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PROCEEDINGS SERIES

Nuclear Decommissioning: Addressing the Past and Ensuring the Future

PROCEEDINGS OF AN INTERNATIONAL CONFERENCE
Vienna, Austria, 15–19 May 2023

NUCLEAR DECOMMISSIONING: ADDRESSING THE PAST AND ENSURING THE FUTURE

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PROCEEDINGS OF AN INTERNATIONAL CONFERENCE ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
IN COOPERATION WITH
THE OECD NUCLEAR ENERGY AGENCY,
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FOREWORD

Decommissioning is the final stage in the operational life cycle of any nuclear or radiological facility. Decommissioning is currently being implemented in many countries, and therefore wide experience already exists concerning the necessary infrastructure and frameworks to support these programmes.

There are valuable lessons to be learned from completed and ongoing decommissioning projects, covering a wide variety of facilities (e.g. educational and research facilities, fuel cycle facilities, research reactors, nuclear power plants), including decommissioning of facilities that experienced nuclear or radiological incidents or accidents.

The IAEA has a unique global role in facilitating the adoption of emerging nuclear technologies, coupled with greater harmonization of regulations to enable safe and efficient decommissioning when the time comes. As an example, nearly half of the nuclear power reactors that are in operation today are anticipated to enter the decommissioning process by 2050. Each facility could take 20 years or more to fully decommission. The IAEA assists countries in ensuring that decommissioning work is conducted within the appropriate technical and regulatory frameworks, by promoting safety standards and good international practices through workshops, networks, expert missions, publications and conferences, among other initiatives.

The growing decommissioning demand worldwide will benefit from both completed and ongoing projects, but the increasing number of facilities to be decommissioned concurrently in the coming decades raises new challenges in terms of the infrastructure, resources and expertise that will be needed to support their decommissioning. Sustainability and circular economy principles demand that decommissioning be implemented safely, in a cost effective and environmentally sensitive manner and while considering the future uses of the sites.

The IAEA ensures that lessons and innovations from successful decommissioning projects are shared, including through the International Decommissioning Network. It also plays a vital role in ensuring safety, even under challenging circumstances. The Fukushima Daiichi nuclear accident in 2011 required innovations such as the use of cosmic ray muon mapping to help locate the damaged fuel and the building of a frozen subterranean wall to prevent groundwater from seeping into contaminated water inside the reactor buildings, as well as the use of robotics for work in areas with limited access. These innovations helped boost effectiveness and efficiency while minimizing the danger to workers, the general public and the surrounding environment.

To this end, the IAEA organized the International Conference on Nuclear Decommissioning: Addressing the Past and Ensuring the Future, from 15 to 19 May 2023 in Vienna. This conference served as a forum for exchanging science based information on the topics of decommissioning nuclear and radiological facilities and conducting objective discussions on the opportunities and challenges involved in the development of safe, secure and efficient processes. The major themes of the conference covered (i) the global status of decommissioning, (ii) the policy, governmental and regulatory framework, (iii) competence development for decommissioning, (iv) the importance of stakeholder engagement and site repurposing, (v) the management of waste from decommissioning, (vi) international collaboration initiatives, (vii) preparation for decommissioning, (viii) decommissioning programme development and implementation, (ix) completion of decommissioning, (x) decommissioning of fuel cycle facilities, (xi) knowledge management, (xii) digitalization, robotics and remote operations to support decommissioning, (xiii) decommissioning of small facilities, and (xiv) technological advances for characterization and dismantling.

The conference was organized by the IAEA, with the participation of IAEA Member States and international partners, including leading international organizations involved in the nuclear industry, such as the European Commission (EC), European Union (EU), European Bank for Reconstruction and Development (EBRD), Electric Power Research Institute (EPRI), OECD Nuclear Energy Agency (OECD/NEA) and World Nuclear Association (WNA).

These proceedings include summaries of the plenary and technical sessions, panel discussions and side events, as well as the full text of the statements delivered in the opening, closing and high level plenary sessions of the conference, with all presentations and papers, where submitted, available on-line as supplementary files.

The IAEA would like to express its appreciation to the members of the International Scientific Programme Committee and the Secretariat of the Conference for convening and organizing this conference. The IAEA officers responsible for this publication were O. Mykolaichuk, V. Michal and H. Mrazova of the Division of Nuclear Fuel Cycle and Waste Technology and V. Ljubenov of the Division of Radiation, Transport and Waste Safety.

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1. EXECUTIVE SUMMARY

1.1. INTRODUCTION

The anticipated increase in the number of nuclear facilities to be permanently shut down between now and 2050 means that significant resources — human, as well as financial — will be needed to implement the necessary decommissioning programmes, some of which will run to the end of this century. For commercial facilities, funds have generally been set aside during operation to cover the costs of decommissioning. However, the decommissioning of a significant number of facilities is funded either directly or indirectly from State resources. In these cases, the availability or not of sufficient funding may delay such implementation. A large, highly skilled workforce will also be needed to implement future decommissioning programmes. Encouraging young people to pursue careers in decommissioning and related materials and waste management is one of the most significant challenges currently facing the nuclear industry.

Decommissioning results in the generation of large quantities of materials and waste, most of which have not been radioactively contaminated. Efforts are being made to ensure that a large proportion of this non-contaminated waste, including metals, concrete debris, and soil, is recycled, or reused, in line with the circular economy principles. In some cases, rubble from demolition can be used to fill the spaces that are created by the removal of structures below ground level. The greater use of metal recycling, including for reuse within the nuclear industry, is also being considered.

A large proportion of the material that has been radioactively contaminated — which typically represents about five per cent of the total material generated by decommissioning — contains very low levels of radioactivity and is suitable for disposal in near surface repositories. A small proportion of the radioactively contaminated material (less than five per cent of the total material generated) is not suitable for release from regulatory control or for near surface disposal, owing to high levels of activity and the presence of highly active or long-lived radionuclides; this material will ultimately be safely disposed of in underground disposal facilities.

Given the extent of future decommissioning needs and the potential for new and emerging technologies to improve the efficiency of decommissioning, it is likely that there will be significant changes in project implementation in the near future, once such technologies are widely adopted and their cost-effectiveness has been proven. Developments include the application of digital techniques to support planning and to optimize project implementation; the greater use of remotely operated tools, including drones and robotics, for the segmentation of plant components, material handling, measurements, and decontamination; the increased automation of waste management activities; and the use of artificial intelligence.

The role of the supply chain is crucial in ensuring that future projects are implemented as effectively and efficiently as possible. There is already evidence of supply chain organizations developing expertise to provide a wider range of decommissioning services in fields such as research and development on new technologies, engineering, dismantling and radioactive waste management. A recent development specific to nuclear power plant decommissioning has been the emergence of decommissioning consortia that bring together specialized companies in order to implement entire decommissioning projects within a fixed budget, by following standardized approaches and assuming all associated project risks.

A short movie with title “Nuclear Decommissioning Film”, made at the occasion of the Conference, has been projected to highlight that decommissioning of a nuclear facility after the end of its operating life is a core element of responsible life cycle planning. Decommissioning activities, set to increase in the coming years as ageing nuclear power plants are retired, include decontamination and dismantling of structures, leading to the removal of regulatory controls so that a facility and site may be reused. The IAEA, hosting an International Conference on Nuclear Decommissioning in Vienna, supports Member States in such activities. The film specifically introduced an example of a project that is currently under way in the French town of La Hague, where a former fuel processing plant is being decommissioned.

1.2. SUMMARY OF THE CONFERENCE

The Conference explored the achievements, challenges and lessons learned in the decommissioning of nuclear facilities, highlighting current priorities and needs and sharing information on strategies and approaches to enhance safety, security and cost-effective implementation of programmes. The scope of the Conference is to address variety of aspects of nuclear decommissioning. The Conference promoted the discussion of cross-cutting topics such as national framework establishment, waste management integration, circular economy principles implementation, developing of integrated approaches with other topics in the different sessions rather than being stand-alone topics.

The following topics were covered during the week:

Global Status of Decommissioning: this session focused on the current state of decommissioning across the Member States. Overview of the global challenges and trends in decommissioning was presented by the IAEA [1]. Decommissioning is currently being implemented in many countries, and therefore wide experience already exists concerning the necessary infrastructure and frameworks to support the programmes.

Policy, Governmental and Regulatory Requirements: this session focused on the relevance of Policy, Governmental and Regulatory Requirements to facilitate proper management of decommissioning and provided for the sharing of practices and experiences. It examined approaches to regulate shutdown of nuclear facilities more effectively, provision and implementation of lessons learned, engagement of public stakeholders, management of funds for decommissioning, and considerations for development of new strategies in design of nuclear power plants and other nuclear facilities.

Competence Development: this session reviewed well-established methods and approaches to competence development to support decommissioning, the roles of project management and leadership in nuclear decommissioning, education and integrated systems for personnel training required for decommissioning activities.

Management of Waste from Decommissioning: this session covered different approaches and methodologies for specific clearance of materials for disposal and landfill, implementation of methods for optimization and minimization of radioactive waste from decommissioning, development of solid radioactive waste monitoring systems. The implementation of circular economy was discussed during of presentations in this session.

Preparation for Decommissioning: this session was focused on the transition to decommissioning phase, implementation of different principles for the transition preparation and definition of a roadmap on preparing the transition to decommissioning.

Programme Development and Implementation: this session addressed the approaches being used for decommissioning and dismantling of nuclear facilities. Current status and prospects of decommissioning programmes were presented, the fleet approach for dismantling of large, activated components of commercial nuclear reactors were discussed. The session focused on the achievements in the decommissioning programmes, including management of aging infrastructures, modelling and optimization for segmentation of reactor pressure vessels and reactor internal structures applied to support decommissioning of several nuclear facilities.

Completion of Decommissioning: the session reviewed the final phases of decommissioning. The presentations were focused on defining the end states, cleaning up and achieving the final state approaches, regulatory challenges in termination of license, and factors influencing duration and finalization of the decommissioning.

Decommissioning of Fuel Cycle Facilities: this session was dedicated to common challenges in decommissioning of research facilities, reprocessing plants, uranium dioxide production facilities and different high hazard legacy facilities. Optimization of costs and risk minimization were touched respectively to different types of the facilities.

Knowledge Management: this session comprised themes on enhancement of knowledge development, knowledge transition, and data management. Focus was given to different systems and tools supporting the knowledge management, such as wiki system, text databases, taxonomy for decommissioning, and knowledge-based governance of decommissioning programmes.

Digitalization: this session covered different innovations, ongoing and planned research in application of digital tools to support decommissioning. It examined digital technologies, e.g., augmented reality, virtual reality, 3D constructions and localization options, and estimation of radioactive source distribution using single gamma cameras. The overall impact and changing environment towards digital tools implementation were largely discussed. During the session was expressed the positive impact of the digital transformation on achievement of sustainable decommissioning, enhancement of safety, supporting risk mitigation and increasing the effectiveness and efficiency of decommissioning.

Robotics and Remote Operations: this session reviewed experiences with application of robotics and remote operation tools, where specific focus was given to analyse the status, barriers, and cost-benefits for decommissioning and radioactive waste management. The idea of implementing transferable technology for remote decommissioning, using of the proven technologies from other industries and demonstration of new emerging technologies was presented. More and more often the new technologies, e.g., artificial intelligence, autonomous mobile robots, and machine learning, are part of the decommissioning implementation.

Decommissioning of Small Facilities: this specific session was focused on small nuclear facilities decommissioning, experiences, lessons learned, and presented case studies. Implementation of different approaches and technologies for decommissioning of small facilities is considered often as an opportunity for testing in small scale with the intention to transmit the knowledge and lessons learned to decommissioning of large facilities.

Technological Advances for Characterization and Dismantling: this session reviewed well-established methods and approaches for the characterization of materials to support accurate planning and optimize segmentation of large components. Innovative techniques and technologies used for radiation visualization, processing of radiation input data and implementation of real time 3D mapping and characterization of hazardous environments were presented.

Additionally, a several panel discussions and side events were held covering international cooperation to advance decommissioning projects, engaging stakeholders and repurposing sites, Euratom activities on the decommissioning of nuclear facilities, joint effort on implementing the decommissioning project as a collaboration between Lithuania, Norway and the IAEA, the IAEA collaborating centres on decommissioning, update on the Fukushima Daiichi decommissioning, the role of the supply chain and technological innovation, and the discussion on attracting the young generation to nuclear decommissioning.

An Exhibition organized during the week allowed the participants to see the latest developments on the products and services on nuclear decommissioning.

The Conference was implemented in as an in-person event with the possibility to connect virtually. The IAEA Conference App was used to provide updates in the Conference programme, notifying the upcoming sessions during the week, and communicating questions by the chat function. All sessions, both those in the plenary room, or in the side event rooms, were streamed in real-time mode on the App and saved as records for the registrants in the same App. Q&A sessions also took place after the panellists' introductory presentations.

1.3. OBJECTIVES AND STRUCTURE OF THE PROCEEDINGS

Designed to be an output of this international conference on nuclear decommissioning, these proceedings are expected to serve as a source of information for a wide audience, including decision makers, regulators, experts, scholars, the public and other stakeholders from Member States and international organizations involved in the nuclear decommissioning, nuclear energy, environment, economics, and social development areas.

The publication contains the summary of the conference president, the major findings, challenges and conclusions from the topical plenary sessions, technical sessions, side events and panel discussions. In addition, the opening session, executive summary, keynote papers (where available), summaries of the technical sessions and panel sessions, the summary of four side events and of the closing session are included.

1.4. KEY OUTCOMES OF THE CONFERENCE

The key outcomes of the Conference are presented below. Each topic will be discussed in more detail in the related session descriptions.

The need to change the regulatory approaches for decommissioning from prescriptive ones to dynamic and more flexible ones has been recognized in several countries and actions are underway to establish new approaches, supported by visual communication tools, taking into account the views of stakeholders. Early engagement with the regulatory authorities was emphasised and it was noted that regulators can be an important catalyst for using technologies that provide demonstrable safety benefits. Continuous efforts are necessary to advance the establishment of national policies and strategies for decommissioning and waste management.

The integration between decommissioning and waste management continues to be the most important element to promote effective decommissioning and provide optimal management of waste arising from the decommissioning avoiding repacking or multiple handling. The practices also show that countries with clearly defined radioactive waste management policies facilitate their decommissioning activities more effectively. Optimization of waste management, waste volume minimization, re-classification to lower categories where appropriate are important elements in the overall decommissioning process. Early incorporation of waste characterization and implementing of flexible approaches in the planning of waste management from decommissioning can assist in decision making on management methods. Using the operators that are still at the site will benefit the characterization results, it is important to identify and preserve the operational and historical knowledge. Automation and modularity for handling, sorting and decontamination processes, especially in legacy nuclear sites are enhancing efficiency of decommissioning. The concept of a circular economy permeated many of the discussions during the conference.

Optimization is an important trend in decommissioning to deliver work on both large and small projects more efficiently, making best use of resources. The fleet approach to build once and deploy several times was presented by several countries and organizations. Management of a fleet of sites or fleet of reactors was discussed as well as the methods and analyses approaches used to best achieve efficiency in decommissioning programmes. Implementation of national programmes for decommissioning and radioactive waste management provides opportunities as well for international cooperation and, sharing lessons learned from executed decommissioning programmes. The effort to develop once and re-use multiple time was emphasized. For example, development of the project plan, supporting documents, and technical solutions for one site, one core or other components could be re-used, with or without adaptations as appropriate. In this context the national and international project lessons learned, and experiences shared plays a significant aspect in achievement of effectiveness and efficiency in decommissioning and waste management.

Several sessions discussed important topics, such as the adoption of new and emerging technologies to support decommissioning. Visualization tools, to improve collaboration and planning, the use of digital twin models to make the work safer and more efficient, to assist in material handling, mock trials, and to guide workers in the field to avoid hazards. Despite significant number of digital tools for mapping and displaying of radiological conditions available on the market, the implementation in large scale is still at a relatively low level. Development of tools for radiological characterization of building and materials is still underway. Digital tools for smart planning are bringing new options for more optimal and accurate planning and preparing of activities in decommissioning, use of digital tools leads to enhancing the physical walkdowns and reducing time. It was recognized that looking to other types of industries to gain from the applications of advanced technologies brings the benefit in usage of proven and workable technology. The adoption of digital technologies and robotics depends on a number of factors, which are still being addressed, including the regulatory acceptance and demonstration of cost benefits to users. Cost benefit analysis is driving the decision process for deployment of the advance technology into the project. Collaboration between organizations working in this field is crucial, both to address the aspect of making-first-move and to avoid the situation of unnecessary duplication of development work.

It has been demonstrated that the increased number of decommissioning projects requires continuous effort in competence development, knowledge management and knowledge preservation. It was noted that these efforts would benefit greatly from enhanced international cooperation. Several international research and innovation project related to waste management and decommissioning were recognized and it was emphasized that international initiatives related to characterization, dismantling, and waste management are supporting the effectiveness of decommissioning.

2. OPENING SESSION

2.1. OPENING STATEMENT BY THE INTERNATIONAL ATOMIC ENERGY AGENCY DIRECTOR GENERAL

Rafael Mariano Grossi
Director General of the International Atomic Energy Agency

Distinguished delegates, colleagues, welcome to the International Conference on Nuclear Decommissioning: Addressing the Past and Ensuring the Future. It is lovely to see everyone back together in person.

As more countries embrace nuclear power to improve energy security and mitigate climate change, the challenge of successfully decommissioning nuclear facilities is set to grow. A crucial factor in meeting that challenge is to address it up front. Today, 56 reactors are under construction worldwide, and many countries are putting into motion plans to expand their nuclear fleet or build their first nuclear power programme. That will mean more decommissioning down the line. When it comes to the end of life of a nuclear reactor, forethought and innovation play pivotal roles. New nuclear power plants, including those with small modular reactors (SMRs), are being designed with their decommissioning in mind - designers are planning how their nuclear power reactors will be dismantled even before construction begins.

The IAEA has a unique global role in facilitating the adoption of emerging nuclear technologies, coupled with greater harmonization of regulations to enable safe and efficient decommissioning when the time comes. Even as we look to the future, the past is rapidly catching up with us. Though more and more countries are considering life extensions of nuclear power plants, many will be decommissioned over the coming years.

In fact, almost half of the 423 nuclear power reactors the world relies on today are expected to enter the decommissioning process by 2050. Each one could take up to 20 years or more to fully decommission. The IAEA assists countries in ensuring that decommissioning work is carried out within the appropriate technical and regulatory frameworks, by promoting safety standards and good international practices through workshops, forums, missions and publications.

Decommissioning requires teams of experts with specialist skills in engineering, physics, chemistry, technology and project management. It is the final stage in the life cycle of any nuclear facility. That is true not just for nuclear power reactors, but also research reactors and other fuel cycle facilities and for thousands of smaller medical, industrial and research facilities that exist in all the member States. It is essential that the work of dismantling facilities and releasing their sites from regulatory control for reuse is carried out safely, cost-effectively, and with attention to sustainability and stakeholder engagement. For that we need the policies, strategies, regulatory infrastructure, the technology and people with the right skills.

