination procedures for alpha-contaminated sites to reduce the risk of internal contamination and reduce waste amounts could be developed with the CDLM.

NSC and Data Bank

- It is suggested to create an NEA working group with predisposal and disposal experts to identify common needs and progress on the application of thermodynamic data and methodologies in both domains. This could be addressed in collaboration with the RWMC.
- Establishing a new NEA joint project on advanced fuel cycles for waste minimisation is suggested.
- Establish international collaboration to improve decay heat data collection and management.
- Analysis of the implications of advanced fuel cycles is suggested.
- New technologies, such as SMR designs, still lack profound understanding of RWM implications. This could be addressed in collaboration with the RWMC.

RF (potential collaboration with the CNRA)

- Early involvement of regulators could assist to promote a stepwise decision-making process as well as to help guide implementers. The development of the guidelines could be a collaboration between the RF and the STCs.
- Performance-based regulations could be considered, especially when assessing the very long term (post-closure phase) for disposal facilities. This would allow implementers some flexibility leading to easier optimisation. Collaboration with other NEA STCs and associated groups, such as the CSNI and CNRA, as well as with other international groups, such as ENSREG and the IAEA could be considered.

Facilitation of co-ordinated research projects

R&D topics

A number of topics that need to be further addressed have been identified:

- quick and reliable waste characterisation;
- solutions for “problematic” or unusual waste streams (challenging without easy waste treatment and/or disposal routes, such as graphite, tritium, organics, reactive metallic, etc.);
- research, development and demonstration on solutions for “mixed wastes”;

- long-term interim storage implications [conditioned waste, spent fuel (burn-up, damaged fuel), material behaviour (concrete, casks, etc.)];
- database to optimise materials over the whole life cycle (long-term behaviour in different environments);
- urgently addressing R&D of societal impact as opposed to technical aspects.

Shared infrastructure

International collaborations could be accelerated in facilitating shared infrastructure HLW management. These are of significant importance countries with smaller programmes (with few reactors).

Encouragement of knowledge preservation and transfer

The importance of knowledge preservation and transfer has been highlighted. This includes training of future workers, technical experts, regulatory staff, decision-makers, etc. Apart from "conventional" nuclear training and knowledge transfer, this provides an opportunity to educate new professionals early on the issue of predisposal waste optimisation. This topic provides an opportunity for collaboration with other international entities such as the IAEA and the EC.

Organisation of a follow-up workshop

Participants expressed their appreciation for the workshop, which, in its form, was unique. It was very helpful to address waste management optimisation from different viewpoints, thus allowing a holistic approach to predisposal optimisation. A collective desire to repeat the workshop was expressed, with the following additional characteristics:

- The follow-up workshop should be organised along cross-functional thematic lines, rather than by STC as was done at the current workshop. This would give each of the STCs an opportunity to present on the same topic in the same session.
- A stronger focus on breakout group discussions as a tool for sharing information, lessons learnt and best practices in other countries.
- Focus on existing national optimisation strategies with implementation feedback and lessons learnt.
- Consider a recurring workshop every 2-4 years.
- Consider a focused CDLM, RWMC and CRPPH session (or even a separate workshop) on the predisposal management of radioactive waste topic to further develop and solve identified issues.

Key messages and conclusion

The workshop provided a rare opportunity for members of all the Nuclear Energy Agency (NEA) standing technical committees (STCs) to present and discuss a common theme in a single forum. All participants found this to be a worthwhile exercise towards achieving a common understanding of the issues and complexities around "optimisation" of a radioactive waste management programmes or system.

A key governing factor is defining what is to be optimised and whom it is being optimised for. Once these have been established, the economic, safety, environmental, technical, social and other variables and constraints can be defined and a model created. Many of the variables will interact with each other – e.g. safety, environment, social and cost will all influence each other. These interdependencies need to be considered, and their relationships may change over time.

One of the main technical considerations for optimisation of predisposal management of radioactive waste is the availability of waste acceptance criteria (WAC) for the end state (generally disposal). This will determine what technical approaches are viable for treatment and conditioning of the waste. If the end state is not known and/or final WAC are not available, it is difficult to determine the optimal course of action.