The increasing focus on achieving a circular economy is leading to exciting innovations in the nuclear decommissioning field. More material is being released from regulatory control and recycled, while cost savings are being made and timeframes condensed. Meanwhile, new technologies such as data science, artificial intelligence, robotics drones are bringing greater effectiveness and safety to decommissioning activities. The IAEA maintains a set of internationally agreed safety standards on decommissioning and provides assistance to Member States on their application, also ensures that lessons and innovations from successful decommissioning projects are shared, including through our International Decommissioning Network. The Fukushima Daiichi nuclear accident in 2011 required innovations, such as the use of cosmic-ray muon mapping to help locate the damaged fuel and the building of a frozen subterranean wall to prevent groundwater seeping into contaminated water inside the reactor buildings, as well as the use of robotics for work in areas with limited access. These innovations helped boost effectiveness and efficiency while minimizing the danger to workers, the general public and the surrounding environment.

Safety is crucial, but it is not the only consideration that we need to take when it comes to decommissioning. Safeguards and security are key to the decommissioning process. The IAEA's expert teams are on hand when spent fuel is moved or disposed of to verify that materials used in nuclear plants are not diverted from peaceful use. Decommissioning should never be a proliferation opportunity. When it comes to decommissioning these activities and the way we deal with it internationally is key and essential. Many of your countries are counting on nuclear to help them decarbonize, to help them meet their national decisions and make them comparable with international commitments like those including in the climate change in the context of the Paris Agreements. We also deal with a world facing energy security issues where geopolitical factors are having an unexpected influence and countries will increasingly rely on nuclear. But none of this will be possible if we do not prepare ourselves us with the policies and strategies for nuclear energy and of course decommissioning that is an essential part of that.

International cooperation and knowledge-sharing supported by the IAEA are vital to meeting the growing global demand for nuclear decommissioning. It is important to get the back end of the nuclear fuel cycle right so that nuclear can play a full and sustainable role in addressing the world's most pressing challenges, from mitigating climate change and air pollution to providing energy security and the nuclear medicine needed to fight cancer and heart disease.

2.2. OPENING STATEMENT BY THE MINISTER OF ENERGY OF BELGIUM

Tinne Van der Straeten
Minister of Energy, Federal Government of Belgium

Good morning to all of you, to conference Chairwomen, director general, ladies and gentlemen, distinguish representatives, thank you Director General for your speech and as you said that this is a good example as we are sitting here, doing all activities as one team. There is another aspect that you did not mention about this table is also an example of balance of gender. I know you dear Director General don't speak a lot about it, but it is visible that you are leading the IAEA with the gender balance in the mind, therefore I take the opportunity to express it here in front of us.

This is a special conference today about international cooperation on dismantling and decommissioning. We have in Europe for a long way been paving the way to security of electric energy for many, many years now. Not only electrical energy but as well for other nuclear applications like medicine. And now comes the time for us to consider the dismantling of older facilities, in the environmentally responsible way and ensuring, the principles of circular economy are maximised. Most importantly, if we want to succeed in this field, we have to reinforce our international cooperation to enable the upscaling of new innovative applications to meet industrial standards.

These issues that we are dealing with today and this week, are issues that go far beyond national borders. In Belgium we are tackling dismantling and decommissioning of five of our nuclear power plants, also research reactors and cyclotrons. We have a skill set that is excellent but is not possible to address everything on our own. In my country we have a very important player in decommissioning which was already involved in decommissioning project in Bohunice and also Kozloduy just to name these, but there are fields in where much remains to be done. It is complex for researchers and enticing for engineers. It is not only about decommissioning it is also about development of new technologies, going above and beyond pilot projects. So, it is also about industrial value chain for decommissioning and dismantling that will provide confidence for the future as we dismantle the power plants and other facilities like cyclotrons in the years to come. We must also address new nuclear power plants that will be build, some small and in other countries larger. They have to be built with decommissioning in mind to provide confidence to our society and enhance public support for nuclear energy.

In my country we have research centre SCK CEN and they have dismantled over the past years the research reactor BR3. This was the first pressurized water reactor in the European Union that was operated until the 90'sand is almost fully dismantled. When we celebrated 70 years of SCK CEN, we all received a small piece of this research reactor. I still have it in my office, and it is an example of how at the end you can reuse decontaminated material. What I learned, looking at this project, is not just about large-scale dismantlement but also the need for highly skilled technologist to do this work. Technical expertise in risk mitigation, waste management, projects validation, very importantly, characterization; all these sub-fields are needed when during dismantling and decommissioning.

We saw also in our country that this will lead to a broad stakeholder network with highly specialized companies also willing to share their expertise. One of them is also presenting here during the week is Cyclade. When we are executing those activities, we need to keep an eye on the ball, and not forget harmonization of legislation and the correct way of categorization of waste.

Many of nuclear power plants and other installations will be dismantled and it is important to have plans in place to not burden our societies needlessly. Standardization maybe is the beginning of the circular model, and when we arrive at the level of legislation internationally, it will help us address legacy issues. I also plead for decommissioning and dismantling by design as way forward to create the future for all nuclear applications, not only for the electricity but also for the medical field. We need to know who is responsible, who is paying for what, and when, to avoid imposing major costs on society at the end of life for the facility. We also have to look at costs of decommissioning and dismantling of medical application facilities which are often hidden costs. It seems to me that in the past we have not addressed these issues, and I say this as coming from a nuclear country. We were one of the first to build nuclear power plants, and we are also regarding medical isotopes, we are ones of the biggest. It surprises me that we are not as far advanced in decommissioning and dismantling as I thought we should be, therefore conference like this is very important also to policy makers like me. We can only work on harmonization of policies if we have this bottom-up approach from experts, from researchers to guide us what is possible, and then comes of course to work to have policies in place that can be also copied to other countries and can be facilitated by for example IAEA.

I am absolutely convinced that during the week we have all the brain power gathered to be able to find new approaches and please consider that future of nuclear applications can only flourish if we introduce decommissioning and dismantling by design. I wish you very fruitful week, I look forward to the conclusions and recommendations that I can consider implementing into our Belgium national policies.

2.3. OPENING STATEMENT BY THE PRESIDENT OF THE CONFERENCE

Laurence Piketty
Deputy CEO, CEA – Alternative Energies and Atomic Energy Commission, France

Good morning, everybody, Director general, honourable minister, distinguished guests and speakers and dear colleagues, it is great honour for me to speak to you today and to chair the IAEA International Conference on Nuclear Decommissioning. This event highly benefits from your individual participation, and I am very grateful for your commitment and interest in decommissioning. It is an exciting subject for which I have dedicated many years of my career. I would also like to express my warmest gratitude to the organization committee for offering me this chairmanship and for the opportunity to meet and discuss together the status and outlook of this major subject.

In 2016, our global community of experts met in Madrid for five days at the conference on Advancing the Global Implementation of Decommissioning and Environmental Remediation Programmes (D&ER). More than 540 people were involved, coming from 54 countries and 4 International organizations. Several objectives and recommendations were identified. Firstly, the need to establish decommissioning and environmental remediation policies and strategies where they did not exist including by putting in place a propriate legal and regulatory frameworks and plans for dealing with the aftermaths of nuclear or radiological accidents or incidents. Secondly, the importance to implement D&ER programmes at the earliest possible opportunity taking advantage of advance planning and making best choice of limited financial resources. Thirdly, to take holistic approaches for the management of waste from D&ER, while encouraging development of greater international training opportunities for young D&ER professionals. Finally, to pursue awareness for the growing needs to address legacy of past nuclear activities. Indeed, we must not forget that the future of nuclear industry also depends on responsible management of the past. And especially today when we need all the carbon-free energies, especially nuclear energy, to fight against the climate change.

It has been seven years since these recommendations were formulated and I think it is a good time to get together again and take stock of the actions that were taken and to look at the challenges to come. To start our reflections allow me to say few words on France's approach in addressing the diversity of facilities in our decommissioning eco system. To respond to the challenges that come with the variety of sites that we had to dismantle, France, and in particular CEA, decided to come back to R&D to identify novel and advanced solutions. Over seventy years ago France started development of its nuclear industry, including all steps of the nuclear fuel cycle. In the French decommissioning sector ORANO, EDF and CEA are the key operators. Those three operators are working in close collaboration on decommissioning and remediation programmes with ANDRA, the national agency for radioactive waste management, along with several companies that are involved in decommissioning.

Operators are often investing hundreds of millions of euros per year and dedicate thousands of employees to decommissioning activities. This is a reminder that decommissioning generates significant and sustained economic activity. Often, we have to dismantle a broad range of facilities some of which age back to the 50s, including different types of reactors, technologies, hot laboratories, fuel cycle facilities, and waste treatment plants. Each dismantling project is highly specific, and we need to prioritize the work among facilities according to their level of radioactivity, radiotoxicity, and robustness as request often by nuclear safety authorities.

Dismantling projects are time consuming, however we must praise successes when we see them. For example, in France, the CEA Grenoble, is a unique case from a nuclear dismantling perspective as it involved the whole site with the goal to entirely repurposed it. After many years, this dismantling project just ended in March 2023 with a decision of the nuclear safety authority to withdraw all the facilities from our nuclear facilities list. So, this is a concrete demonstration of one way to go.

Throughout this week we will hear that these topics are major interest for many countries, not all of them have opted for the same approach and it is in everyone’s interest to get together on regular basis to share our experiences. We should bear in mind that any country with nuclear facilities with encounter these challenges at same point and we should encourage practitioners from as many countries as possible to join this discussion. International cooperation is a necessity in order to coordinate research and development and decommissioning and environmental remediation, and the exchange of information, knowledge and experiences among decommissioning experts. I praise the participation of international organizations today as it allows building multi-organizational approaches to an international project to combine competencies and bring synergies.

Decommissioning is not an unfettered path and does not replace overnight. As it was said earlier, dismantling facilities is a time-consuming business with high financial stakes, requiring careful management of skills. Each step involves detailed administrative and technical assessment which is monitored closely by the nuclear safety authority before any official authorization can be granted. It is also our responsibility to make a good use of the long duration of dismantling projects to develop technological innovations to strengthen our expertise, and therefore avoid passing on this responsibility to the next generations. For this purpose, we need to identify future needs, to anticipate societal development, and the speed technology changing and the promising benefits from robotics and artificial intelligence, need to be exploited by the nuclear industry in order to remain competitive and to meet future challenges.

I would like to underline this point, the new generation inclusive is an asset, upon which we have to rely, and I deeply believe that this is crucial to make the decommissioning industry attractive for young talents. We should invest more in education, on sustainable development, which would include the role of decommissioning, to raise awareness among young researchers in this field.

This conference is great opportunity to work together to address those many challenges with all the expertise and resources that we have at our disposal today and within all IAEA Member States. We will discuss achievements and challenges in the dismantling of nuclear facilities and with no less than 15 sessions, 5 panels and 3 side events. The next five days will give us plenty of opportunities to share views and identify objectives and recommendation and strengthen our networks. The main topics will be covered and organized from the broadest to the most specific topics in order to have a global vision on the needs and then to reflect on the way to implement technological evolutions in an operational way.

To conclude, I am sure that working together we have all that is needed to implement reliable, sustainable, and long-term strategies to face the challenges ahead. Together we have extensive expertise in many fields, complementary skills, and great capacity to foster innovation. We all agreed that the decommissioning of nuclear sites should not be left to future generation, this week is a great opportunity to work together and to move forward to more promising future. I wish you success in your discussions during this week. I am sure that they will be very fruitful when we review this conference on Friday.

3. SESSION 2: GLOBAL STATUS OF DECOMMISSIONING

3.1. SUMMARY OF THE SESSION

The decommissioning of nuclear power plants, research reactors, and fuel cycle facilities is a domain of growing importance, especially given the likely increased rate of the permanent shutdown of these plants over the next couple of decades. For example, two-thirds of more than 400 nuclear power reactors have already be operation for over 30 years. Considering this the nuclear industry will need more professionals working in decommissioning and attracting younger generation of workers to the industry is a key issue.

The number of nuclear facilities that require decommissioning is expected to increase significantly over the next 10 to 20 years. There is no simple relationship between the age of a facility and the timing of permanent shutdown, as multiple factors, including political and economic forces, can influence this decision. The timing may also depend on maintenance, refurbishment costs, and electricity market conditions, among other things. However, government policies are increasingly promoting strategies for immediate dismantling in line with sustainability principles, so that the burdens associated with decommissioning, such as the management of waste, are not passed on to future generations. The potential of sites to be reused for the construction of new nuclear facilities or other purposes is also an important consideration.

The anticipated increase in the number of nuclear facilities to be permanently shut down between now and 2050 means that significant resources — human, as well as financial — will be needed to implement the necessary decommissioning programmes, some of which will run to the end of this century. For commercial facilities, funds have generally been set aside during operation to cover the costs of decommissioning. However, the decommissioning of a significant number of facilities is funded either directly or indirectly from State resources. In these cases, the availability or not of sufficient funding may delay such implementation. A large, highly skilled workforce will also be needed to implement future decommissioning programmes. Encouraging young people to pursue careers in decommissioning and radioactive waste management is one of the most significant challenges currently facing the industry.

Decommissioning results in the generation of large quantities of materials and waste, most of which have not been radioactively contaminated. Efforts are being made to ensure that a large proportion of this non-contaminated waste, including metals, concrete debris, and soil, is recycled, or reused, in line with circular economy principles. In some cases, rubble from demolition can be used to fill the spaces that are created by the removal of structures below ground level. The greater use of metal recycling, including for reuse within the nuclear industry, is also being considered.

A large proportion of the material that has been radioactively contaminated — which typically represents about five percent of the total material generated by decommissioning — contains very low levels of radioactivity and is suitable for disposal in near-surface repositories. A small proportion of the radioactively contaminated material (less than five percent of the total material generated) is not suitable for release from regulatory control or for near-surface disposal, owing to high levels of activity and the presence of highly active or long-lived radionuclides; this material will ultimately be safely disposed of in underground disposal facilities.

Given the extent of future decommissioning needs and the potential for new and emerging technologies to improve the efficiency of decommissioning, it is likely that there will be significant changes in project implementation in the near future, once such technologies are widely adopted and their cost-effectiveness has been proven. Developments include the application of digital techniques to support planning and to optimize project implementation; the greater use of remotely operated tools, including drones and robotics, for the segmentation of plant components, material handling, measurements, and decontamination; the increased automation of waste management activities; and the use of artificial intelligence.

The role of the supply chain is crucial in ensuring that future projects are implemented as effectively and efficiently as possible. There is already evidence of supply chain organizations developing expertise to provide a wider range of decommissioning services in fields such as research and development on new technologies, engineering, dismantling, and radioactive waste management. A recent development specific to nuclear power plant decommissioning has been the emergence of decommissioning consortia that bring together specialized companies to implement entire decommissioning projects within a fixed budget, by following standardized approaches and assuming all associated project risks.

In 2022 the IAEA invited students and young professionals to present innovative and original essays about decommissioning of nuclear facilities, in total we had 39 essays submitted from 23 Member States. Following a rigorous review of the essays, four winners were selected and invited to attend the conference to present their work. An award ceremony was organized as the Young Generation Challenge Winners Recognition event and held during the closing part of the Opening session. Three winners, participating in person, from the United Kingdom, the United States of America and Argentina were handed their diplomas by the IAEA Director General, together with HE Ms Tinne Van der Straeten, Minister of Energy of Belgium and Ms Laurance Piketty, Conference President.

3.1.1. Overview of Global Challenges and Trends in Decommissioning

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Abstract

This paper provides an overview of global challenges and trends in nuclear decommissioning together with examples of activities supported by the IAEA to support growing demands from Member States for assistance in this domain. Ongoing and recently completed projects provide many valuable lessons for the future, of relevance to a wide variety of facilities (educational and research facilities, fuel cycle facilities, research reactors and nuclear power plants), including decommissioning of facilities which experienced nuclear or radiological incidents and accidents. The increasing number of facilities to be decommissioned concurrently in the coming decades raises new challenges in terms of the infrastructure, resources and expertise needed to support their decommissioning. The experience gained from the implementation of decommissioning projects over recent decades provides valuable insights to enable future projects to be carried out with greater efficiency and with increased safety.

1. INTRODUCTION

The growing decommissioning demand over the last 20 years is evident from the number of nuclear facilities being permanently shutdown and entering the decommissioning phase and/or already decommissioned. The number of power reactor in permanent shutdown and under decommissioning has doubled over this period - from slightly less than 100 reactors in 2002 to close to 210 reactors in 2023 - while the number of reactors fully decommissioned, i.e., released from regulatory control, remains relatively low (currently 22).

Greater progress has been achieved with decommissioning of research reactors. Here, 450 reactors have been fully decommissioned, and 67 reactors are currently undergoing decommissioning, with a falling number of research reactors being shutdown for decommissioning each year. In addition, more than 150 nuclear fuel cycle facilities have been fully decommissioning and a further 74 are currently under decommissioning.

2. COLLABORATIVE PROJECT ON GLOBAL STATUS OF DECOMMISSIONING OF NUCLEAR INSTALLATIONS

In 2019 IAEA initiated a collaborative project on Global Status of Decommissioning of Nuclear Installations with the overall objective of collecting and analysing authoritative information on the current status and future evolution of nuclear decommissioning activities around the world. The project scope covers nuclear power plants, research reactors, fuel cycle facilities and waste treatment and storage facilities. The collaborative project was implemented between June 2019 to March 2022 with 5 Consultancy meetings and 3 Technical meetings organized with a strong support from the International Decommissioning Network.

Project implementation required the collection and evaluation of information on the current status and decommissioning plans for all facilities within the project scope, using an approach based on the collection and evaluation of information derived from a focused questionnaire and relevant IAEA databases – PRIS (Power Reactor Information System), RRDB (Research Reactor Database) and iNFCIS (Integrated Nuclear Fuel Cycle Information System).

The project outcomes were presented in IAEA Nuclear Energy Series No. NW-T-2.16 [1], published in March 2023 ahead of this conference. The report provides a global overview of nuclear facilities covered by the project, together with baseline information taken from the IAEA's databases. Considerations are presented on policy and institutional arrangements and on legal and regulatory frameworks for decommissioning. An overview and analysis of current decommissioning strategies was undertaken, including drivers for strategy selection and current major trends in strategy definition. The main factors impacting the implementation of decommissioning projects are highlighted, including a SWOT analysis (strengths, weaknesses, opportunities, and threats) and an analysis of major current trends in programme implementation. The report also includes a review of resources needed for decommissioning, including the size of the workforce together with the costs incurred to date, estimates of liabilities for future work and a summary analysis of technologies needed to deliver decommissioning projects, main current challenges, and overall conclusions of the project.

3. ISSUES, CHALLENGES AND TRENDS

Many nuclear facilities are likely be retired from service over the next 1-2 decades. The majority of NPPs and other nuclear facilities currently in service have been in operation for more than three decades. The decommissioning strategy applied to the majority of these facilities is expected to be immediate dismantling, i.e., the facility is dismantled as soon as practicable after shutdown. Some facilities will undergo a period of safe enclosure, which may last several decades, before proceeding with final dismantling. National policy is an important driver for selection of the decommissioning strategy, together with the waste management infrastructure and funding. There is nonetheless a general trend to earlier decommissioning licensing and reduction of ‘post-shutdown (transition)’ phase. Immediate dismantling is now being considered even for some graphite moderated reactors. Multifacility typically adopt an integrated site-wide approach to decommissioning.

Sustainability and circular economy principles – including minimizing the quantities of materials requiring disposal – are increasingly impacting decommissioning approaches, with government policy on these issues being an important driver. The development of a comprehensive waste management framework remains a challenge in many countries, including for high volumes of lightly contaminated materials and irradiated graphite, together with establishment of robust financing arrangements.

As the implementation of decommissioning programmes will continue for several decades it will be crucial that young professionals are attracted to work in the industry. This is one of the most significant current challenges facing the industry, and addressing it requires the adoption of best current approaches to training and competence development, including maximizing the use of digital technologies and better integration of knowledge management systems. Contracting skills and dismantling technologies are potential areas of weakness and need further attention.

As regards programme development and implementation, current important priorities include reducing time (i) between permanent shutdown and actual start of decommissioning, and (ii) between end of dismantling and final release from the regulatory control. Waste management infrastructure and supply chain represent important external threats. Effort is needed on improving approaches to supply chain management, including improvement of contractual approaches, and on learning from the other industries, such as from oil and gas or demolition industry. Decommissioning risk management and associated costing implications are other areas that may benefit from lessons learnt in other industries such as the above.

Technological advancements include better use of the project management tools, including simulations to optimize dismantling and waste management approaches, and greater use of robotics for physical and radiological characterization. Virtual and mixed reality technologies enable improvements in worker safety and overall decommissioning efficiency. The importance of considering decommissioning at the design stage of new nuclear facilities, including fusion facilities, small modular reactors etc., is emphasised. An important finding was also that further development is anticipated in approaches to segmentation and treatment of large components of nuclear power plants and developments in the field of materials and waste management of research reactors, together with technologies for site characterization and environmental monitoring.

4. SUPPORT PROVIDED BY THE IAEA

The IAEA provides variety of support to Member States to address decommissioning issues and challenges. Following is non-exclusive list of such supporting activities:

- Development of safety standards and technical guidelines;
- Establishment of the IAEA International Decommissioning Network (in 2007);
- Collaborative projects on different aspects of nuclear decommissioning;
- Wide support of capacity building in the IAEA Member States – workshops, training courses, technical meetings, eLearning tools, Technical Cooperation projects etc.;

— Expert missions, scientific visits, fellowships;
— Decommissioning Peer reviews – ARTEMIS (Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation) and tailored peer reviews based on the Member State request;
— Collaborating centres on decommissioning – recently (as of October 2023) are six centres approved in Europe and Asia;
— Intensive cooperation with other international organizations as well as national institutions;
— Joint Convention on the Safety of Spent Nuclear Fuel and Radioactive Waste Management (including decommissioning);
— Organization of webinars on decommissioning etc.

IAEA has organized a series of major decommissioning conferences to discuss achievements, challenges and lessons learned in the decommissioning of nuclear facilities, highlighting current priority needs and sharing information on strategies and approaches that enhance safe, secure, and cost-effective implementation of decommissioning programmes.

The first such conference was held in Berlin in October 2002 under the title 'Safe Decommissioning for Nuclear Activities' [2]. Outcomes of that conference resulted in multiple safety guides and technical reports published on decommissioning of large and small nuclear facilities, development of action plan on decommissioning, enhanced coordination with the European Commission and OECD Nuclear Energy Agency and development of first decommissioning databases and web-based tools.

The second conference was held in Athens in December 2006 with title 'Lessons Learned from the Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities' [3]. Suggestions from the conference were widely addressed through new IAEA guidelines and events, commonly considered graded approach to decommissioning and International Decommissioning Network established later in 2007.

The third Conference, 'Advancing the Global Implementation of Decommissioning and Environmental Remediation Programmes' [4], was held in Madrid in May 2016. Important follow-ups of the conference are, e.g., collaborative projects on decommissioning, development of eLearning tools, decommissioning peer reviews, IAEA Collaborating Centres on decommissioning, application of more holistic approaches to decommissioning and circular economy, and a focus on increased emphasis on attracting young professionals to decommissioning.

5. SECOND CYCLE OF THE GLOBAL STATUS PROJECT

The 'Global Status of Decommissioning' project has been the first attempt by the IAEA to undertake a comprehensive analysis of the status of decommissioning programmes worldwide, including plans for the future (in effect a 'pilot' study). Data collected and evaluated over the course of the project provides a significant improvement in understanding the global situation on nuclear decommissioning, particularly for power reactors.

The exercise has also highlighted data gaps that remain. The second cycle will enable an evaluation of progress as well as an in-depth analysis of trends on (i) policy – e.g. adoption of circular economy principles; (ii) strategy – e.g. addressing the anticipated timeframe for permanent shutdowns, decommissioning strategies being selected, time taken during major stages following shutdown towards release from regulatory control; (iii) organizational level – e.g. contractual arrangements; (iv) technologies – e.g. practical application of digitalization to support advanced remotely operated techniques.

The second cycle will also enable a more detailed analysis of resource needs for future decommissioning, including human and financial resource needs.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Global Status of Decommissioning of Nuclear Installations, IAEA Nuclear Energy Series No. NW-T-2.16, IAEA, Vienna (2023)

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Proceedings of the IAEA Conference "Safe Decommissioning for Nuclear Activities", Berlin, 14-18 October 2002, IAEA, Vienna (2003)

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Proceedings of the IAEA Conference "Lessons Learned from the Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities", Athens, 11-15 December 2006, IAEA, Vienna (2007)

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Proceedings of the IAEA Conference "Advancing the Global Implementation of Decommissioning and Environmental Remediation Programmes", Madrid, 23-27 May 2016, IAEA, Vienna (2017)

3.1.2. Decommissioning of Belgian Reactors: The Journey Begins

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Abstract

Belgium had 7 operational Pressurized Water Reactors (PWR) on 2 sites, Doel NPP and Tihange NPP, having jointly a net electric capacity of approx. 5927 MWe. In September 2022 and January 2023, the units Doel 3 and Tihange 2 were definitively shut down and entered a “Post Operational phase” (POP). The POP lasts +/- 5 years per unit and aims primarily at ensuring the defueling of the units before the start of the actual dismantling works. The Belgian safety requirements for nuclear installations require a “notification of permanent shutdown” for the nuclear reactors. This notification of permanent shutdown aims at describing the modifications made to the installations in order to guarantee the safe operation of the remaining safety functions of the reactor after its final shutdown and at describing the preparatory works for dismantling foreseen by the licensee during the post-operational phase. The paper gives an overview of the results of the review and assessment of the notification of permanent shutdown of these two reactors by the Belgian Regulatory Body in order to share its return of experience. The paper introduces also the preparatory works performed by the Belgian Radioactive Waste Management Organization on the decommissioning plans of these NPP units, including the preparation for independent oversight on radioactive waste production during decommissioning.

1. INTRODUCTION

1.1. Some Belgian actors

The paper will speak about several actors involved in the general preparation of the future decommissioning of NPP’s in Belgium:

- FANC, the Federal Agency for Nuclear Control, the safety authority;
- The General Regulations regarding the protection of the public, workers, and the environment against the hazards of ionizing radiation, laid down by Royal Decree of 20 July 2001 (GRR-2001 [1]) implements many articles of the Law of April 15th, 1994, and made the FANC, created by that Law, operational. The FANC constitutes the Safety Authority;
- Bel V, the technical subsidiary of the FANC;
- The FANC delegates to Bel V regulatory missions of inspections and assessments of nuclear installations in Belgium. FANC and Bel V form together the Belgian Regulatory Body;
- ENGIE Electrabel as the licensee and operator of the two nuclear power plants at Doel and Tihange;
- The “Organisme National des Déchets Radioactifs et des Matières Fissiles Enrichies” – “Nationale Instelling voor Radioactief Afval en verrijkte Splijtstoffen” (ONDRAF/NIRAS) (i.e., the national organisation for radioactive waste and enriched fissile materials).

1.2. NPP’s in Belgium and phase-out

The 7 reactors on the Doel and Tihange sites are operated by ENGIE Electrabel, a member of the ENGIE group.

Article 4 of the law of 31 January 2003 on nuclear energy phase out limited the operational period of four Belgian reactors (Doel 3 and 4, and Tihange 2 and 3) to 40 years, and to 50 years for Doel 1 and 2, and Tihange 1. The objective of the law is to ensure the nuclear phase-out of Belgium in 2025.

However, in March 2022, the Belgian government agreed to allow an additional 10-year long-term operation for the two most recent units (Doel 4 and Tihange 3) up to 50 years. Negotiations are still on-going, and the law of 31 January still has to be modified accordingly. The definitive shutdown dates for Doel 4 and Tihange 3 may thus be modified soon, as a consequence of the recent government decision.

The phase out law foresees definitive shutdown dates of the Belgian reactors as given in Table 1.:

TABLE 1. DEFINITIVE SHUTDOWN DATES OF THE BELGIAN REACTORS

Reactor	Shutdown date
Doel 1	15th February 2025
Doel 2	1st December 2025
Doel 3	1st October 2022
Doel 4	1st July 2025
Tihange 1	1st October 2025
Tihange 2	1st February 2023
Tihange 3	1st September 2025

2. PREPARATION FOR THE FINAL SHUTDOWN AND POST-OPERATIONAL PHASE

The post-operational phase begins on permanent shutdown of the NPP and ends 1) when all the fissile material is removed from the unit and the final cleaning of the spent fuel pool and related systems is performed, and 2) when the dismantling license is granted. The POP is expected to last some 3 to 5 years, mainly depending on the required spent fuel cooldown time specific for each NPP unit and the time needed to perform the complete defueling.

Since 2018, the FANC and Bel V exchanged with the licensee ENGIE Electrabel about the future decommissioning of its plants, with a focus on Doel 3 and Tihange 2 as these are the first units to be taken out of service end of 2022 and beginning of 2023 respectively. The objectives are to develop a structured and comprehensive approach on:

(a) The “post-operational phase”,

(b) The preparation of the dismantling licence;

(c) The discussion of the basic design of new facilities that will be needed on site to carry out the dismantling and process the dismantling waste.

2.1. Notification of permanent shutdown

The Belgian Safety Requirements for Nuclear Installations (SRNI-2011) [2] requires a notification of permanent shutdown. The article 17/1 of SRNI-2011, details the information that should be included in the shutdown notification to the FANC:

- The inventory of radioactive substances used during operation and radioactive waste from the operation to be removed (with their physical, chemical, and radiological characteristics, their quantities, and their intended destination);
- The measures to maintain the installations in a safe post-operational situation pending their dismantling (including any preliminary decontamination and disassembling operations) as well as the modifications to the installations planned during this period;
- The applied maintenance and control programme;
- The management of human resources in order to maintain the installations in a safe state;
- The provisional planning for decommissioning;
- The impact of dismantling on the facilities that remain in operation.

Regarding the notification of permanent shutdown, most of the discussion focussed on:

- The description of plant modifications during the Post Operational Phase (adaptations to the Safety Analysis Report (SAR) and the Technical Specifications);
- The definition of the design basis of the nuclear island (which includes the reactor building, the nuclear auxiliaries building, the building of the spent fuel pool) during the POP after permanent shutdown.

The FANC received the notification of permanent shutdown of Doel 3 and Tihange 2 on 1st April 2022 and 1st August 2022, respectively.

2.2. Definition of the "nuclear Island"

During the POP, the reactor is not operated anymore, and the spent fuel pool is progressively defueled so that the residual risks are decreasing in the installation. In this framework, the licensee proposes a reduction of the nuclear island, to focus on the SSCs that remains important to safety for fulfilling the remaining safety functions (decay heat removal, confinement & ventilation and fire protection). The other SSCs, not required anymore, can thus be abandoned gradually during the POP (de-energised or shut down after final shutdown, i.e., corresponding systems will be switched off and remain unpressurised and cold), which allows to optimize the maintenance, ageing and qualification activities within the installation. The definition and the implementation of the nuclear island in POP is a quite complex activity that requires to define adequate design basis and performs screening and scoping of all SSCs to ensure the full availability of the remaining safety functions in POP.

To optimize the safety functions by maintaining both an uncompromised level of safety and reasonable plant programs in POP, ENGIE Electrabel plans to optimize the nuclear island in POP. ENGIE Electrabel developed a structured approach for the definition and the establishment of the nuclear island in POP.

2.3. Preparatory activities

After the final shutdown (end of electricity production), post-operations activities will be performed during the Post-Operational Phase, still applying the operating license. The objective of the post-operations activities is to safely shut down the nuclear units within a predefined perimeter and until a predefined end state is reached.

Based on the notification of permanent shutdown, the regulatory body evaluated the activities that could be safely performed in the framework of the exploitation licence, i.e., without the dismantling license. Thanks to this approval, modifications to the installations will be processed according to the procedure of article 12 of the GRR-2001. The regulatory body could in this basis approve the principle of the following activities:

- The chemical decontamination of the primary circuit and related systems, in order to reduce the dose impact of future dismantling activities;
- The partial conversion of the turbine hall in a buffer storage of dismantling materials before further treatment and adjacent to the material & waste treatment part of the installations;
- The deconstruction of a cooling tower.

3. PREPARATION FOR DISMANTLING

3.1. Approval of decommissioning plans by ONDRAF/NIRAS

One of the general missions of ONDRAF/NIRAS (Radioactive Waste Management Organization) as laid down by law consists of the approval of decommissioning plans. Every nuclear operator submits a decommissioning plan of their facilities for approval to ONDRAF/NIRAS. The final decommissioning plan has to be submitted three years before ending operation at the latest. The decommissioning plan evolves from an initial plan towards a final decommissioning plan and more specifically from a cost evaluation of the decommissioning activities to a more industrial scenario of dismantling and material & waste management. Based on the nuclear phase-out law in Belgium, the Licensee has to progressively submit its final decommissioning plans and finalize several optimization exercises amongst others the management by ONDRAF/NIRAS of the radioactive waste resulting from the post-operational and dismantling phase. The reference program of the waste production (quantities, types of waste, timing of production) must be accordingly modified so ONDRAF/NIRAS can provide the necessary installations regarding treatment, conditioning interim storage, and final disposal options of the different radioactive waste types to ensure a safe and proper management.

A second topic includes the forward planning by the Belgian radioactive waste management organization in preparation for the oversight during the decommissioning. Belgoprocess, the subsidiary of ONDRAF/NIRAS and situated in Dessel, operates (or will operate) several waste management facilities. These include the installation for processing of low level waste, intermediate storage facilities for catA, catB and catC waste and the installation for production of monoliths. The catA monoliths are the final package for the near surface disposal site for low level and short-lived radioactive waste in Dessel. Based on the current forecasts this disposal site will receive its nuclear permit in 2023 and will be operational in 2027. Both the waste producer and ONDRAF/NIRAS can benefit by securing the compliance with the disposal criteria as soon as possible throughout the waste management process. Therefore ONDRAF/NIRAS is seeking to implement a methodology to perform independent controls on the site of the waste producer. This methodology is focused on verifying the radioactive waste compliance as much as possible upstream (closest to the creation of the waste) and thus before conditioning and disposal of the radioactive waste. These controls can be, but are not limited to, an independent sampling, radiological and non-radiological measurements, visual inspection of the radioactive waste packages, etc. Both the waste producer and ONDRAF/NIRAS needs to prepare accordingly whereby the frequency of these independent controls is depending on the pre-characterization performed by the waste producer and the risk of a specific waste type to exceed one or more disposal criteria.

3.2. Approval of dismantling license application by FANC

The dismantling of a NPP may not begin without a dismantling license for which the operator should apply to the FANC (article 17.2 of the GRR- 2001) In the framework of a dismantling license application, the licensee has to establish a Safety Report for Dismantling (SRD) for the FANC.

The content of the SRD and the final decommissioning plan is largely the same but the first is more focused on safety aspects and the second more on decommissioning costs, radioactive waste and financial provisions.

A structured exchange of information between FANC and ONDRAF-NIRAS via working groups allows both parties to gain a better understanding of current and future nuclear decommissioning projects and harmonize their work.

For FANC, the licensing for the dismantling of any facility follows the same licensing trajectory as any new facility, the process is described at art. 17.2 of the of the GRR- 2001. The application for a dismantling license shall include at least proposals from the operator on the following matters:

- The process for dismantling of the installations;
- The disposal and destination of activated or contaminated materials, radioactive substances or devices containing such substances and, if applicable, the information specified in article 18.2 of GRR-2001;
- The destination of the site and any other provisions that would guarantee the health and safety of workers and the general public as well as protection of the environment, both during and after dismantling and preparatory operations;
- For class I facilities, the Safety Report for Dismantling (SRD);
- A environmental impact assessment report or a screening note for certain dismantling projects.

The dismantling license applications for the Doel 3 and Tihange 2 units are foreseen to be submitted by ENGIE Electrabel at the end of 2023. Preliminary discussions on the required details and contents of this license application have started between the regulatory body and the licensee.

4. MISCELLANEOUS

The FANC proposed to impose additional conditions or to modify the conditions of the existing license in order to take account of the state of the facility as described in the notification of permanent shutdown. These additional conditions include:

- A system of hold points and witness points to allow the regulatory body to follow up closely the POP;
- Specific reporting requirements on the progress of the POP;
- A requirement to submit a dismantling license application within 2 years after the final shutdown.

In addition to this license modification, the FANC and Bel V also performed several specific on-site inspections to verify the final shutdown of the NPPs and the start of the first POP activities.

Complementary information on topic can be found on the website of the Federal Agency for Nuclear Control: www.fanc.fgov.be

REFERENCES

[1] GRR-2001, General Regulations regarding the protection of the public, workers and the environment against the hazards of ionizing radiation, laid down by Royal Decree of 20 July 2001,

http://www.jurion.fanc.fgov.be/jurdb-consult/consultatieLink?wettekstId=7460&appLang=fr&wettekstLang=fr

[2] SRNI-2011, The Royal Decree on the Safety Requirements for Nuclear Installations,

http://www.jurion.fanc.fgov.be/jurdb-consult/consultatieLink?wettekstId=15152&appLang=fr&wettekstLang=fr

3.1.3. Decommissioning of VVER-440 Nuclear Power Plants in the European Union

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Abstract

The decommissioning of the Bohunice V1 (Slovakia) and the Kozloduy NPP Units 1-4 (Bulgaria) nuclear power plants has progressed substantially over the past 8 years. The European Union has co-financed to a large extent the decommissioning of those plants (including dismantling of equipment and components in the turbine halls and the dismantling and decontamination in the reactor buildings), the safe management of radioactive waste (including the completion of the waste and materials management infrastructure and related activities), and the disposal of low/intermediate level waste.