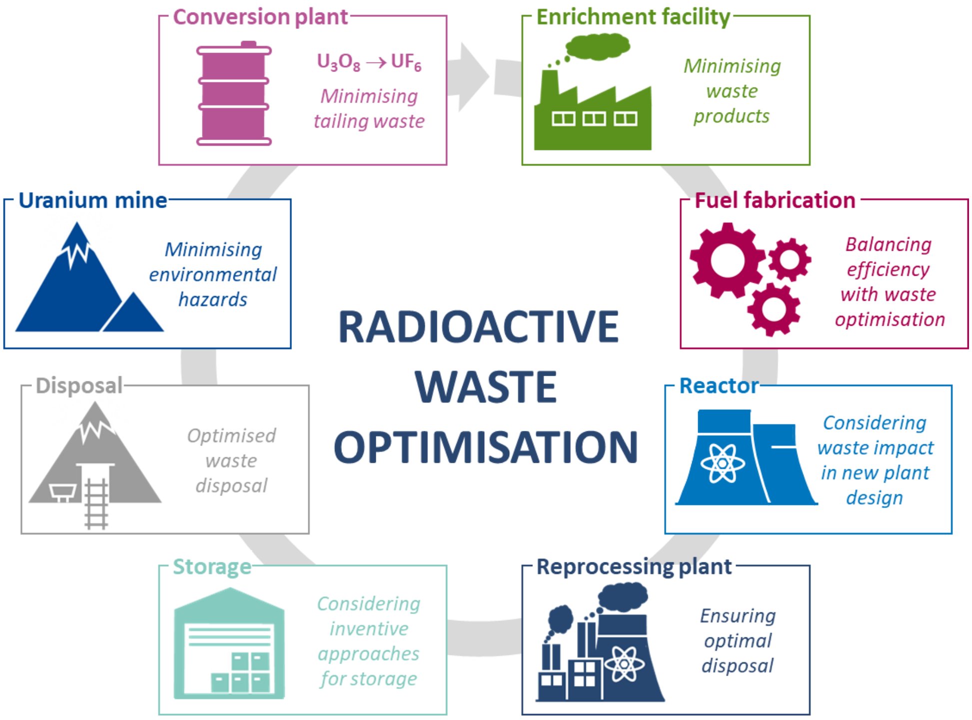
Figure 4[21] summarises the considerations for a sustainable, holistic waste management programme. All of the technical and non-technical elements interact with each other in complex ways and all need to be taken into account.

Figure 4: Holistic waste management considerations

21. The RWMC stated its plan to apply a holistic, sustainable approach in organising its future activities in the RWMC Statement [NEA/RWM(2019)2]. Please note that this is an internal official document not available to the general public.

Optimisation always needs to consider the desired end point, which is generally to minimise the environmental footprint in a safe yet economically viable manner for the entire nuclear cycle (as shown in Figure 5), plus the decommissioning and remediation of the individual facilities towards the final disposal.

Figure 5: Optimisation considerations for radioactive waste management



Several themes and key messages emerged over the course of the workshop presentations and discussions. These are summarised below.

- "Optimisation" means different things to different people. Examples include:
  - A regulator may interpret it in the context of ICRP radiological protection.
  - A facility operator may interpret it in terms of a safe, cost-minimising solution.
- The issue of optimising predisposal WM is complex and largely unexplored:
  - There is a need to optimise the whole system (from facility design to disposal of wastes), not bits and pieces of the system.
  - This is difficult to do if some parts of the system are not fully defined or developed (e.g. disposal for some waste types). For such a situation:
    - It is important to avoid technologies that are potentially incompatible with future storage or disposal options, especially if they are irreversible. However, this should not default to deferral of decision-making.
    - Stepwise decision-making is useful.
    - Repackaging older stored wastes to meet repository WAC might need to be considered.

- There is no universal WM optimal solution suitable for all countries:
    - There are different situations and issues for different groups of countries:
        - countries with no nuclear power programme and no plans to implement one;
        - countries with developed, ongoing nuclear power programmes (with and without reprocessing);
        - those undergoing nuclear phase-out;
        - those newly embarking on a nuclear programme.
    - Within each group different policies, strategies, local preferences and constraints, resource availability, etc., will affect the optimisation choices.
    - Optimisation priorities should be framed in the context of national policy.
    - Application of graded approaches should be considered.
    - There are many (overlapping) levels of national and international safety requirements and conventions related to RW that need to be considered. This can lead to differences between country programmes as well as issues for sharing international facilities, transportation, etc.
- The optimised approach is not necessarily the preferred nor expected approach by all stakeholders, e.g. due to non-technical factors.
- Boundary conditions are in a state of flux: a range of credible scenarios need to be developed as a basis for long-term planning.
- New/advanced reactor designs may produce different waste types that will present other challenges (e.g. liquid fuels, sodium-bonded fuels, different construction materials).
- The collaboration of various nuclear areas and relevant organisations is a key to tackle the cross-cutting issues:
    - Some characteristics of the waste are influenced or determined by choices made well upstream of its actual generation (e.g. construction materials, how a facility is operated); this should also be integrated into the optimisation process.
- It is necessary to develop collective choices with intergenerational dimensions in the field of RWM.
- More than ever, the RWM governance must be based on the involvement of an informed and vigilant civil society.
- "Waste management begins before waste production" – integrated WM must consider the whole programme life cycle, from design to decommissioning stages.
    - The cradle-to-grave principle is, however, difficult to apply to legacy situations.
- Cost is a big driver for decommissioning projects.
- Often there is a lack of co-ordination between decommissioning organisations and waste management organisations.
- Transportation of various types of waste and spent fuel is important, but not covered in the current RWMC programme of work.

- "Better integration" means discussion of the overall problem with all parties on equal footing.
  - For this purpose WM must also be highly visible in the organisation.

Conclusions

During the NEA workshop on the Multifactor Optimisation of Predisposal Management of Radioactive Waste a number of key areas were identified.

Overall, the issue of optimising predisposal waste management is both complex and largely unexplored. There is no universal solution for optimal waste management applicable to all countries, since the optimised approach is not necessarily the preferred nor expected approach of all stakeholders. This may be due to country-specific technical and non-technical factors. More than ever, the governance of radioactive waste management must be based on the involvement of an informed and vigilant civil society. It has become clear that waste management begins before waste production and that integrated waste management needs to consider the whole programme life cycle, from design to decommissioning stages. To allow waste management optimisation, the issue must be highly visible in organisations and the field.

Further, the success of holistic predisposal optimisation is determined to a large degree by the willingness of all interested parties to:

- compromise;
- attempt to understand differing perspectives in their own organisations;
- attempt to understand regulatory authorities and the public perspective;
- continue to seek solutions that are acceptable to everyone.

Figure 6: Workshop participants

Appendix A: Agenda

DAY 1 – Monday 10 February 2020

1. PLENARY SESSION

1.1 Welcome Remarks
William D. MAGWOOD IV, Director-General, NEA

1.2 Welcome Remarks from the Chair of RWMC
Hiroyuki UMEKI, RWMC Chair

2. INTRODUCTION SESSION

2.1 Introduction of the Workshop Objectives, Organisation and Sessions
Rebecca TADESSE, Head of Division of RWMD, NEA

2.2 International Initiatives Concerning the Optimisation of Predisposal RWM
Andrey GUSKOV, IAEA

2.3 International Initiatives Concerning the Optimisation of Predisposal RWM (cont.)
Aurélie DURAND, Legal Officer, European Commission, Directorate-General for Energy, European Commission

2.4 NEA Activities Concerning RW Management, Perspectives
Hiroyuki UMEKI, RWMC Chair

3. RWMC SESSION

3.1 Session Introduction by the Session Chair
Hiroyuki UMEKI, RWMC Chair

3.2 Optimisation of Predisposal Radioactive Waste Management – Systemic Approach of a Complex Issue
Jean-Paul MINON, Former RWMC Chair