Dealing with six VVER-440 units altogether, these decommissioning programmes represent a well-documented benchmark for future decommissioning of other VVER type reactors and more generally pressurized-water reactors (PWRs). Indeed, the decommissioning of the more numerous PWRs in the EU will benefit from the VVER decommissioning lessons learnt. While these programmes built on the experience of the processing facilities and technologies used in the decommissioning of the Greifswald nuclear power plant, their objective is reaching further, up to the release of the facilities as "brown field" for other industrial use in the course of this decade.

This paper illustrates the technical results achieved thus far, including successful practices in the application of the ALARA principle and the minimization of radioactive waste, mostly obtained via maximization of recycling as well as via the deployment of state-of-the-art processing facilities. In addition, programme level information, such as risk management, synergies, knowledge management, schedules and budgets are detailed.

1. INTRODUCTION

Nuclear countries of the European Union (EU) recently (as of May 2023) operate 100 power reactors and 30 research reactors in addition to 2 power & 2 research reactors under the construction. 74 power reactors are shutdown for decommissioning as well as 42 research reactors. 3 power reactors and 88 research reactors can be considered as decommissioned.

Amount of work ahead is thus significant what can be demonstrated on the EU projected decommissioning expenditures until 2026 –€65 billions, with the expected peak of decommissioning work around 2045. This will include also 19 operational VVERs (plus eventually another one reactor close to the completion) of both VVER-440 and VVER-1000 type.

2. NUCLEAR DECOMMISSIONING ASSISTANCE PROGRAMME

In the framework of their EU accession negotiations, Bulgaria, Lithuania, and Slovakia took a formal commitment to close 8 power reactors located on their territories. Since the early 1990s, the European Commission (EC) has been working closely with those Member States to meet the closure commitments and to support the decommissioning process. In addition to RBMK reactors in Lithuania, it includes 4 reactors VVER-440 at Kozloduy NPP and 2 reactors VVER-440 at V1 NPP (Jaslovske Bohunice).

Nuclear Decommissioning Assistance Programme [1] was established and it is supervised by European Commission. Its implementation is monitored by DG ENER. Though majority of financial support is provided by EC, national resources are also used (up to around 40%) and other donors are welcome to contribute as well. National decommissioning operators are in charge for implementation of the overall decommissioning projects in cooperation with professional companies selected based on international open bids to perform particular works.

Performance indicators are set up and monitored in every project to enable short- and long-term control and to support risk assessment. They perform also basis for communication and supports periodical review of targets.

As for V1 NPP, that was shutdown in 2006 (Unit 1) and 2008 (Unit 2), a significant progress was already achieved. In addition to many remarkable completed works outside the nuclear island, such as demolition of 4 large cooling towers, were all 12 steam generators and 2 reactor pressure vessels retrieved from their operational instalment positions and segmented with completion date in 2022. Other important works were done on dismantling of auxiliary buildings and constructions and effective management of radioactive waste. The V1 NPP decommissioning programme is expected to be completed by December 2027.

Kozloduy NPP that was shutdown in 2002 (Units 1-2) and 2006 (Units 3-4) has also achieved noticeable progress. Plasma melting facility started operation in 2019 (see Figure 1), dismantling and demolition of auxiliary buildings was completed in 2020, primary circuitry decontaminated in 2022 and I/LLW disposal facility was completed in 2023. The Kozloduy NPP overall decommissioning programme is expected to be concluded by December 2030.

FIG. 1. Plasma melting facility at Kozloduy NPP (courtesy of SERAW, Bulgaria)

3. LESSONS LEARNT – THE POWER OF KNOWLEDGE SHARING

Many useful lessons learnt can be shared among VVER-440 decommissioning programmes and beyond. DG ENER systematically works on development of process to identify, manage, and share efficiently and routinely the relevant expertise that is available.

An example to be highlighted is sharing of knowledge and lessons learnt from decontamination of primary circuitry that was first done in V1 NPP and later on in Kozloduy NPP using the same decontamination equipment and procedures. It allows for high decontamination factors and significant activity removed under the safe and effective conditions.

Another case is a guide developed by SERAW (Kozloduy NPP) to share update on treatment of low and intermediate level radioactive waste using Plasma Melting Process, and its Performance Analysis.

REFERENCES

[1] EUROPEAN COMMISSION, DG ENER, Nuclear Decommissioning Assistance Programme (NDAP), https://energy.ec.europa.eu/publications/nuclear-decommissioning-assistance-programme-ndap_en

3.1.4. Overview of the U. S. Nuclear Regulatory Commission Decommissioning Programme

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Abstract

The United States of America Decommissioning Program continues to make progress to decommission and remediate the commercial complex nuclear facilities and legacy sites. Since promulgating the 1997 License Termination Rules to regulate the decommissioning of nation's commercial nuclear facilities, nearly 80 complex sites, including 12 power reactors have completed decommissioning and licenses terminated for unrestricted use. Substantial progress is also being accomplished to complete the remediation of legacy sites and the transfer to long term surveillance plans to the US Department of Energy. Since 2013, eleven power reactors have permanently ceased operations and entered decommissioning status. Most of the newly shutdown plants were expected to enter a significant dormancy period or safe storage, however, many of the utility operators have chosen to move directly to active decommissioning. As of October 2022, the power reactor decommissioning program has increased significantly to 26 units with 18 being in various stages of active decommissioning. The current trends are to contract the decommissioning work to a decommissioning company or transfer the licenses to decommissioning companies willing to assume financial risks and technical responsibilities to decommission the sites. This presentation will provide an overview of the United States of America decommissioning program challenges, including the status of the reactor decommissioning program, legacy site remediation, improvements to the regulatory framework, lessons learned and technical guidance initiatives to improve the program.

1. INTRODUCTION

The Nuclear Regulatory Commission (NRC) is the United States of America independent safety regulator for all commercial uses of radioactive materials. Each year, the NRC and the NRC Agreement States issue and terminate hundreds of licenses for medical, industrial and research facilities. As shown below *(FIG. 1)*, over the past 25 years significant progress has been accomplished to clean up and terminate over 80 complex decommissioning sites. All complex material sites, including 12 power reactors, have been terminated for unrestricted use except for the Uranium Mill Tailing Radiation Control Act sites that remain under US DOE long-term stewardship. The NRC decommissioning regulatory process promotes the prompt decommissioning of licensed facilities and ensuring safety and

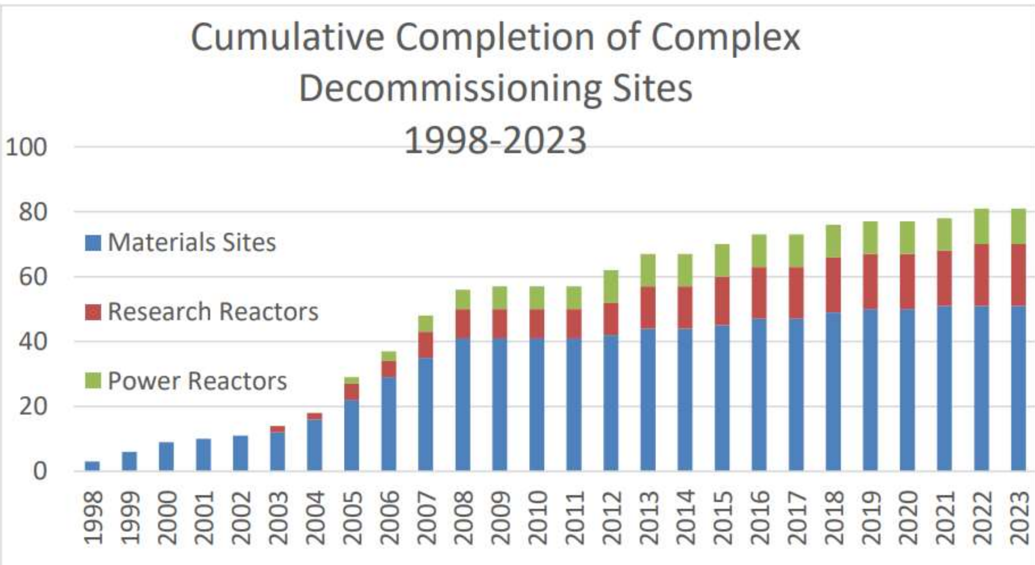

FIG. 1. Cumulative Completion of Complex Decommissioning Sites

security. NRC is committed to fulfilling the promise that licensed facilities and sites will be cleaned up for future use and economic development.

2. OVERVIEW OF NRC REGULATORY FRAMEWORK

In the early 1990's, the first 3 power plants shutdown and started decommissioning. The decommissioning regulations were revised in 1997 to reflect the lessons learned from these 3 plants. In the late additional regulations in the 1990's and 2000's, more plants shutdown and NRC used these regulations to terminate 8 more power reactor licenses. The NRC has developed a robust framework of regulatory requirements and continues to improve the regulatory and technical guidance. After evaluating the actions taken to reduce legacy sites, NRC initiated regulations for licensees to implement to prevent the spread of contamination during operations. The NRC recognized the need to issue new regulations to improve the transition of operating power plants to decommissioning.

3. LEGACY SITE UPDATE

In the US, there are two types of legacy sites, the Uranium Mill Tailing Radiation Control Act legacy sites that will remain under regulatory control into perpetuity and the Site Decommissioning Management Plan sites. In 1996, the Site Decommissioning Management Plan was implemented by the NRC to complete the decommissioning of legacy sites. As shown in Table 1, the NRC and Agreement States have made steady progress to reduce the number of legacy sites. The legacy sites were formerly licensed by the Atomic Energy Commission, the NRC's predecessor regulator, that were terminated without verifying the sites meet the unrestricted use criteria. Significant progress continues to be made to reduce the legacy sites under regulatory control.

TABLE 1 LEGACY SITE REDUCTION SINCE 1969

Year	**Total Sites to Remediate**	**NRC Sites**	**Agreement States**	**Net Reduction**
1996	60	60	0	0
2009	60	17	43	0
2016	16	5	11	-44
2023	13	4	9	-47

4. REGULATORY IMPROVEMENTS

In 2011, NRC found that additional requirements were needed to help prevent legacy sites, new regulations and regulatory guides were issued to provide licensees with acceptable approaches for compliance. Based on the decade of experience, the regulations have been effective. In 2013, the first of 13 power reactors unexpectedly shutdown before the end of their operating licenses due to changes in the energy markets and other reasons. In 2001, NRC determined the need to develop new regulations to make the transition of power reactors from operations to decommissioning more efficient. Due to external events, the rulemaking for the new regulations were deferred to 2014 and are expected to be issued in 2024.

5. DYNAMIC CHALLENGES AND OPPORTUNITIES

In 2013, the reactor decommissioning program began to evolve creating new challenges and opportunities for the NRC to manage. Changes in the US energy markets resulted in more nuclear power plants ceasing operations before the expected end of the operating license. With the increased shutdowns, utility operators elected to sell the shuttered plants to decommissioning companies requiring the NRC's approval to transfer the license. This has led to most of the plants to choose immediate decommissioning and resulted in some of the plants in safe storage to be sold and begin decommissioning.

In 2014, the first of the license transfers with asset sale was completed for the Vermont Yankee plant. The NRC must review the proposed licensee's technical qualifications and financial assets in order to approve the license transfer. As the asset sale includes not only the safe decommissioning of the reactor plant, but also the safety and security to manage the spent nuclear fuel. The license transfers along with utility operators choosing the more traditional business approach to contract and oversee a company to decommission the plants, has caused a record number of plants to be in active decommissioning. The dynamic increase of active decommissioning has had significant impacts to the decommissioning inspection program and the expected early submittal of multiple license termination plans. NRC has taken several comprehensive actions to address the challenges with the expansion of the decommissioning program. The expansion provided the opportunities to re-structure of the Regional Offices organizations that perform inspections, improve the inspection programmes, and risk-inform the inspection procedures, cross qualifying headquarters personnel as inspectors, and adding new and upgrading decommissioning training courses. In 2021 and 2023, the Humboldt Bay and La Crosse power reactor licenses were terminated respectively, bringing the number of power reactors licenses terminated to 12. However, the current number of plants in active decommissioning will be challenging to manage.

TABLE 2 US NRC FEBRUARY 2023 DECOMMISSIONING STATUS

US NRC February 2023 Decommissioning Status
17 Power Plants in Active Decommissioning
8 Power Plants in SAFSTOR
No Additional Power Reactor Announced Shutdowns
2 Research Reactors
4 Complex Materials Sites
16 Uranium Mill (UMTRCA) Sites in Decommissioning

ACKNOWLEDGMENTS

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REFERENCES

[1] UNITED STATES NUCLEAR REGULATORY COMMISSION, Status of the Decommissioning Programme Annual Report (2021), https://www.nrc.gov/waste/decommissioning.html

3.1.5. Current Status of the Japanese Decommissioning Programme: Fukushima and Future Nuclear Energy Policy Direction for Steady and Efficient Decommissioning

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Abstract

The decommissioning of TEPCO Fukushima Daiichi Nuclear Power Station is progressing steadily based on the Mid-and-Long-Term Roadmap established by the Government of Japan (GOJ). All units at the site are being kept stable. The monitoring data indicates that the environment impact on the site and surrounding area have been significantly reduced. Regarding the financial aspect, based on the reserve fund for decommissioning of Fukushima Daiichi Nuclear Power Station, every year TEPCO keeps in reserve an amount designated by the Nuclear Damage Compensation Facilitation Corporation (NDF). In accordance with a 'Withdrawal Plan' created by the NDF and TEPCO, TEPCO withdraws funds from the reserves and carries out decommissioning. As the entity that manages and supervises the implementation of decommissioning by TEPCO, the NDF is tasked with appropriately managing the funds for decommissioning and the implementation system for decommissioning, and steadily managing the work based on the reserve fund system. In addition to that, the GOJ announced the outline of Draft Action Guideline for future nuclear energy policy direction and implementation in December 2022 (followed by the Cabinet Approval of the "Basic Policy toward Implementation of Green Transformation (GX)" in February 2023), and the Guideline highlighted the importance of achieving steady and efficient decommissioning process, as conventional nuclear reactors are expected to get into the phase of decommissioning on Nuclear Island from the mid-2020s onward. In that context, the Guideline notes to needs of institutional measures for accumulating and sharing knowledge and know-how, securing funds, which has been continuously discussed in ad-hoc working group among experts under the GOJ since July 2022.

1. INTRODUCTION

This paper first summarizes the decommissioning efforts taken for the TEPCO Fukushima Daiichi Nuclear Power Station since 2011 when a big tsunami hit after the Great East Japan Earthquake. The decommissioning is progressing steadily based on the Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station established by the Government of Japan (GOJ).

After that, this paper also covers the outline of Draft Action Guideline for future nuclear energy policy direction and implementation, announced by the GOJ, in December 2022. The Guideline highlighted the importance of achieving steady and efficient decommissioning process, as conventional nuclear reactors are expected to get into the phase of decommissioning on Nuclear Island from the mid-2020s onward.

2. DECOMMISSIONING OF FUKUSHIMA DAIICHI NUCLEAR POWER STATION

The decommissioning of Fukushima Daiichi is a continuous risk reduction activity to protect the people and the environment from the risks associated with radioactive materials. Also, safe, and steady decommissioning is a prerequisite for reconstruction of Fukushima. This section states the Mid-and-Long-Term Decommissioning Roadmap *(FIG. 2)*, the current status of decommissioning, and the radiological environmental impact assessment regarding the discharge of ALPS (Advanced Liquid Processing System) treated water which is planned to start in 2023.

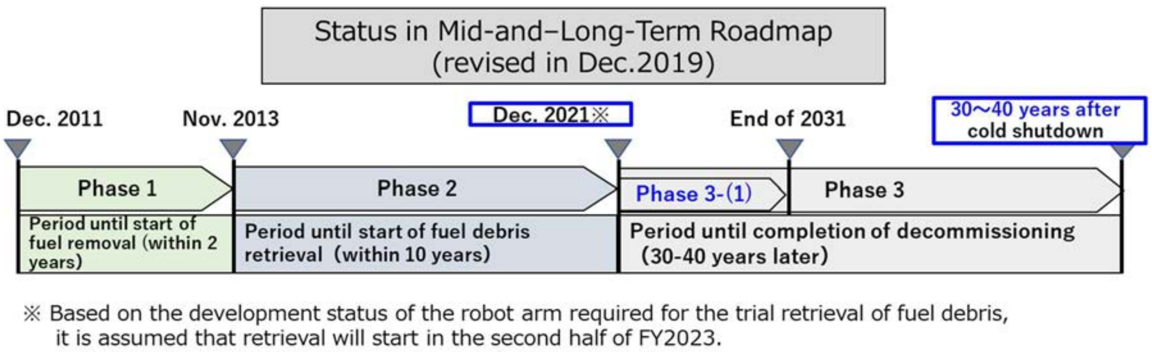

FIG. 2. Status of Mid-and-Long-Term Roadmap

2.1. Mid-and-Long-Term Decommissioning Roadmap

The Mid-and-Long-Term Decommissioning Roadmap was first adopted in December 2011. It clarified that the Government of Japan lead the entire decommissioning effort. Since then, GOJ revised the roadmap several times to set appropriate milestones and timeline. The latest revision was conducted in December 2019.

2.2. Current Status of Decommissioning at Fukushima Daiichi Nuclear Power Station

The fuel removal from the Unit 3 was completed in 2021 following the Unit 4.

The amount of contaminated water generated has reduced from 540 tons (2014) to 130 tons (2021) per day because of various preventive measures.

Fuel debris retrieval will be carried out with safety as top priority. Robotic arm for trial retrieval is now under preparation in cooperation with a company from the United Kingdom. Retrieval of debris is one of the most difficult challenges, therefore international collaboration is important.

Internal investigation of the Primary Containment Vessel in the Unit 1 using Remotely Operated Vehicles (ROVs) is also underway.

In April 2021, the Government of Japan announced the Basic Policy on handling of ALPS (Advanced Liquid Processing System) treated water at the Fukushima Daiichi NPP. ALPS treated water is the water which meets regulatory standards by purification except for tritium. The water will be measured before the discharge and will be diluted further. The amount of discharge will be controlled below the annual discharge limit. The Government of Japan will take measures based in international standards and international practice. The safety of the handling of the ALPS treated water will also be reviewed by the IAEA, which has expertise and scientific knowledge in the field of nuclear safety.

2.3. Radiological Environmental Impact Assessment

TEPCO has conducted the assessment of radiological impact on public and environment, using internationally recognized methods, regarding the discharge of ALPS treated water. The result indicated that effects of the discharge of ALPS treated water into the sea on the public and the environment is minimal. The impact on humans is about one-thousandth of the radiation dose received from a single dental x-ray. This assessment considers the effect of bioaccumulation and long-term accumulation.