3.3 The Technical Factors Impacting the Optimisation of RWM
Peter SWIFT, Sandia National Laboratories (United States)

3.4 Regulator's Role in the Optimisation of Predisposal Management of Radioactive Waste
Walter BLOMMAERT, RF Chair

3.5 The Challenging Public Dialogue: Radioactive Waste Management
Yves LHEUREUX, ANCCLI (France)

3.5 Breakout Groups Discussions
Prepared Topics

3.6 Group Photo

DAY 2 – Tuesday 11 February 2020

4. PLENARY SESSION

4.1 Sharing Results Among Groups and Discussions
Slides preparation by Group Leaders

4.2 Panel Discussion with the Whole Group
Chair of each Group, Hiroyuki UMEKI, RWMC Chair

4.3 Closure of RWMC Session

5. CDLM SESSION

5.1 Session Introduction by the Session Chairs
Christine GEORGES, CEA (France)
Boris BRENDEBACH, BMU (Germany)

5.2 Optimised Activated Radioactive Waste Disposal for Reactor Dismantling
Nicolas CHAPOUTIER, Framatome (France)

5.3 Holistic View on Predisposal RW Management Aspects in Decommissioning of Complex Facilities Considered "Legacy"
Elena SHCHELKANOVA, Leading Specialist of Andreeva Bay Division of the North-Western Centre for Radioactive Waste Management (SevRAO) (Russia)

5.4 The Importance of a Proper Characterisation and Inventory Assessment to Reduce Financial Risks and to Secure a Safe Disposition of the Waste Material
Arne LARSSON, VP Technology, Cyclife Sweden AB (Sweden)

5.5 Dismantling and Decontamination Techniques and Associated Generation of Secondary Radioactive Waste
Karsten SCHMIDT, EWN (Germany)
5.6 Breakout Session
5.7 Sharing Results Among Groups and Discussions
5.8 Conclusions from the Session Chair, Discussion in Whole Group, Finalising
Christine GEORGES, CEA (France)
Boris BRENDEBACH, BMU (Germany)
5.9 Session Close

DAY 3 – Wednesday 12 February 2020

6. NDC SESSION

6.1 Session Introduction by the Session Chair
Bill MCCAUGHEY, DOE (United States)
6.2 Criteria and Methods to Investigate Back-end Strategies
6.2.a. Overview of Recent NDC Activities on the Back End of the Fuel-Cycle
Michel BERTHÉLEMY, NEA/NTE
6.2.b. Presentation of the Forthcoming NDC Back End Strategies Report
Bill MCCAUGHEY, DOE (United States)
6.2.c. Methods and Tools to Evaluate Backend Strategies
Luc VAN DEN DURPEL, Nuclear-21 (Belgium)
6.2.d. Point of View of the Industry
Armand LAFERRERE, Orano (France)
6.3 Roundtable Discussion on Future Priorities for the NDC in the Area of the Back End of the Fuel Cycle
All Participants
6.4 Conclusions from Session Chair
Bill MCCAUGHEY, DOE (United States)

7. NLC SESSION

7.1 Introduction by the Chair of the NEA Nuclear Law Committee
Roland *DUSSART-DESART, Chair of the NEA Nuclear Law Committee (NLC) and former Head of the Legal Division, FPS Economy, SME, Self-employed and Energy (Belgium)*
7.2 The International Legal Framework Relating to Radioactive Waste Management
Chair: Nuria PRIETO SERRANO, Lawyer, Technical Division/Department of International Relations, Enresa (Spain)
7.2.a Main International Instruments
Nuria PRIETO SERRANO, Lawyer, Technical Division/Department of International Relations, Enresa (Spain)
7.2.b Main EU Instruments
Aurélie DURAND, Legal Officer, European Commission, Directorate-General for Energy, European Commission
7.2.c Challenges of Implementing Such a Framework at the National Level: The Finnish Experience
Kai HÄMÄLÄINEN, Section Head, Nuclear Waste Regulation and Safeguards, Regulation of Nuclear Waste Facilities, Radiation and Nuclear Safety Authority (STUK) (Finland)
7.2.d Challenges of Implementing Such a Framework at the National Level: The German Experience
Christoph BUNZMANN, Federal Office for the Safety of Nuclear Waste Management (BMU) (Germany)
7.2.e Discussion on Topic
Chair and Speakers
7.3 Nuclear Third-Party Liability as Applicable to Radioactive Waste
Chair: Roland DUSSART-DESART, Chair of the NEA Nuclear Law Committee (NLC) and former Head of the Legal Division, FPS Economy, SME, Self-employed and Energy (Belgium)
7.3.a Overview of the International Nuclear Liability Conventions
Elena DE BOISSIEU, Legal Adviser, NEA Office of Legal Counsel
7.3.b Nuclear Liability at the National Level: The Russian Experience
Elena AZAEVA, Senior Head of Direction, TENEX, Joint-Stock Company, Legal Department, Division for Legal Support of Foreign Operations (Russia)
7.3.c The Insurance Sector's Perspective
Gilles TREMBLEY, Managing Director, Assuratome (France)
7.3.d Discussion on Topic
Chair and Speakers
7.4 The Transboundary Aspects of Predisposal Management
Chair: Benjamin MAQUESTIEAU, Deputy Director-General, ONDRAF (Belgium)
7.4.a Managing Radioactive Waste Generated by Foreign Operators: A French Experience
Laurence CHABANNE-POUZYNIN, General Counsel Public, Nuclear, Environmental & Real Estate Law Department, Orano (France)
Olivier BARTAGNON, Technical Expertise and Residues Return Department, Recycling Business Unit, Orano (France)

7.4.b Managing Radioactive Waste Generated by Foreign Operators: A Swedish Experience
Arne LARSSON, VP Technology, Cyclife Sweden AB (Sweden)
7.4.c Managing the Radioactive Waste Generated by the Krško Nuclear Power Plant (NEK)
Leon KEGEL, Head of Planning and Development Section, Slovenian Agency for Radioactive Waste Management (ARAO) (Slovenia)
7.4.d Discussion on Topic
Chair and Speakers
7.5 Session Close

DAY 4 – Thursday 13 February 2020

8. CRPPH SESSION

8.1 Radiological Protection Aspects of Predisposal – Introduction by the Session Chair
Ioannis KAISSAS, EEAE (Greece)
8.2 Balancing Protection from RP and other Occupational RW Management Risks
Ludovic VAILLANT, CEPN (France)
8.3 Optimisation of Worker Exposure Protection from Decommissioning RW Management Operations: Experience from Decontamination of nuclear power plants in France
Gilles RANCHOUX, EDF (France)
8.4 Optimisation of Worker Exposure Protection from Normal Nuclear Power Plant Operations: Experience from German Nuclear Power Plants
Melanie SCHMIDT, Vattenfall (Germany)
8.5 Discussion
Series of Pre-developed Questions
Key Elements of an Optimum Protection Solution
Criteria for Identifying the Optimum Protection Solutions
8.6 Conclusions by the Session Chair
Ioannis KAISSAS, EEAE (Greece)

9. NSC AND DATA BANK SESSION

9.1 Introduction by the Chairs
Andreas PAUTZ, PSI (Switzerland)
Marcus ALTMAIER, KIT-INE (Germany)
9.2 Work at PSI to Support Interim Storage of Spent Nuclear Fuel
Andreas PAUTZ, PSI (Switzerland)
9.3 Interface Between Pre-Disposal and Final Disposal of Waste. Thermodynamic Challenges
Marcus ALTMAIER, KIT-INE (Germany)
9.4 Thermodynamic Data for Conditioning and Vitrification of Nuclear Waste
Sophie SCHULLER, CEA (France)
9.5 Decay Heat Data and Calculations
Anders SJÖLAND, SKB (Sweden)
9.6 SFCOMPO Database – Valuable Asset for Spent Nuclear Fuel Transportation, Storage, and Repository Applications
Steve SKUTNIK, ORNL (United States) (via WebEx)
9.7 Radioactive Waste from Advanced Fuel Cycle Reprocessing Technologies in Russia
Anzhelika KHAPERSKAYA, Rosatom (Russia)
9.8 Use of ADS Systems to Reduce Minor Actinide Content in Spent Fuel and Potential Impact on the Geological Disposal of HLW
Hamid Aït ABDERRAHIM, SCK•CEN (Belgium)
Kazufumi TSUJIMOTO, JAEA (Japan)
9.9 Panel Discussion
All Participants
9.10 Session Close