TEPCO also conducted dispersion simulation. The simulation found that the area assessed to have higher tritium concentration on the surface layer than current levels in the surrounding sea area (0,1 to 1 Bq/L) will be limited to the area of 2 to 3 km from the Fukushima Daiichi NPP for the annual average.

The Nuclear Regulation Authority (NRA) reviewed the report of assessment of radiological impact on public and environment by TEPCO and approved the basic design of ALPS treated water discharge related facilities. The IAEA review team also reviewed the report.

3. NUCLEAR ENERGY POLICY DIRECTION AND IMPLEMENTATION IN JAPAN

The GOJ aims to reduce to greenhouse gas emissions to net zero by 2050, and nuclear power will support this decarbonization efforts according to the “Basic Policy toward implementation of Green Transformation (GX)” approved by the Cabinet of GOJ in February 2023. The Basic Policy outlines the nuclear energy policy direction, such as maximizing the use of the existing NPPs, developing next-generation advanced reactors, and international collaboration in the context of building a robust nuclear supply chain, ensuring the safety of nuclear facilities, etc.

4. POLICY EFFORTS FOR THE SMOOTH DECOMMISSIONING OF EXISTING NUCLEAR POWER PLANTS

The Basic Policy also notes the importance of achieving a steady and efficient decommissioning process. As the background of this policy, the existing NPPs in Japan are expected to enter the phase of decommissioning on Nuclear Island from the mid-2020s onward. In this regard, the GOJ recognized the need for institutional measures to accumulate and share knowledge and expertise and to secure funding, which have been discussed continuously in an ad hoc working group of experts under the Ministry of Economy, Trade and Industry (METI) since July 2022.

REFERENCES

[1] The Inter-Ministerial Council for Contaminated Water and Decommissioning Issues, Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station, December 27, 2019. https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20191227_3.pdf

The International Atomic Energy Agency, IAEA INTERNATIONAL PEER REVIEW OF MID-AND LONG-TERM ROADMAP TOWARDS THE DECOMMISSIONING OF TEPCO'S FUKUSHIMA DAIICHI NUCLEAR POWER STATION (Fifth Review), June - August 2021.

https://www.iaea.org/sites/default/files/21/08/review-report-270821.pdf

[2] The Inter-Ministerial Council for Contaminated Water, Basic Policy on handling of ALPS treated water at the Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Station, Treated Water and Decommissioning issues, 13 April, 2021.

https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/bp_alps.pdf

[3] United Nations Scientific Committee on the Effects of Atomic Radiation, SOURCES, EFFECTS AND RISKS OF IONIZING RADIATION UNSCEAR 2020/2021 Report, Levels and effects of radiation exposure due to the accident at the Fukushima Daiichi Nuclear Power Station: implications of information published since the UNSCEAR 2013 Report, Volume II, SCIENTIFIC ANNEX B, 2021.

https://www.unscear.org/unscear/uploads/documents/unscear-reports/UNSCEAR_2020_21_Report_Vol.II.pdf

[4] Tokyo Electric Power Company Holdings, Inc., Radiological Impact Assessment Report Regarding the Discharge of ALPS Treated Water into the Sea (Design stage / Revised version), April 2022.

https://www.tepco.co.jp/en/hd/newsroom/press/archives/2022/pdf/220513e0101.pdf

[5] The Japan Society of Mechanical Engineers, Proceedings of FDR2022 International Topical Workshop on Fukushima Decommissioning Research, October 2022

https://www.jstage.jst.go.jp/article/jsmefdr/2022/0/2022_Plenary2/_article

3.1.6. Chornobyl NPP Decommissioning: Prospects and Challenges

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Abstract

State Specialized Enterprise "Chornobyl Nuclear Power Plant" (SSE ChNPP) is an enterprise for decommissioning of ChNPP Units and transformation of Shelter Object into an environmentally safe system.
Now the ChNPP is at a stage of "Final Shutdown and Preservation of Reactor Facilities". This stage started in 2015 and will last until approximately 2028.

Tasks of this stage are as follows:

- Bringing the ChNPP Units to a state that excludes the possibility of their use for electricity generation;
- Release of Units from ionizing radiation sources which are subject to control;
- Preservation of reactors and most radiation contaminated equipment.

1. INTRODUCTION

The next stage is "Safe Enclosure of Rector Facilities" during a period of time that will allow natural decay of radioactive radiation until the acceptable level. It will last approximately until 2045.

After that the ChNPP will proceed with the last stage – "Dismantling of Reactor Facilities". This stage will include the dismantling of equipment and clearance of the site for the purpose of maximum lifting of restrictions and regulatory control (approximately until 2064).

1.1 Background

The Chornobyl NPP as a generating enterprise consisted of 4 Units with RMBK-1000 reactors (High-Power Channel-Type Reactors). The Units were commissioned in 1977, 1978, 1981 and 1983, respectively. The Units were shutdown in 1991 (Unit 2), 1996 (Unit 1) and 2000 (Unit 3).

The equipment and buildings of three Units of ChNPP should be dismantled, partially disposed, partially segmented, and delivered for processing. This is a work for the nearest half a century. The largest problem is Unit 4 destroyed because of explosion in 1986. The whole world knows Unit 4 as Shelter Object. Today, the Shelter is under the NSC's Arch and is waiting for start of dismantling of its unstable structures. The Russian occupation in 2022 disrupted the work schedule.

2. NUCLEAR FACILITIES RELATED TO CHERNOBYL NUCLEAR POWER PLANT

2.1 Interim Spent Fuel Wet-Type Storage Facility

Interim Spent Fuel Wet-Type Storage Facility (ISF-1) was designed for temporary storage of spent fuel assemblies (SFAs) accumulated during the Chornobyl NPP operation. The ISF-1 was constructed during 1983-1986 and commissioned in September 1986.

According to the design, it was intended to have two Stages of ISF-1 construction. 1st Stage was for acceptance, management, and storage of spent nuclear fuel (SNF). The 2nd Stage should have included a complex of shielding cells for fragmentation, loading and storage of SFAs in transfer baskets with their further transportation in transfer casks TK-11 to a fuel processing plant. The 2nd Stage of ISF-1 was not constructed.

Nowadays, a little over 19 thousand spent fuel assemblies from ChNPP Units 1, 2, and 3 are being stored in ISF-1.

2.2 Interim Spent Fuel Dry-Type Storage Facility

Interim Spent Fuel Dry-Type Storage Facility (ISF-2) is a facility designed for acceptance, preparation for storage and 100-year storage of more than 21 thousand spent fuel assemblies (SFAs) of SSE ChNPP. The construction started on 12 November 1996 and was completed in y. 2021. The production capacity of the facility is 2 500 SFAs per year. After drying, the SFAs are cut into two bundles, placed in fuel tubes and then in custom-made double walled canisters (196 bundles in a canister). The canisters are further transported to the concrete storage modules in the Concrete Storage Area (CSA) where the fuel will be stored in the special modules for 100 years.

Since the beginning of ISF-2 operation, 9% of SFAs have already been transported from ISF-1 to ISF-2 (1 842 SFAs in total, and 198 SFAs in 2022). After the de-occupation, the ChNPP prepared the entire process chain for transportation of SNF, checked all required qualification requirements to personnel, and conducted the tests. The ChNPP is performing preparation for future transportation of SNF.

2.3 Industrial Complex for Solid Radioactive Waste Management

Industrial Complex for Solid Radioactive Waste Management (ICSRM) is designed for acceptance, processing and/or disposal of solid radioactive waste (SRW) accumulated during the operation, and those produced during decommissioning of ChNPP, including operational radioactive waste (RAW) of the Shelter Object.

The construction started on 05 March 2001, and was completed on 25 February 2009. The productivity of the facility is following:

- SRW Processing Plant – 20m^3 of RAW per day.
- Incinerator – 50 kg/h of solid RAW and 10 kg/h of liquid RAW.
- Cementation installation – 10 m^3 per day.
- Packing installation for Low-and Intermediate-Level - Long-Lived Waste – 1.5 m3 per day.

Capacity of the Temporary Storage Facility for Low- and Intermediate-Level and High-level Waste is 3 500 m^3, service life – 30 years.

The first two Lots were constructed on the ChNPP industrial site, while Lot 3 – on Vector Complex site in the Exclusion Zone.

In 2022 we continued removal of SRW from Units 1, 2 and 3, NSC-SO Complex, and facilities located within the SSE ChNPP industrial site. 600 m^3 of SRW (100% from the planned) was transported for disposal to the RAW Disposal Facility “Buriakivka”.

2.4 Liquid Radioactive Waste Treatment Plant

Liquid Radioactive Waste Treatment Plant (LRTP) is designed for treatment of liquid radioactive waste (LRW) accumulated during the operation, and operational LRW of the Shelter Object. LRTP is intended for the LRW treatment during 10-year of operation. Its minimum design capacity is 2 500 m^3 of non-treated liquid RAW per year.

The construction of the facility started on 16 September 1999 and the facility was commissioned in 2018. The value of the project was more than 37 million euros. The project was funded under the International Technical Assistance (from the Nuclear Safety Account of the European Bank for Reconstruction and Development).

The solidified liquid waste in the form of cement compound (end product) is packed into 200-litre drums, and then transported in reinforced-concrete containers to a long-term controlled storage site for conditioned RAW.

Activities on the last 3rd stage of “hot” tests of the Retrieval Facility (RF) and Solid RAW Processing Plant (SWPP) of the ICSRM were completed in 2022. The ChNPP is waiting for a license giving a right to process RAW in terms of “Operation of the ICSRM’s RF and SWPP”.

2 032 packages of treated liquid RAW (that is 101.6% of 2022 plan) were produced and transported for disposal to the Engineered Near-Surface Disposal Facility (ENSDF) of Vector Complex in 2022.

2.5 New Safe Confinement

New Safe Confinement (NSC) is a multifunctional complex for transforming the Shelter Object into an environmentally safe system. It consists of 19 substructures. Hence, the huge arch-type structure 257 meters in span, 109 meters in height (that is 35-storeyed building), 160 meters in width (that is one and a half football pitch) and over 36 thousand tons in weight, known to the whole world as the Arch, is only a part of the sophisticated engineering system of NSC.

The engineering was supported by the Project Management Unit consisting of companies Bechtel (USA), Battelle Memorial (USA), and ChNPP. Contractor responsible for design, procurement and construction was NOVARKA Consortium.

The main functions of the NSC are following:

- Restriction of radiation impact on general public, personnel and the environment.
- Restriction of the spread of ionizing radiation and radioactive substances located inside the Shelter.
- Creation of conditions for unstable structures dismantling, radioactive materials retrieval, accumulated water pumping up, ensuring implementation of measures to control and maintain the Shelter Object and its industrial site.
- Monitoring of all the Shelter Object state parameters and technological processes management.
- Preventing unauthorized access to the radioactive materials and ensuring IAEA safeguards system functioning.

More than 32 000 m^3 of technological materials and solid RAW, 4 units of buried machines and high-level waste were removed during clearing-up and levelling the area and excavation activities for construction of foundations for the NSC and the Arch assembly area.

Thus, over 55 000 m^3 of solid radioactive waste and technological materials were removed from a place of future construction only to start the construction.

160 000 m^3 of RAW under the NSC project and 233 000 m^3 of RAW under all projects of SIP (Shelter Implementation Plan) were removed during excavation activities over a period of the project implementation.

400 steel piles (diameter – 1 m, depth – 24 meters) were driven and about 400 bored piles (diameter – 1 m, depth – 19 meters) were installed only to arrange the temporary and permanent foundations of the Arch. If all piles put in a row, we will get more than 17 kilometres of piles.

81 000 m^3 of concrete were placed.

8 000 tons of re-bars were assembled.

Almost 90 000 m^2 of work area was concreted.

145 255 000 m^3 of ready-mix concrete was produced and placed since the project beginning.

Ventilation Stack VT-2 (153 m height and 330 tons in weight) was dismantled.

The following was used for the arch-typed structure:

- 5 700 main elements (tubes >800 mm in diameter).
- 4 000 auxiliary elements (node connections).
- 650 000 bolts (M30).
- 24 860 tonnes of steel structures
- 5 400 tonnes of temporary structures

The Arch was slid by 224 hydraulic jacks that enabled to lift simultaneously more than 36 000 tons of structures and move them for 60 cm per one cycle. In total, the Arch structure covered 327 meters until its design position.

Since the NSC's Arch installation in 2016, the quantity of radioactively contaminated water pumped out from the Shelter Object (SO) decreased by more than 6 times (from ~ 2 200 m^3 during 2013-2016 to ~ 330 m^3 in 2018).

In 2017, the total "uncontrolled" gas-aerosol release from the SO decreased by more than 5 times (up to 23 MBq) in comparison with the average value of release during 2013-2016. After closing the tilting panel and sealing the NSC, there is no "uncontrolled" release into the environment.

Dose rate values around the SO decreased by 10-20 times.

3. CHORNOBYL NPP OCCUPATION, AFTERMATH

The armed aggression of Russian Federation against Ukraine and seizure of SSE ChNPP industrial site impacted negatively on all areas of ChNPP statutory activities.

The occupation troops looted and damaged material values – external buildings and warehouses, office rooms and their equipment, consumables. The logistics to provide ChNPP with materials and personnel was destroyed.

The occupation resulted in a decision of the State Nuclear Regulatory Inspectorate of Ukraine to temporarily (from April until August 2022) terminate some licenses for implementation of activity on decommissioning of Units 1, 2 and 3, activities at the RAW management facilities and some types of activity in the field of nuclear energy use.

After liberation of ChNPP from the Russian occupiers, the following was done within the scope of resumption of activity at the SSE ChNPP industrial site: demining and explosive ordnance disposal, ensuring the delivery of the required number of qualified personnel to the ChNPP site, rebuilding and re-equipping of work and office rooms, resumption of radiation and dosimetry control activities, individual dosimetry control of ChNPP staff and radioecological monitoring.

REFERENCES

[1] CHERNOBYL NUCLEAR POWER PLANT, https://chnpp.gov.ua/ua/

[2] EUROPEAN BANK FOR RECONSTRUCTION AND DEVELOPMENT, https://www.ebrd.com/what-we-do/sectors/nuclear-safety/chernobyl-shelter-implementation.html

3.1.7. Regulatory Oversight and Challenges during Decommissioning of KANUPP

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Abstract

After completing fifty years of plant operational life, Karachi Nuclear Power Plant (KANUPP) permanently ceased its operation in 2021 and entered the decommissioning stage with a deferred dismantling strategy. Pakistan Nuclear Regulatory Authority (PNRA) has established a comprehensive regulatory framework and issued a National policy and Regulations on decommissioning. The paper aims to discuss the review of changes in technical specifications, and regulatory oversight during defueling and spent fuel and dry storage activities during the transition period. The paper also presents the regulatory oversight challenges in waste management activities, chemical hazard removal activities, waste treatment/storage/disposal and looks at declining safety culture considering outcomes resulting from previous regulatory safety culture assessment and strategy to over overcome these challenges.

1. INTRODUCTION

Pakistan Nuclear Regulatory Authority (PNRA) was established as a national regulatory body by Government of Pakistan with promulgation of PNRA Ordinance on January 22, 2001. The Ordinance empowers PNRA to regulate nuclear installations and radiation facilities for ensuring protection of the workers, the public and the environment from the harmful effects of ionizing radiation. Development of regulatory framework; licensing and authorization; review and assessment; and inspection and enforcement are core functions of PNRA. Karachi Nuclear Power Plant (KANUPP) was Pakistan's first CANDU type pressurized heavy water reactor (PHWR) with a total gross generation capacity of 137 MWe and achieved its first criticality in August 01, I971. KANUPP completed its operational life of 50 years, including design life of 30 years and beyond design life of 20 years, and permanently ceased its operation on August 01, 2021 [1]. Currently, KANUPP has acquired decommissioning license and going through phase-I of its decommissioning stage in accordance with approved final decommissioning plan. Since KANUPP is the first ever nuclear installation being decommissioned in Pakistan, it was not only challenging for KANUPP to adopt the transition from an operating facility to a decommissioning project but also for PNRA to implement already developed regulatory framework for decommissioning and to ensure safe transition to decommissioning phase. This paper will first discuss the PNRA's regulatory framework for decommissioning and process adopted for decommissioning licensing of KANUPP. Thereafter, overall PNRA experience will be described to highlight key regulatory oversight activities performed at KANUPP in view of pre-shutdown, post-shutdown and phase-I of decommissioning. Finally, regulatory challenges faced in course of licensing and oversight and approaches to address them will be discussed.

2. NATIONAL POLICY AND REGULATIONS ON DECOMMISSIONING

On behalf of Government of Pakistan, PNRA promulgated "National Policy on Safe Management of Radioactive Waste, Decommissioning and Spent Nuclear Fuel in Islamic Republic of Pakistan" in 20I8. The policy mainly outlines responsibilities of Government of Pakistan, nuclear power program owner i.e., Pakistan Atomic Energy Commission (PAEC) and nuclear regulator i.e., Pakistan Nuclear Regulatory Authority (PNRA) in areas of radioactive waste management, decommissioning and spent nuclear fuel management [2]. In addition to national policy, PNRA issued national regulations on Decommissioning of Facilities using Radioactive Material i.e., PAK/930. This PNRA regulation is based on IAEA General Safety Requirement part 6 on Decommissioning of Facilities. PAK/930 first describes general requirements applicable to decommissioning and then covers specific requirements in hierarchal order of decommissioning journey such strategy, planning, funding, conduct and completion of decommissioning. Key regulatory requirements outlined under PAK/930 are summarized in Table 1. In addition to standalone regulation on decommissioning, PNRA has other set of specific regulations that cover different considerations for decommissioning under their respective scopes.

TABLE 1 PNRA REGULATORY REQUIREMENTS IN PAK/930

Areas of PAK/930	Specific requirements
General Responsibilities	— Decommissioning strategy plan; — Financial assurances and resources; — Notification prior to shutting down the facility permanently; — Acceptable destination for all waste; — Appropriate radiological surveys; — Records and reports; — Quality assurance programme; — Skills, expertise, and training.
Decommissioning Strategy	— Finalization of decommissioning strategy; — Authorization to implement the final decommissioning plan; — Site strategy to ensure that interdependences between the facilities; — Review if strategy in case of sudden permanent shutdown.
Decommissioning Planning	— Prepare and maintain a decommissioning plan; — Decommissioning planning for new facilities; — Contents of initial and final decommissioning plan; — Review frequency of initial and final decommissioning plan; — Retention of records and reports.
Conduct of Decommissioning	— Optimization analysis for new and untried methods; — Emergency planning arrangements; — Waste management path; — Processing and storage capabilities and transport packages; — List of SSCs and surveillance program; — Event reporting.
Completion of Decommissioning	— End state criteria; — Decommissioning completion report; — Full or part release of site from regulatory control.