DAY 5 – Friday 14 February 2020

10. OUTCOMES SESSION

10.1 Summary of the Workshop from Rapporteur
Mike GARAMSZEGHY, Consultant (Canada)
10.2 Panel Chair Discussions "Path Forward and Areas of Collaboration on Predisposal Management"
All Participants
10.3 Conclusions of the Workshop
Workshop Chair

Appendix B: Breakout session questions

1. What are the drivers for a good radioactive waste management (RWM) disposal programme?
    a. Please name drivers in order of importance.
    b. Considering the drivers, what does RWM optimisation look like on a global level?
2. Which elements of waste management need to be considered when developing a nuclear system (taking into account the complete nuclear product life cycle: new fuel, new reactor design, decommissioning, waste treatment and waste disposal and storage facility), taking into account evolving society?
3. What challenges does the nuclear industry face that hinder achievement of a good RWM predisposal programme?
    a. Is there a need for development of a methodology to support optimisation of RWM predisposal?
    b. Where could international collaboration be beneficial to address issues related to predisposal management of radioactive waste?
4. What would you consider high priority R&D issues for predisposal and how would you envisage the role of the Nuclear Science Committee (NSC)/Data Bank (DB) in these efforts?
5. Can you briefly describe what you understand by a “holistically developed, optimised and sustainable predisposal RWM programme”?

Table 2: RWMC session breakout groups

Group 1	Group 2	Group 3
Christophe BRUGGEMAN (Leader)	Nancy GREENCORN (Leader)	Gareth GARRS (Leader)
Tomohiro HIGASHIHARA (Secretariat)	Takune KURATA (Secretariat)	Jinfeng LI (Secretariat/Note-taker)
Shin MORITA (Note-taker)	Wei-Whua LOA (Note-taker)	Lisa SMADJA (Assistant)
Lisa SMADJA (Assistant)	Lisa SMADJA (Assistant)	
Sunyoung CHANG	Susanne PUDOLLEK	Bill MCCAUGHEY
Olivier BARTAGNON	Manlu LIU	Tomáš KOVALOVSKÝ
Jean-Paul MINON	Xirui LU	Norikazu YAMADA
Matthew BUCKLEY	Artem PETROSYAN	Leon KEGEL
Kyung-Woo CHOI	Arne LARSSON	Özge YILDIRIM
Ioannis KAISSAS	Frédéric LEDROIT	Elena AZAEVA
Ichiro OTSUKA	Wolfgang NECKEL	Marie-Noëlle MARTIN
Pierre FORBES	Jeongken LEE	Stanislav FOKIN
Zoltan LENGYEL	Wilma BOETSCH	Mircea IONESCU
Hamid Aït ABDERRAHIM	Richard GUPPY	Gianfranco BRUNETTI
Katalin PALSZABO	Karsten SCHMIDT	Laurent GAGNER
Sophie SCHULLER	Nicolas CHAPOUTIER	Yves LHEUREUX
Paula BERGHOFER	Jaakko LEINO	Marina NEPEYPIVO
Przemyslaw IMIELSKI	Tania NAVARRO RODRIGUEZ	Elena SHCHELKANOVA
Benjamin MAQUESTIEAU	Tatyana RAKITSKAYA	Gilles TREMBLEY
Coralie PINEAU	Ludovic VAILLANT	Armand LAFERRERE
Kazufumi TSUJIMOTO	Melanie SCHMIDT	
Group 4	**Group 5**	**Group 6**
Enrico ZACCAI (Leader)	Hiroyuki UMEKI (Leader)	Mike GARAMSZEGHY (Leader)
Martin BRANDAUER (Secret./Note-taker)	Madoka KOIZUMI (Secret./Note-taker)	Porsche WILLIAMS (Secret./Note-taker)
Lisa SMADJA (Assistant)	Ursula ARNAL DIFFU (Assistant)	Alyssa CLARK (Assistant)
Jiri FALTEJSEK	Xiaoqin NIE	Ben Mekki AYADI
Boris BRENDEBACH	Jeremy HUNT	Monica Carmen DUCU
Viorel TOBOSARU	Patrick LEDERMANN	Christine GEORGES
Walter BLOMMAERT	Marina NEPEYPIVO	Haiyong JUNG
Nuria PRIETO SERRANO	Erwin NEUKATER	Jungjoon LEE
Veronica ANDREI	Roland DUSSART-DESART	Arnaud LECLAIRE
Aurélie DURAND	Gaël MENARD	Kevin GOVERS
Cécile EVANS	Marcus ALTMAIER	Joseph AFONSO
Kwangyoung SOHN	Peter SWIFT	Anders SJÖLAND
Andrey SAMOYLOV	Kai HÄMÄLÄINEN	Daniel UPMANN
Kazuyuki KATO	Laurence CHABANNE-POUZYNIN	Fanny FERT
Marion COUTURIER	Anatoly GRIGORIEV	Azhelika KHAPERSKAYA
Juliane KRUEGER	Julia LOPEZ DE LA HIGUERA	Katalin PAUTZ
Sophie MISSIRIAN	Julio PARDILLO PORRAS	Xisen SHI
Gilles RANCHOUX	Ruta RIMSA	Alberto UBALDINI
	Luc VAN DEN DURPEL	Andrey GUSKOV

Table 3: CLDM session breakout groups

Group 1	Group 2	Group 3
Mike GARAMSZEGHY (Leader)	Walter BLOMMAERT (Leader)	Christine GEORGES (Leader)
Tomohiro HIGASHIHARA (Secretariat)	Takune KURATA (Secretariat)	Jinfeng LI (Secretariat/Note-taker)
Shin MORITA (Note-taker)	Wei-Whua LOA (Note-taker)	Lisa SMADJA (Assistant)
Lisa SMADJA (Assistant)	Lisa SMADJA (Assistant)	
Luc VAN DEN DURPEL	Jiri FALTEJSEK	Sunyoung CHANG
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Hiroyuki UMEKI	Patrick LEDERMANN	Norikazu YAMADA
Gareth GARRS	Kyung-Woo CHOI	Marina NEPEYPIVO
Erwin NEUKATER	Nuria PRIETO SERRANO	Leon KEGEL
Enrico ZACCAI	Aurélie DURAND	Veronica ANDREI
Wolfgang NECKEL	Joseph AFONSO	Pierre FORBES
Wilma BOETSCH	Kwangyoung SOHN	Gaël MENARD
Cécile EVANS	Andrey SAMOYLOV	Stanislav FOKIN
Katalin PALSZABO	Christoph BUNZMANN	Peter SWIFT
Paula BERGHOFER	Przemyslaw IMIELSKI	Kai HÄMÄLÄINEN
Fanny FERT	Sophie MISSIRIAN	Laurence CHABANNE-POUZYNIN
Jaakko LEINO	Gilles RANCHOUX	Anatoly GRIGORIEV
Tania NAVARRO RODRIGUEZ	Kazufumi TSUJIMOTO	Julia LOPEZ DE LA HIGUERA
Tatyana RAKITSKAYA	Ludovic VAILLANT	Katalin PAUTZ
Ruta RIMSA	Zoltan LENGYEL	Alberto UBALDINI
Christophe BRUGGEMAN		
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Susanne PUDOLLEK	Ben Mekki AYADI	Xiaoqin NIE
Olivier BARTAGNON	Tomáš KOVALOVSKÝ	Jeremy HUNT
Xirui LU	Viorel TOBOSARU	Matthew BUCKLEY
Artem PETROSYAN	Ik JEONG	Ioannis KAISSAS
Haiyong JUNG	Arnaud LECLAIRE	Frédéric LEDROIT
Jungjoon LEE	Kevin GOVERS	Roland DUSSART-DESART
Elena AZAEVA	Nancy GREENCORN	Marie-Noëlle MARTIN
Jeongken LEE	Mircea IONESCU	Marcus ALTMAIER
Hamid Aït ABDERRAHIM	Gianfranco BRUNETTI	Richard GUPPY
Anders SJÖLAND	Daniel UPMANN	Karsten SCHMIDT
Sophie SCHULLER	Nicolas CHAPOUTIER	Kazuyuki KATO
Laurent GAGNER	Azhelika KHAPERSKAYA	Marion COUTURIER
Yves LHEUREUX	Marina NEPEYPIVO	Juliane KRUEGER
Julio PARDILLO PORRAS	Elena SHCHELKANOVA	Benjamin MAQUESTIEAU
Melanie SCHMIDT	Bill MCCAUGHEY	Coralie PINEAU
Virginie WASSELIN	Andrey GUSKOV	Armand LAFERRERE
		Gilles TREMBLEY