3. REGULATORY OVERSIGHT DURING DECOMMISSIONING OF KANUPP

3.1. During pre-shutdown period

During pre-shutdown stage, regulatory oversight at KANUPP mainly consisted of planned regulatory inspections and review of periodic regulatory submissions. Major focus areas were ageing management program of fuelling machines to ensure safe defueling of reactor after permanent shutdown, onsite activities related to qualification and testing of prototype spent fuel dry storage cask and preparation and storage of actual casks. With an anticipatory approach, PNRA also evaluated the applicability of various requirements mentioned in Regulations on Safety of Nuclear Power Plants Operation, i.e., PAK/913 and communicated its position to KANUPP for implementation after permanent plant shutdown. PNRA also conducted safety culture assessment at KANUPP using the new IAEA methodology, i.e., IAEA SRS-83. The whole process was carried out in two phases, namely the data collection and data analysis. For the data collection, three tools were employed, i.e., observations, interviews, and document review [4]. As KANUPP decommissioning was first of a kind activity to be initiated, PNRA deliberated number of coordination meetings with KANUPP to finalize the modalities and to streamline matters related to decommissioning license application and other associated submissions.

3.2. During post permanent shutdown period

During this period, oversight at plant continued which included regulatory inspections and review of KANUPP application for decommissioning license. PNRA also approved several modifications related to number of operation crews, training syllabus, retraining requirement, surveillance call up cards and change in organization structure, among others. Defueling of core started after two months of permanent shutdown and continued for eight months till complete defueling of core. PNRA inspectors conducted field inspections to witness the defueling activity and to ensure availability of procedures, qualified manpower and radiation protection measures. Regulatory oversight remained continued on transfer of spent fuel from wet storage to dry storage. PNRA also permitted KANUPP to change testing frequency of emergency diesel generators from one week to two weeks and to withdraw testing routines of various safety systems after performing due diligence from safety standpoint.

3.3. During phase-I of decommissioning

After the award of decommissioning license to KANUPP, phase-I of decommissioning formally commenced as per final decommissioning plan. PNRA adopted the approach to conduct inspections of modified processes and programs approved during review of final decommissioning plan. These include quality assurance program, radiation protection program and waste management program, among others. During this stage, PNRA, so far, has conducted a detailed inspection of physical protection program and environmental surveillance program at KANUPP. Further, PNRA Regulation on Safe Management of Spent Fuel i.e., PAK/918 was promulgated in 2020 and PNRA also conducted an inspection to verify its compliance. Shortcomings noted during inspection were communicated and KANUPP prepared an action plan for complete compliance of PAK/918. KANUPP is in process of implementing number of engineering modifications for cost optimization and ease of surveillance to make dormant period safer and efficient. PNRA selects the safety significant activities of modifications as per quality plan submitted by KANUPP and perform regulatory inspection as and when required.

4. REGULATORY CHALLENGES AND APPROACHES

4.1. Human and organizational factors

During the last two years of plant operation before permanent shutdown, KANUPP faced increased number of unplanned shutdowns. Root causes of these events were attributed to technological obsolesce, depletion of experienced manpower and human error. Stress factor was a contributing factor as KANUPP was going through repetitive maintenances jobs after every shutdown. Further, construction of two new design NPPs at the same site was also another key driver that caused uncertainty among work force when it comes to their prospective career growth and workplace satisfaction. Observing the development, PNRA decided to assess the safety culture during the pre-shutdown stage by using the IAEA methodology defined in Safety Report Series-83 (SRS-83). Six overarching cultural themes were captured: vocal for safety, existence of shared space, value for learning, blurred vision, weak quality work and dilapidated physical working environment [4]. These were communicated to KANUPP for formulation of effective action plan to continue with strong cultural aspects and to overcome weak cultural footprints in post shutdown and decommissioning phase.

4.2. Licensed main control room operators.

After KANUPP permanent shutdown and considerable removal of decay heat from core, PNRA evaluated the requirements and scope of number of operating crews, existing retraining syllabus of licensed personnel and retraining period required for license revalidation. During the evaluation, feedback of other CANDU operating countries through CANDU Senior Regulators forum was also sought to optimise the regulatory decision. After ensuring that the revised training syllabus is sufficiently covering safety of permanently shutdown plant, PNRA allowed KANUPP to implement reduced training syllabus along with change in revalidation training period to fourteen non-continuous days in a year which was previously two months in a year. The requirement of number of operation crews and number of licensed operator in each crew was also reduced considering the safety requirement of plant in permanently shut down.

4.3. Regulatory oversight of dry storage cask and compliance with technical specifications

As KANUPP was the pioneer to establish and operate first spent fuel dry storage facility in Pakistan, it was a challenge for PNRA to carryout design certification of cask including review of its safety analysis report and inspecting the factory tests for qualification. Thereafter, testing and qualification of first prototype cask was performed at KANUPP site and it was again a challenge for PNRA to regulate the various processes involved in preparation of cask especially its vacuum drying before final transportation. For effective oversight, PNRA developed an internal working procedure by compiling regulatory and design certification requirements to provide guidelines to its inspectors about the selection of control points important to safety and to provide list of key items to be checked in different onsite cask preparation activities. These are visual inspection of fuel bundles, basket loading, cask dose mapping, welding of cask lid and its dye penetrant testing, leak testing and cask internal conditioning. The procedure also covered oversight activities related to verification of cask related operating limits and controls, surveillance program, training, and qualification of personnel [5]. PNRA conducted several inspections related to spent fuel dry storage activities according to its procedure. Number of discrepancies was found in compliance of operating limits and controls (OLCs). These were mostly related to inconsistencies of time duration of certain processes to be completed within OLCs defined in safety analysis report with the time duration of actual field operation of casks [6]. These discrepancies were communicated to KANUPP and cases for modification in relevant sections of safety analysis report were submitted to PNRA for review and approval.

4.4. Emergency planning and safety-security interface

As KANUPP was under permanent shutdown state and radiological risks were to be reassessed in view of emergency preparedness. Therefore, PNRA required KANUPP to submit emergency preparedness plan and physical protection program. After their regulatory approval, fundamental challenge was to verify implementation of these approved programs at KANUPP. To overcome, this PNRA conducted two inspections each for radiological emergency plan and physical protection program and required KANUPP to demonstrate adequacy and effectiveness of both these program in a single joint safety-security emergency exercise. This exercise was witnessed by PNRA inspectors and areas for improvement were communicated to KANUPP.

4.5. Regulatory oversight of waste management activities and removal of hazardous material

At KANUPP, radioactive waste generated during phase-I and phase-II of decommissioning will be stored in RAWSA along with legacy waste of last 50 years. After necessary processing, treatment and packaging, this waste will be shifted in near surface disposal facility to be constructed at KANUPP site. The fundamental challenge in regulating the radioactive waste in RAWSA is its bulk and uncharacterized nature which is stored in trenches and retrieval of this waste was not considered in the initial design of the facility. As per final decommissioning plan, this waste will be retrieved and shifted to radioactive waste management facility for treatment, conditioning, and storage. Another issue is the retrieval and storage of radioactive spent resin from moderator and primary systems which were initially stored in two underground tanks. These tanks were designed to hold the spent resin produced during the plant design life of 30 years [1]. In addition to radioactive waste, KANUPP will also remove other hazardous material like asbestos from the piping of different process system installed turbine building, service building and reactor building. Asbestos is highly carcinogenic, and its physical characterization is not completed at KANUPP, therefore it will be a challenge for PNRA to regulate asbestos abatement with respect to human health. KANUPP has outlined asbestos removal and disposal methodology in final decommissioning plan and PNRA will oversee the activity in the future.

5. CONCLUSION

PNRA experience with decommissioning of KANUPP has been incrementally progressive yet challenging. PNRA proactively started the development of regulatory framework for the decommissioning activities and issued Regulations on ‘Decommissioning of Facilities using Radioactive Material i.e., PAK/930’. Regulatory oversight at KANUPP remained continued in post permanent shutdown period and during phase-I of decommissioning. Post permanent shutdown period mainly regulated in view of change in various testing routines of systems, components and structures, permanent removal of fuel from the core and spent fuel dry storage activities. On the other hand, regulatory oversight performed so far has brought various regulatory challenges as well. These are to keep oversight on human and organizational factors by performing safety culture assessment, change in organizational structure and change in license revalidation requirement of main control room operators. Regulatory oversight of dry storage activities and their compliance with stated technical specification is also important to ensure the long-term safe storage of spent fuel. Decommissioning waste at KANUPP will mostly be generated in phase-III. Radioactive waste generated during phase-I and phase-II of decommissioning will be stored in RAWSA along with legacy waste of last 50 years. Regulating the retrieval, treatment and storage will be a challenge for PNRA. These challenges will be handled with the help of in-house technical capabilities, international feedback, and guidelines of IAEA. Continuous oversight on the decommissioning activities will remain in act throughout the KANUPP decommissioning phase.

REFERENCES

[1] KANUPP Final Decommissioning Plan, Rev-1, July 2022

[2] National Policy on Safe Management of Radioactive Waste, Decommissioning and Spent Nuclear Fuel in Islamic Republic of Pakistan, (RWP-01/2018), 2018.

[3] PNRA Safety Evaluation Report on based on Review of KANUPP Final Decommissioning Plan and Other Licensing Submissions as per PAK/909, WSD-011(03), June 2022.

[4] Report on Safety Culture Assessment of K-1, RNSD-III-RI-TR-0I/2021, April 2021

[5] Procedure for Regulatory Oversight of Spent Fuel Dry Storage Activities at K-1, PNRA-RNSD-III-WP-021, Rev-0, March 2022.

[6] Operating Controls and Limits, Chapter 12 of SAR SC-108

3.1.8. Overview of the German Decommissioning Programme: Status, lessons learned and future challenges.

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Abstract

The German decommissioning experiences date back to the early 1970s, when the first decommissioning licenses for research reactors were granted. In recent years the number of decommissioning projects that are conducted in parallel increased due to the German phase-out decision.

The phase-out of the use of nuclear energy for the commercial generation of electricity was initiated in 2000 by the consensus on atomic energy policy and subsequently enshrined in the Nuclear Phase-out Amendment Act in 2002. Following the 2011 Fukushima disaster, this phase-out was further consolidated and accelerated in a broad political and social consensus. Fixed dates for the shutdown of German nuclear power plants (NPP) were laid down in the Atomic Energy Act for the first time. Eight power plants were immediately shut down in 2011. Others followed over subsequent years. However, to prepare for possible tense situation in energy sector in Europe as well as in Germany, the Atomic Energy Act was amended on December 9, 2022, to permit the continued operation of the three nuclear power plants until April 15, 2023, at the latest.

This paper provides a status of the decommissioning of nuclear facilities in Germany, the lessons learned from past and current decommissioning projects as well as current and future challenges resulting from the phase-out decision with respect to the decommissioning programme in Germany and strategies for their resolution from a regulatory point of view.

1. INTRODUCTION

The German decommissioning experiences date back to the early 1970s when the first decommissioning licenses for research reactors (RR) were granted. In recent years the number of decommissioning projects that are conducted in parallel increased due to the German phase-out decision.

The phase-out of the use of nuclear energy for the commercial generation of electricity was initiated in 2000 by the consensus on atomic energy policy and subsequently enshrined in the Nuclear Phase-out Amendment Act in 2002. Following the 2011 Fukushima disaster, this phase-out was further consolidated and accelerated in a broad political and social consensus. Fixed dates for the shutdown of German nuclear power plants (NPP) were laid down in the Atomic Energy Act (AtG) for the first time. Eight power plants were immediately shut down in 2011. Others followed over subsequent years. However, to prepare for a possible tense situation in the energy sector in Europe as well as in Germany due unprovoked and illegal war of aggression against Ukraine, the Atomic Energy Act was amended on December 9, 2022, to permit the continued operation of the three nuclear power plants until April 15, 2023, at the latest.

This paper provides a status of the decommissioning of nuclear facilities in Germany, an overview of the decommissioning policy as well as the legal and regulatory framework in place. Lessons learned from past and current decommissioning projects as well as future challenges resulting from the phase-out decision with respect to the decommissioning programme in Germany, and strategies for their resolution with an emphasis of maintaining a high level of safety are presented from a regulatory point of view.

2. OVERVIEW OF THE GERMAN DECOMMISSIONING PROGRAMME

As of 1 March 2023, 27 NPPs are in different phases of decommissioning. Three NPPs of rather prototype character have been dismantled and the respective sites released from regulatory control:

— Kernkraftwerk Niederaichbach (KKN), a heavy water gas cooled reactor, cooled with carbon dioxide, and moderated by heavy water with a gross electric power of 106 MW;

— Heissdampfreaktor Grosswelzheim (HDR), a hot steam reactor with a gross electric power of 25 MW, and
— Versuchsatomkraftwerk Kahl (VAK), a boiling water reactor with a gross electric power of 16 MW.

Three NPPs are currently in the post-operational phase and the decommissioning licensing procedures well advanced. Furthermore, the three remaining NPPs in operation on 1 March 2023 already submitted applications for decommissioning licenses.

With respect to research reactors, six decommissioning projects are being conducted at the moment and 31 decommissioning projects are completed, ranging from sub-critical assemblies to tank-type reactors with thermal output of 40 MW. For 3 RR the decommissioning licensing procedures are pending.

Two facilities of the nuclear fuel cycle (without storage and disposal facilities) are in the process of being decommissioned:

— Wiederaufarbeitungsanlage Karlsruhe (WAK), a reprocessing pilot plant that includes a vitrification facility, and
— Siemens Power Generation Karlstein (SPGK), a facility that encompassed a hot cell research facility, middle-active lab, analytics, waste incineration and waste water treatment.

Nine nuclear fuel cycle facilities have already been completely dismantled.

3. POLICY, LEGAL AND REGULATORY FRAMEWORK

Based on the purpose of the AtG, also in accordance with international recommendations [1, 2], the ultimate objective of all decommissioning actions is to release nuclear facilities from regulatory control under nuclear and radiation protection law.

For the decommissioning, safe enclosure, and dismantling of a nuclear facility in Germany, a license is required pursuant to § 7 (3) of the AtG. It must be noted that by an amendment to the AtG in 2017 safe enclosure is not allowed for those NPPs addressed by the phase-out decision. In individual cases, the competent authority may approve temporary exemptions for parts of installations if this is necessary for reasons of radiation protection. In the past, decommissioning projects were divided into several phases, with a separate license being granted for each phase. The experience gained from previous decommissioning procedures (licensing and supervisory procedures) for nuclear facilities in Germany shows, both about the technical execution and the technical rules and legal regulations to be applied, that adequate means exist to allow decommissioning projects to be licensed and carried out safely. As a result, the licensees reduced the number of phases foreseen for the latest NPP decommissioning projects to one or two.

Apart from § 7 (3) AtG and radiation protection law, few requirements in the legal and regulatory framework address specifically the decommissioning of nuclear facilities. The licensing and supervisory authorities stipulate the requirements for decommissioning in most cases with analogous application of the rules and guidelines that exist for the construction and operation of the facilities. The “Guide to the decommissioning, the safe enclosure and the dismantling of facilities or parts thereof as defined in § 7 of the Atomic Energy Act” (Decommissioning Guide) [3] includes proposals for an appropriate application of the sub statutory regulations for planning, preparation, and implementation of decommissioning projects as well as their licensing and supervision.

To keep the regulatory framework up to date, so that the necessary precaution in line with the state of the art of science and technology to prevent damage caused by the decommissioning of nuclear facilities is ensured in the future, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) prepares a concept how to develop sub statutory regulations for decommissioning once those regulations for construction and operation of nuclear facilities are not updated anymore as a consequence of the German phase-out decision.

One aspect in this regard is the technical qualification of responsible persons and the necessary knowledge of persons otherwise engaged in the decommissioning projects required by § 7(2) AtG. According to the Decommissioning Guide, the operator has to ensure that an adequate number of staff with the required qualification and knowledge is available in all phases and periods of the decommissioning project until release from regulatory control under nuclear and radiation protection law. The use of own staff as responsible persons in terms of the technical qualification guideline is to be maintained with regard to preserving the knowledge about the facility and ensuring the fulfilment of responsibility and control obligations.

4. MAINTAINING COMPETENCE

Experiences gained from the supervision of decommissioning projects show that a high level of safety is reached. To maintain this high level of safety under the prevailing circumstances of the German phase-out decision, the necessary personnel with the required qualifications needs to be maintained at all levels of the relevant interested parties (licensing and regulatory authorities, expert organizations, advisory bodies, utility companies, research institutes, higher education institutions, and industry). Recently, several incidents or even reportable events occurred in different NPPs, where components were dismantled that were not foreseen dismantling yet. Insufficient or misleading labelling of the components, weaknesses in the pre-job briefing of the (contracted) personnel, and deficiencies in the controlling duties of the licensee might have contributed to these incidents/events. A process was initiated to evaluate these incidents/events in order to come up with suggestions, on how to strengthen the dismantling processes to prevent the occurrence of such incidents/events in the future.

Under the joint leadership of BMUV and the Federal Ministry for Economic Affairs and Climate Action (BMWK), the federal ministries have developed a government strategy for competence building and the development of future talent for nuclear safety. The future demand of relevant interested parties was also taken into account. The framework setting “Strategy for Competence Building and the Development of Future Talent for Nuclear Safety” [4] was adopted by the German Government on 26 August 2020. It sets out specific catalogues of measures covering the fields of education and teaching, advanced and continuing training, research and development, knowledge retention, committee work and networks, international networking and cross-border activities, career prospects and recognition in society.

During the development process of the strategy needs/demand analyses were first carried out in order to then plan specific measures in advance. The needs/demand analyses were carried out in a step-by-step approach, with the first step being the identification of needs at the federal level. The second step identified needs beyond the federal level (e.g., licensing and supervisor authorities, advisory bodies, expert organizations, associations). The inquiries were carried out by means of questionnaires.

The needs/demand analyses also provide a good basis for dealing with the retirement of a large number of experienced staff. It identifies different areas of action on which measures to maintain and build expertise and specialist capacities should be focussed. For example, a large number of experienced staff of the competent licensing and supervisory authorities has already reached retirement age and left in the last few years or will do so in the years to come. This generation change represents a great challenge for the competent licensing and supervisory authorities, which is also addressed in the concept of the Federal Government. Vacancies are attractive for young people with a university degree in a relevant area of licensing and supervision, among other things because of the lifelong employment as a civil servant. In the decommissioning sector, the career perspective is 20 years. In the areas of waste management and radiation protection, there will continue to be attractive positions in the future. Available positions can often only be filled with applicants without relevant nuclear knowledge. This circumstance is countered by internal and external training and further qualification measures, internal job rotations as well as suitable measures to maintain competence and transfer knowledge.