Appendix C: List of participants

Armenia	
PETROSYAN, Artem	Ministry of Energy Infrastructure and Natural Resources
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Austria	
NECKEL, Wolfgang	Nuclear Engineering Seibersdorf GmbH
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ABDERRAHIM, Hamid Aït	Belgian Nuclear Research Centre (SCK•CEN)
BLOMMAERT, Walter	Federal Agency for Nuclear Control (FANC)
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SHI, Xisen	
XIAOXIA, Fu	
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KAPLAN, Ivo	Radioactive Waste Repository Authority (SÚRAO)
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CHAPOUTIER, Nicolas	Framatome
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GAGNER, Laurent	Orano
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GARRS, Gareth	LLW Repository Ltd
GUPPY, Richard	Radioactive Waste Management Ltd/Nuclear Decommissioning Authority (NDA)
United States	
MCCAUGHEY, William	US Department of Energy (DOE)
SWIFT, Peter	Sandia National Laboratories (SNL)

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BERTHELEMY, Michel	OECD Nuclear Energy Agency (NEA)
BRANDAUER, Martin	OECD Nuclear Energy Agency (NEA)
BRUNETTI, Gianfranco	European Commission
CHANG, Sunyoung	OECD Nuclear Energy Agency (NEA)
CLARK, Alyssa	OECD Nuclear Energy Agency (NEA)
DE BOISSIEU, Elena	OECD Nuclear Energy Agency (NEA)
DURAND, Aurélie	European Commission
GUSKOV, Andrey	International Atomic Energy Agency (IAEA)
HIGASHIHARA, Tomohiro	OECD Nuclear Energy Agency (NEA)
IVANOVA, Tatiana	OECD Nuclear Energy Agency (NEA)
KOIZUMI, Madoka	OECD Nuclear Energy Agency (NEA)
KURATA, Takune	OECD Nuclear Energy Agency (NEA)
LI, Jinfeng	OECD Nuclear Energy Agency (NEA)
LOA, Wei-Whua	OECD Nuclear Energy Agency (NEA)
MORITA, Shin	OECD Nuclear Energy Agency (NEA)
MUROYA, Nobuhiro	OECD Nuclear Energy Agency (NEA)
RAGOUSSI, Maria-Eleni	OECD Nuclear Energy Agency (NEA)
SMADJA, Lisa	OECD Nuclear Energy Agency (NEA)
SUYAMA, Kenya	OECD Nuclear Energy Agency (NEA)
TADESSE, Rebecca	OECD Nuclear Energy Agency (NEA)
Williams, Porsche	OECD Nuclear Energy Agency (NEA)
ZACCAI, Henri	World Nuclear Association (WNA)