5. PROGRAMME DEVELOPMENT AND IMPLEMENTATION

Setting end dates for the operation of the NPP in Germany allowed a better planning of the subsequent decommissioning activities. As a result, the licensing procedures of the NPP being shut down after 2011 were initiated well before the date of final shutdown and enable a significant shortening of the transition period from operation to decommissioning. Some decommissioning licenses could even be granted before that date (Philippsburg 2, Gundremmingen C).

With respect to the first dismantling activities, changes in strategy are recognized. Earlier decommissioning projects of NPP rather followed a phased approach starting with creating space in the facility for components and material processing. Dismantling and eventually packaging of reactor core internals, large components and remaining structures and components are implemented during the next phase followed by the clearance measurements of buildings and solid material which were separately licensed and conducted sequentially or only slight overlaps.

The latest decommissioning projects are regulated by two licenses, where the dismantling of the reactor pressure vessel (RPV) and the biological shield are addressed separately, or even a single license. In these projects, the dismantling of the reactor core internals is foreseen at the beginning. This has the advantage that components with higher dose rates are extracted from the facility early, which reduces the occupational exposure of the personnel for following dismantling activities, e.g., the dismantling of large components like steam generators and pressurizers and enables to dismantle the RPV sooner in the projects.

For large component dismantling, different strategies are applied. In some cases, dismantling is conducted in-situ (e.g., steam generators in Mülheim-Kärlich), cut and fragmented in smaller pieces in the former spent fuel pool (e.g., steam generators in Biblis) or extracted as one piece and transferred for external treatment in a dedicated treatment facility on the site (e.g., steam generators in Neckarwestheim und Philippsburg) or off-site (e.g., steam generators of the PreussenElectra fleet).

In any case, the components and materials processing infrastructure needs to be set-up in parallel to the dismantling activities. Possible delays in having the infrastructure ready to accept the respective material steams, buffer storages are foreseen insight of the facilities or even outside if the building in the supervised area of the site. Planning the needed infrastructure and streamlining the process of dismantling, buffer storage and processing in an efficient manner is recognized as a challenge in the decommissioning projects.

6. SUMMARY AND OUTLOOK

Decommissioning of nuclear facilities is progressing well in Germany. 27 nuclear power plant, six research reactor and two nuclear fuel cycle facility decommissioning projects are conducted in parallel as of 1 March 2023. The strategies for dismantling applied differ from fleet to fleet or in same activities even in the decommissioning projects of one fleet. There is no one size fits all and decision often driven by constraints that need to be evaluated on a case-by-case basis. The pure number of ongoing decommissioning projects coupled with the German decision to phase-out the use of nuclear energy for the commercial generation of electricity causes challenges for the German decommissioning programme. The goal to deliver the decommissioning projects in an efficient manner results in challenges with respect to logistical aspects and the availability of personnel. Experiences gained trigger the need to keep the regulatory requirements for decommissioning up to date, so that the necessary precaution in line with the state of the art of science and technology to prevent damage caused by the decommissioning of nuclear facilities is ensured in the future, and to the necessary personnel with the required qualifications needs to be maintained at all levels of the relevant interested parties (licensing and regulatory authorities, expert organisations, advisory bodies, utility companies, research institutes, higher education institutions and industry). For both aspects, concepts/strategies were developed and are being implemented in the moment, so that Germany is fit for purpose to conduct its decommissioning programme safely.

REFERENCES

[1] Decommissioning of Facilities, General Safety Requirement No. GSR Part 6, Vienna (2014).

[2] Decommissioning of Nuclear Power Plants, Research Reactors and other Nuclear Fuel Cycle Facilities, Specific Safety Guide No. SSG-47, Vienna (2018).

[3] Leitfaden zur Stilllegung, zum sicheren Einschluss und zum Abbau von Anlagen oder Anlagenteilen nach § 7 des Atomgesetzes, Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2021.

[4] Strategy for Competence Building and the Development of Future Talent for Nuclear Safety, The Federal Government, 2020.

4. FRAMEWORK TO ENABLE EFFECTIVE NUCLEAR DECOMMISSIONING

4.1. KEYNOTE ADDRESS OF THE VICE PRESIDENT

Dr. Marta ŽIAKOVÁ, Chairperson, Nuclear Regulatory Authority of the Slovak Republic, Slovakia

Madam President, Session Chairs, Distinguished Delegates, Ladies and Gentlemen,

I am pleased to welcome you to the second day of International Conference on Nuclear Decommissioning: Addressing the Past and Ensuring the Future. I would like to thank the IAEA for the opportunity to chair this day of the conference, focusing in particular on the enabling framework for the effective decommissioning of nuclear facilities.

Decommissioning is a normal stage in the lifetime of a nuclear facility, it cannot be avoided, and sooner or later all facilities in the nuclear fuel cycle, as well as small medical, industrial and research facilities, will need to be decommissioned. This stage in the lifecycle of facilities is becoming increasingly important, as it will be difficult to demonstrate the sustainability of the nuclear industry without managing the safe and environmentally sound decommissioning, and without safe management of resulting radioactive waste. The successful implementation of decommissioning and the safe achievement of planned and agreed objectives contributes to public confidence and acceptance of the continued peaceful use of nuclear energy. Especially in the context of the emerging effects of global climate change and the recent energy crisis.

In the last years and decades, decommissioning has become a growing activity worldwide due to the final shutdown of operational facilities for various reasons - aging, technical obsolescence, political decisions, and other reasons. A further increase in decommissioning activities is expected in the future. Therefore, decommissioning, as a constantly developing industry globally, should be accompanied by the corresponding development of policies, strategies, regulations, technical capacities, human and financial resources, and other elements of an appropriate framework that would allow for the effective and safe decommissioning of nuclear facilities.

Today, decommissioning presents new challenges, such as technological, regulatory, safety, financial, and various other aspects. These challenges require thorough preparation and the establishment of the mentioned framework for decommissioning. In addition, consistent and harmonised criteria are needed in terms of safety, quality, and cost-effectiveness. Such an appropriate framework ultimately contributes to achieving the desired goal of decommissioning: the safe conduct of decommissioning, protection of people and the environment, safe management of the decommissioning waste and the ultimate removal of all regulatory controls after completion of decommissioning.

Different players are involved in decommissioning planning and implementation (mainly governments, regulators, and operators/licensees), including numerous interested parties. Their roles and responsibilities, as well as communication mechanisms, need to be well established within the framework. In many countries, considering public input before completing decommissioning, especially in the case of a restricted release, can be a significant challenge.

Some decades ago, decommissioning was often carried out on an ad hoc basis, lacking a systematic approach, adequate waste management options, and sufficient resources. This approach led to delays in implementation, high costs, and increasing volumes of waste. Since then, significant progress has been made, and a global consensus has been reached on many key aspects of decommissioning. A number of decommissioning projects have been completed, including the decommissioning of 22 NPP units.

At the last Conference in Madrid, Governments were invited to develop national policies and decommissioning strategies if they do not already exist. National policies and strategies for the management of spent fuel and radioactive waste are generally developed and maintained by Member States. Such policies are usually based on internationally accepted principles and are regularly reviewed by the IAEA's peer review and advisory services. This recommendation led to the initiation of a new IAEA Safety Guide on national policies and strategies for the safety of radioactive waste and spent fuel management, decommissioning and remediation.

The Madrid Conference also recommended special attention to be given to regulatory activities during the decommissioning transition period, as well as to the timely development of decommissioning plans in accordance with relevant IAEA safety requirements. With the increasing number of permanent shutdowns of nuclear reactors, the importance of this issue is also growing in individual Member States.

The previous Conference further identified a number of requirements related to strengthening the existing legal and regulatory frameworks for the release of materials and sites for alternative uses after the cessation of activities involving radioactive materials. In that regard, a new guidance on release has been developed and is expected to be published soon. While the preferred option is unrestricted release, there is still no international consensus on the criteria for the restricted release of a site after decommissioning, and how these criteria should be derived and applied.

Related experiences and lessons learned in this area are now being discussed and analysed within the IAEA-led International Decommissioning Completion Project (COMDEC), which began in 2018. Feedback from the COMDEC project will be used in the ongoing revision of the WS-G-5.1 safety guide on release of sites from regulatory control.

A number of decommissioning projects are currently facing the challenges of completing decommissioning and reaching end state. These include, for instance, the Bohunice V1 NPP in Slovakia, consisting of two VVER 440 units with the V-230 reactor (twin), where two pressure reactors have been completely dismantled in situ. The beginning of demolition activities will follow after the removal of activated and contaminated concrete from the reactor shafts, which is still ongoing.

Progress has also been made in regulatory approaches to the decommissioning of accident damaged nuclear installations and related remediation activities (DAROD). The completion of the international DAROD project and the publication of the final project report in the IAEA TEC-DOC-1989 series responded to one of the gaps in the existing international safety standards and related guidelines identified in Madrid.

A suitable example of decommissioning of an NPP after an accident is the A1 NPP with a heavy-water moderated and gas-cooled reactor which is continuously being decommissioned. The reactor was shut down in 1977 after an operational accident with fuel damage. Currently, the preparation of the last decommissioning phase is underway, which also includes considerations about reaching the end state. A significant contribution to the smooth progress of decommissioning can be attributed to the regulatory framework created in the late 1990s, in addition to the creation of a financial mechanism and appropriate structure for radioactive waste management up to disposal.

In addition, a large number of smaller facilities remain to be decommissioned, especially in countries without nuclear power programmes. As a good example of the application of a graded approach, I would like to mention the publication of the IAEA's safety guide on the decommissioning of small facilities (medical, industrial and research) in 2019.

Despite visible progress in decommissioning over the last decade, some challenges persist, and new ones continue to emerge. Decommissioning is still a relatively new activity for many countries. In addition to recently shut down nuclear reactors, an increasing number of other facilities, including various types of nuclear fuel cycle facilities, as well as medical, industrial and research facilities, are entering the decommissioning phase, posing new challenges due to limited experience in this area.

Newcomer countries have the advantage of learning from existing experience to avoid some of the challenges faced by countries with ongoing decommissioning programmes.

Countries that are just initiating their decommissioning programmes would greatly benefit from the guidance and recommendations on best practices in developing national policies and strategies, regulatory frameworks, planning and implementing decommissioning projects, and communication with stakeholders, as these are based on the experiences of countries with more advanced decommissioning programmes.

As concerns the novel types of facilities, such as new small reactors using multi-module devices, decommissioning planning should be carried out at the design phase. Accordingly, regulatory framework should respond to this challenge and enable effective planning of decommissioning of novel types of facilities, as well as consider modification of requirements, and assess the possibility of using the existing legislative framework.

The availability of qualified and experienced personnel is likely to be one of the most important issues to be addressed in the future decommissioning programmes. A huge part of decommissioning activities is implemented over a relatively short period, usually within a few years, through a series of projects dealing with activities of different nature. Therefore, challenges related to competence development are also closely related to the diversity of skills needed in the short term. The transition from operations to decommissioning will involve a shift in culture, particularly in attitudes of operations personnel as they move from operating and maintaining the facility to dismantling and finally demolishing it.

Furthermore, the existing financial mechanisms for decommissioning are being challenged by the global economic crisis, and at the same time, new models are being explored. Estimating decommissioning costs and collecting the necessary funds for future decommissioning is threatened by the highly variable cost of inputs, which raises the need for means to ensure cost-effective decommissioning and management of decommissioning funds from the long-term perspective.

Today's agenda is dedicated to decommissioning frameworks, with particular focus on the aspects that provide for their complete and effective implementation. There will also be room for discussion of general principles and examples of good practice.

We have an ambitious agenda ahead of us, which presents a unique opportunity to examine the ongoing and accomplished decommissioning projects worldwide, and to inspire the incorporation of key elements into our national programs and nuclear decommissioning frameworks. I am confident that by doing so, we can enhance the decommissioning processes and implement them more effectively to meet the expectations of stakeholders and the public.

4.2. SESSION 3: POLICY, GOVERNMENTAL AND REGULATORY FRAMEWORK

Decommissioning is currently being implemented in many countries, and therefore wide experience already exists concerning the necessary infrastructure and frameworks to support these programmes.

This session considers national policies and strategies, governmental, regulatory, and institutional frameworks, including decision-making processes. A total of eight oral presentations were delivered by speakers from Spain, France, Sweden, Italy, Slovakia, Iraq, Argentina, and the United States of America, supplemented by eight posters.

There was a general recognition of the need to change regulatory approaches to decommissioning from prescriptive to dynamic and more flexible has been recognized in several countries due to the increasing complexity of some decommissioning projects. This new approach is based on a redesigned regulatory framework and inspection approach, using visual communication tools to promote positive mindset and behaviour considering the views of stakeholders.

Efforts to protect the environment have recently expanded to include various aspects of sustainability in the context of nuclear decommissioning. These aspects are crucial for the circular economy and are gaining in importance. However, the current conceptual approach to decommissioning is inherently limited and will need to be adapted if sustainability is to be truly implemented.

There is a need to discuss the sustainability of funding mechanisms and decommissioning funding schemes. Ensuring sufficient funds for decommissioning is a challenge considering circumstances such as inflation and rising utility prices.

As more and more decommissioning projects enter their final stages, the guidelines for site clean-up and verification necessary to release a site from regulatory control are increasingly important. In several countries, there is a visible willingness to derive lessons learned and to analyse the experience from the process of granting and terminating licenses for the decommissioning of nuclear facilities.

The opening presentation of this session provided an overview of the evolution of the José Cabrera NPP (*FIG. 3. Jose Cabrera NPP site in Spain as of November 202FIG. 3*) decommissioning process from a regulatory perspective, focusing on the current status of the site and the regulatory challenges to be taken

FIG. 3. Jose Cabrera NPP site in Spain as of November 2022 (CSN, Spain)

up in the near future, and highlighting the lessons learned in the process. José Cabrera is facing the final phase of the decommissioning process, with a clean-up plan currently underway. In this context, a working group was set up between Spanish Nuclear Safety Council (CSN) and Enresa to analyse the experience of the decommissioning of the José Cabrera NPP with a view to applying it to the upcoming decommissioning processes. The working group was tasked with identifying the difficulties encountered by these companies in the licensing process for the José Cabrera NPP and to develop mechanisms for improvement that would facilitate the forthcoming decommissioning processes.

French presentation addressed the issue of safety in ongoing decommissioning and legacy waste retrieval and conditioning projects. French Nuclear Safety Authority (ASN) experience shows that regulating decommissioned facilities can be challenging when it comes to complex projects and timely decommissioning. ASN's initiative has been to work openly with Orano Recyclage La Hague to test and implement various initiatives to enhance regulations in a more dynamic and effective way. Four years of trials have resulted in successful good practices including a redesigned regulatory framework, visual tools, new kind of inspections and enabling mindset. ASN intention now is to build on these benefits by widening these enabling regulations from La Hague to the other shutdown facilities.

Increasing attention is being paid to other aspects related to the wider environmental impact of decommissioning activities, including addressing sustainability issues. A new conceptual framework for decommissioning to support the application of circular economy principles in the nuclear installation life cycle was presented in papers from Sweden and Norway. They took as an example Sogin, the company responsible for the decommissioning of Italian nuclear facilities, which has developed and implemented a circular economy strategy to reduce the environmental impact of decommissioning activities in the early phases of its projects. Sogin has identified three drivers that lead it to apply a circular economy strategy in its activities, namely: re-use of structures, systems and components, recycling of materials and overall reduction of environmental impact.

As reported by the Italian authors, the state-owned company Sogin has made a strong commitment to transparency and has put in place communication plans that comply with Italian environmental compatibility laws. In addition to publishing information about decommissioning projects on the Internet and holding press conferences, Sogin has developed RE.MO. (which stands for Rete di Monitoraggio, or Monitoring Network), a portal that allows the public to follow the company's work. With the introduction of RE.MO., Sogin has achieved its objective of increasing the transparency of the activities that carries out at Italian nuclear sites. This has strengthened its relations with the institutions and the public.

Ensuring adequate appreciation of operators' contributions to decommissioning funds through inflation compensation should be an integral part of prudent managed funds for nuclear end-of-cycle activities (decommissioning, storage, processing, and disposal of RAW and SNF). The Slovak paper therefore sees the need to include one more area, namely financial management and investments, in a holistic view of the nuclear industry. Especially when other forms of electricity generation do not have to consider long-term operation and are not obliged to create their own future decommissioning/dismantling funds.

The Iraqi authors presented that the decommissioning of destroyed nuclear facilities is a complex and challenging process because it depends mainly on radioactive characterization, which is used to determine the decommissioning strategy. In Iraq there are difficulties due to the lack of information from the operation period including the possible accidents and the subsequent looting of sites of destroyed facilities. Iraq has no previous experience in decommissioning of nuclear facilities and therefore appreciates the IAEA's assistance in overcoming most of the challenges by providing advice, recommendations, equipment to carry out the decommissioning activities.

The importance of considering ways to improve the decommissioning process for future facilities was highlighted by the Argentina paper. It is essential to find solutions to incorporate a methodology that prioritizes the ease of the decommissioning from the design and construction of nuclear facilities, without compromising safety or functionality. This can be achieved through the development of tools that assist in decision-making during the design process and by exploring additional options such as dismantling of large components for the off-site treatment or immediate dismantling.

The US NRC is updating and developing guidance on site remediation, survey, and dosimetry considerations for discrete radioactive particles in order to make the decommissioning process more efficient.

4.3. SESSION 4: COMPETENCE DEVELOPMENT

Once nuclear facilities reach the end of their working lives and are prepared for decommissioning, a different type of organizational structure will need to be established. This is because the operation of nuclear facilities and their subsequent decommissioning place significantly different challenges on the managers and the workforce present at those facilities. These differences stem from the distinct nature of facility operation (a process-based activity) versus decommissioning (a project-based activity). The organizational transformation needs to ensure that personnel are competent to undertake the tasks assigned to them, and that they understand the behavioural changes required to perform effectively in a working environment that is more dynamic (i.e., less stable) during operation.

A pre-requisite for defining organizational needs for decommissioning is an exercise to define the resources and skills needed to implement the decommissioning strategy set out in the decommissioning plan, along with the contacting strategy planned to be applied. This involves defining the extent to which personnel will be employed by the implementing organization (licensee) or whether external specialist contractors will be used. When an approach based on maximizing the use of own personnel is chosen, significant efforts are likely to be made to retain staff from the operating phase of the facility. Competence development will be employed to ensure that retained personnel are capable of fulfilling their new responsibilities. Where skill gaps are evident, a recruitment process will need to be followed to fill identified gaps, and incoming staff will require special training to ensure they develop appropriate skills and behaviours.

Competence development is essential at all levels of a decommissioning organization, and the long duration of programmes presents specific challenges for preserving competencies. Competency typically involves a combination of knowledge, skills, and attitudes (or behaviours). In general, personnel involved in decommissioning are expected to have acquired the necessary basic knowledge to perform their duties by the time of their recruitment often through academic or vocational education. Competence development for decommissioning primarily focuses on skill development – through training and access to necessary sources of knowledge. Moreover, it ensures that behaviours are appropriate for work in a demanding and hazardous environment. Training plays a crucial role in this regard, together with fostering an appropriate culture throughout the organization.

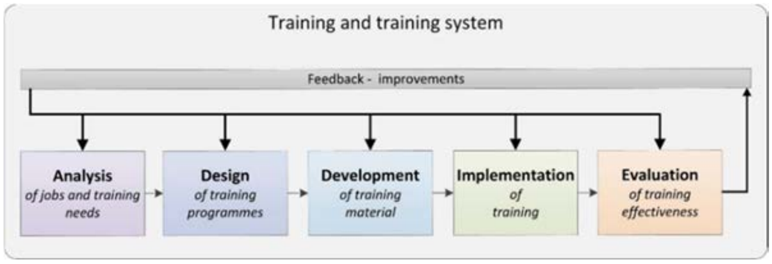

FIG. 4. Overview of the SAT Process (reproduced from Ref [4])

Training plans and programmes are usually defined using a methodology known as Systematic Approach to Training (SAT) [4], which is widely used throughout the nuclear industry (*FIG. 4*). This methodology is based on the ADDIE model for training development:

— A: Analysis of needs
— D: Design learning objectives
— D: Develop course materials
— I: Implement training.
— E: Evaluation of results

Application of the outcomes from the evaluation process aims to ensure that a process of continuous improvement takes place.

Leadership has traditionally played an important role in the nuclear industry due to its importance in establishing a strong safety culture and promoting good safety performance. This role remains crucial during decommissioning. Good leadership is also important in fostering a work culture appropriate for decommissioning throughout the entire workforce, including contractors. Achieving this may require the implementation of a change management programme to ensure a seamless transition from operation to decommissioning. Project leaders also play an important role in establishing communication strategies with stakeholder groups, including local communities. Therefore, leadership development programmes need to recognize that good leadership skills are acquired through engagement with others and learning from experience.

The session included presentations and discussions on various aspects of competence development, including workforce training (France and the Russian Federation), leadership (Indonesia), and university-level educational programmes for professional staff (France and the Russian Federation).

The importance of developing a systematic approach to the development and implementation of training programmes for decommissioning personnel was emphasized (e.g., France). Such an approach should include:

— Elaboration of a long-term plan;
— Identification of needs in terms of resources and skills;
— Analysis of the existing competence base;
— Consideration of feasibility of transforming existing competencies (from operation) to required competencies for decommissioning;
— Communication of needs/plans with the workforce;
— Deployment of training programmes;
— Evaluation of outcomes.

It was noted that certain types of workforce training may be effectively delivered by specialized training institutes, which may be closely linked to the decommissioning organization (e.g., France, Russian Federation). The rapid evolution of digital technologies (including use of virtual reality environments, simulation of tasks and serious gaming), together with developments in robotics (e.g., allowing operators to sense the response of virtual tooling) is playing an increasingly important role in supporting workforce training. The importance of adapting training programmes to identified needs was emphasized.

The role of leadership in the motivation of personnel and nurturing appropriate behaviours, with appropriate flexibility given the dynamic nature of decommissioning, was emphasized (e.g., France, Indonesia). It was noted that is particularly important in terms of developing and sustaining a strong safety culture but applied also to establishing a mindset focussed on effective decommissioning delivery.

Specialized Master-level degree programmes focussed on decommissioning and radioactive waste have been established in recent years (e.g., in France and the Russian Federation). These programmes address various aspects including (in various combinations):

— Legal and regulatory requirements;
— Project and safety management;
— Technological requirements for implementation.

It was noted that several educational programmes have been established on a multinational collaborative basis, e.g., the European Leadership for Safety Education (ELSE) project in France, co-funded by the European Union, ELSE comprises a combination of online (MOOC[1]) and face-to-face courses. It is worth noting that the World Nuclear University provide extensive higher-level educational programmes.

4.4. SESSION 5: MANAGEMENT OF WASTE FROM DECOMMISSIONING

The Management of Waste from Decommissioning Session provided 7 presentations from Germany, France, India, United Kingdom and China describing their continual efforts in waste reduction, material reuse and recycling. In addition to that 7 posters were presented.

The German presentations (TUEV Nord and Framatome GmbH) addressed the clearance of materials for disposal in landfills, the influence of the past (inventory) and the way forward (waste routes) on decommissioning projects. It was highlighted that the German nuclear dismantling projects are using by default a decommissioning strategy from "hot" to "cold" or from the inside to the outside. The overall dismantling sequence typically consists of radiological evaluation and characterization, system decontamination, segmentation, and packaging of the main primary components into the waste containers, removal of other large components while considering interactions with waste management and existing material route options including landfills disposal.

Presentations from France (Andra and Orano) provided an overview on optimizing decommissioning and related waste management by enhancing innovations and considering the principles of circular economy in the French national radioactive and complex waste management programme – see illustrative *FIG. 5*. Several practical examples of research developments within the French national innovation programme were provided (i) to preserve existing surface disposal facilities, (ii) on treatment and conditioning of radioactive waste, (iii) to optimize a site and waste characterization and (iv) to support Cigéo project on deep geological disposal. Examples of circular economy practices presented by Orano included the low-level metallic materials recovery project, asbestos destruction and by-product recovery project and spent ion exchange resins cementation experience.

The presentation provided by India (Bhabha Atomic Research Centre) introduced the development of their solid radioactive waste monitoring system for the clearance of gamma emitters during decommissioning of nuclear reactors. The system is remotely operated and automated including 3D mechanical manipulator with a controlled automatic sequencing of movement. The system provides for

FIG. 5. Illustration of waste management hierarchy (Courtesy of ANDRA, France)

[1] MOOC – massive open online course

detection of very low-level radioactivity of solid waste in 200 litres drum. Due to the high accuracy and lower detection levels, it enables utilization for segregation of inactive waste. It is also capable to detect embedded point sources (hot spots) with high accuracy.

The United Kingdom presentation (Cyclife-UK) covered development of a national framework to address the waste characterization challenges and promote changes in a large-scale decommissioning scenario. Implementation of their framework started with the identification of concerns and selection of topics for further investigation followed by detailed exploration of topics and mapping of a current status and a proposed way forward.

The presentation from the Nuclear and Radiation Safety Centre covered the radioactive waste minimization practices in decommissioning of China's nuclear facilities. The presentation highlighted the following needs: to increase awareness of the involved staff on the importance of waste minimization, to further carry out research on practical limits, procedures, information, and expert systems and to strengthen specific technologies for waste minimization and characterization.

The session noted the importance of good radioactive waste characterization and data preservation. Both are essential for filling knowledge gaps and facilitating the selection of effective dismantling and decontamination methods and optimizing waste management strategies. Practical information management not only supports decision-making, enabling smooth implementation of the waste management hierarchy, but also allows management efforts and resources to focus on aspects that pose the most adverse environmental impacts. This issue is particularly important in legacy waste management, as noticed in many national decommissioning projects. Experience has long confirmed that enhanced remote and in-situ characterization capabilities could benefit the initial and long-term waste characterization process. Developing and deploying more automated, advanced technologies to reduce workers' radiation exposure, along with good project planning, monitoring, and oversight of activities, can enhance decommissioning safety and achieve the decommissioning objectives as planned.

The session concluded that the main decommissioning challenge is the adoption of clear national radioactive waste management policies and developing final disposal solutions. Countries with clearly defined radioactive waste management policies (e.g., Finland) have demonstrated their capacity to facilitate more effective decommissioning activities. This session specifically remarked on the importance of engaging with stakeholders during decommissioning planning, which should start early during the design and construction phase, with periodic updating during the operational life of the nuclear facilities. Stakeholder engagement is crucial to address pertinent public concerns and enhance acceptance of decommissioning projects.

4.5. SPECIAL SESSION: EURATOM ACTIVITIES ON THE DECOMMISSIONING OF NUCLEAR FACILITIES

Eleven presentations were provided during the session organized by EC Research and Innovation Directorate. The introductory overview presented the multi-financial framework of the EC for 2021-2027 (*FIG. 6*), the main achievements of the Horizon Europe and the Euratom Programme and an outline of the follow-on presentations.

Project ANUBIS (Advancing NUclear dismantling in Belgium through Improving Sustainability) was presented to develop the necessary technologies and competences to maximize the reuse and recycling of materials coming from future decommissioning operations of the Belgian NPPs in a cost-efficient way. Together with industrial partners, SCK CEN will implement innovative digital technologies to improve decommissioning operations such as material characterization or decontamination. SCK CEN has recently been scaling opportunities for industrial applications by building the material treatment facility that can also serve as innovation hub for decommissioning technologies development.

Optimization of metallic waste characterization and procedures for waste minimization and recycling within the EU project PREDIS (Predisposal Management of Radioactive Waste) were presented and discussed. Neutron activation calculations of the reactor construction materials allows classification of activated metallic waste and non-activated waste with surface contamination. Both are based on the knowledge of difficult to measure radionuclides determination. Identification of difficult to measure nuclides using radiochemical analysis is costly, time consuming, and impractical for large numbers of waste packages. Internationally available experience offers the scaling factor methodology, which can usually be applied to the evaluation of difficult to measure nuclides inventory for different waste streams.

Attractive solutions for the encapsulation of ashes resulting from thermal treatment of ion-exchange resins have been introduced. Spent ion exchange resins represent an important waste stream generated during the operation of nuclear power facilities. Thermal treatment of resins is an effective waste reduction method though it results in production of some amount of radioactive ashes. Efforts to propose solutions for safely managing the radioactive ashes have been carried out within the framework of the EU project PREDIS. The Institute of Environmental Geochemistry of the Ukrainian National Academy of Sciences presented the immobilization of thermally treated organic wastes in a geopolymer binder.

The pyrolysis of spent ion exchange resins has been presented as the one of the most effective methods for reducing radioactive waste volume. The above-mentioned Institute of Environmental Geochemistry has developed a novel technology and equipment for the thermal treatment of radioactive solid organic waste. The thermal treatment unit consists of a hopper for loading waste, a gasification chamber, a gas afterburner, a heat exchanger, and a smoke exhauster. The system can expand functions using a plasma torch. Ash generated after the gasification process is removed from the system and loaded into special steel containers for further encapsulation.

The Euratom Council Directives and IAEA Safety Standards provide the basis for the underlying legal and regulatory framework in radioactive waste management and decommissioning. However, the implementation of international safety standards and EU directives can vary from one country to another, as they are adapted to local considerations and national policies. Related to waste management and decommissioning Project HARPERS (HARmonized PracticEs, Regulations and Standards), aims to establish and clarify the benefits and added value of more aligned and harmonized regulations, practices, and standards. This includes exploring possibilities for shared processing, storage, and disposal facilities between Member States. Identifying relevant regulatory differences across Member States, assessing the rationale for these differences, and establishing the potential for their harmonization, especially regarding cross border services/facilities, transitioning to circular economy principles, and implementing advanced technologies, are the primary focuses of the HARPERS project.

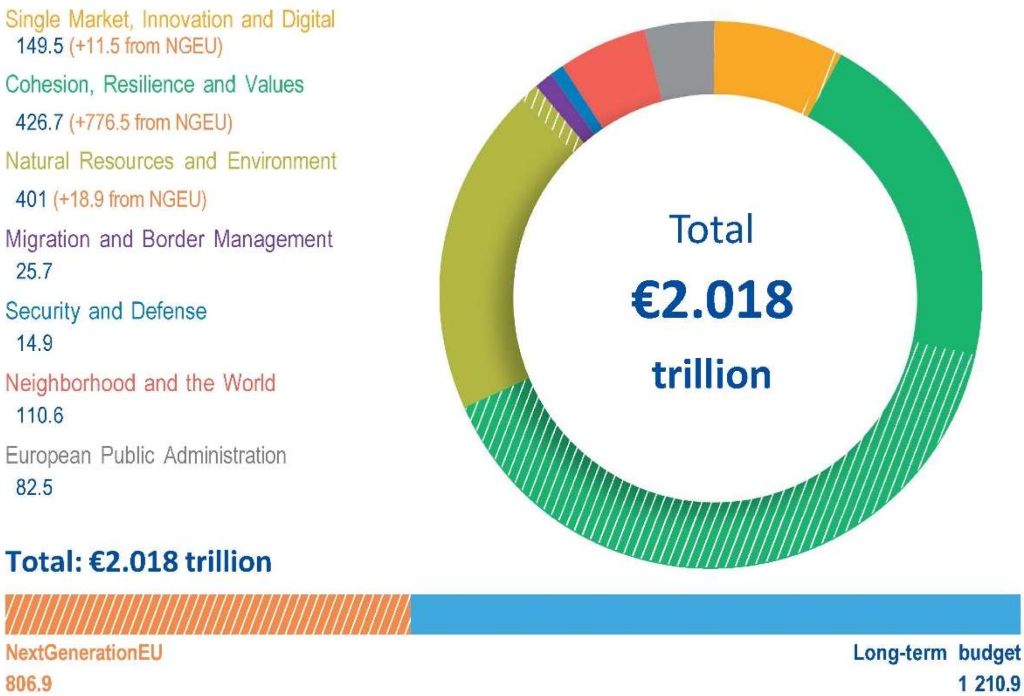

FIG. 6. The ECs 2021-2027 long-term budget & Next GenerationEU - 2024 (courtesy of EC)

Project CLEANDEM (A Cyber physicaL Equipment for unmAnned Nuclear DEcommissioning Measurements) was introduced in the follow-up presentation. Human resources are still needed for operations conducted in the dismantling steps, over a wide range of radiological conditions, from the harsh initial conditions to the final decommissioning stage. Eleven leading actors from four European countries' nuclear industry and research, have joined their expertise and efforts in the pan-European CLEANDEM consortium to develop a mobile unmanned ground platform, equipped with upgraded highly mature detection technologies for radiological measurements. The project will also focus on improvement of low-cost sensors for rapid neutron/gamma and distributed dose rate mapping, neutron/gamma detection and identification, and air and surface contamination monitoring. These efforts will be supported by continuously updated Digital Twins containing all available radiological information.

The Euratom project MICADO with its innovative procedure for the characterization of radioactive waste packages was presented and discussed. Waste management is a topic of public debate worldwide. Regardless of the waste origin, the primary concern is the radiological emissions and their impact on human health and the environment. The MICADO project initiated under the H2020 Euratom call, aims to demonstrate the feasibility to improving the characterization of radioactive waste packages. This is achieved through a toolbox of up-to-date and novel gamma and neutron detection technologies, functioning as modular elements, along with a digital software platform used as a basis for the digitalization of detector information and the off-line analysis for uncertainty assessment.

Project PLEIADES (PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processES) was also presented and discussed. It is an international project that receives funding from the Euratom research and training programme 2014-2018, aiming to make the decommissioning of nuclear facilities more efficient, by demonstrating innovative digital decommissioning approaches inspired by the BIM (Building Information Modelling) concept. BIM provides a digital twin and enables all information related to a building to be managed through a central 3D model, enhancing information exchanges between different works and enabling implementation scenario simulations. PLEIADES applies this concept to the dismantling domain and demonstrates how a BIM-like models (containing data required for decommissioning planning) can be used for scenario simulations improving safety, minimizing radiation exposure, optimizing costs and schedules.

Among innovative technologies that could be used, laser cutting technology is one of the most promising in this context compared to conventional cutting techniques currently deployed, especially for both PWR and BWR type reactors. A European Consortium composed of 6 companies (ONET Technologies, CEA, IRSN, Tecnatom, EQUANS and Vysus Group) has been granted an H2020 project called LD-SAFE (Laser Cutting Demonstration for Nuclear Power Reactors Dismantling). This project focuses on removing the last technical, financial, and psychological barriers to propose laser cutting technology as an alternative to the conventional cutting techniques used for the decommissioning of mainly power reactor internals and pressure vessels. The purpose of the LD-SAFE project is to demonstrate that both the in-air and underwater laser cutting technologies are effectively operational for the dismantling of the most challenging components of light-water reactors.

The decommissioning of shut down graphite moderated nuclear reactors worldwide is still in its early stages, with most reactors in "safe store" condition. The complex geometry, design and large dimensions of such reactors make their decommissioning an industrial and technical challenge. The H2020 project INNO4GRAPH (INNOvative tools FOR dismantling of GRAPHite moderated nuclear reactors) is an example of international collaboration to address common challenges connected to graphite retrieval operations. The project started in September 2020 for a three-year period gathering 13 entities from five different countries with graphite reactors undergoing the decommissioning. The INNO4GRAPH project aims to support operators in defining the most optimal ways to decommission graphite reactors, including tools that can help to safely remove radioactive material, and cost-efficient solutions for dismantling operations in reactors of such complexity and dimension. This goal will be achieved through the development of physical and digital tools and methods to support the decommissioning of European graphite reactors.

5. FRAMEWOK TO MANAGE NUCLEAR DECOMMISSIONING

5.1. KEYNOTE ADDRESS OF THE VICE PRESIDENT

Mr. Brian WILCOX, Director of Reactor Decommissioning, Canadian Nuclear Laboratories, Canada

The theme of today is Managing Nuclear Decommissioning.

We begin the morning with presentations on The Preparation for Decommissioning. This session shares experiences on the transition from Operations to Decommissioning, Planning for Decommissioning, and Optimization for large complex national projects such as the decommissioning of nuclear plants in Japan.

In the parallel session, the theme is the Decommissioning of Nuclear Fuel Cycle Facilities. Again, there are excellent presentations on the challenges and risks of physical work and the strategy and resource management related to lifecycle projects; many of which take years.

In the afternoon, you will be treated to presentations on developing and optimizing programs. Again, lessons learned will shared on the management, optimization, and successes of very interesting and complex projects such as a fleet approach to reactors and prioritization of very complex and geographically dispersed projects.

The day continues with presentations on the final phase of decommissioning – defining and achieving the end state. Again, an outstanding opportunity to learn from a variety of international speakers.

I want to share some of my experiences in the strategy and implementation of the Management of Decommissioning Projects. To give you some context, my organization is performing decommissioning at 6 sites located across 3 Provinces in Canada. These range from the first power reactor to produce electricity in Canada to very complex, multi-mission sites that performed research on reactor fuel, reactor safety, isotope production and development of waste disposal approaches including deep geologic disposal.

Management approaches to projects vary just as much as the projects themselves, and there is no perfect approach. Certainly not a complete list, I will touch on these topics:

- Establishing a Decommissioning Organization;
- The importance of a defined End State and Waste Management Plan;
- Creating, Monitoring and Managing a Decommissioning Strategic Plan;
- Public, Indigenous and Stakeholder Engagement;
- Culture and Morale;
- Flexibility and Adaption.

Implement an organization whose sole mission is to plan and execute decommissioning work. This helps in the transition from operations, and it creates a clear mission for the team. Typically, a decommissioning organization is comprised of Project Managers, Project Engineers, Schedulers and Field Supervisors. The workers that perform the physical work (characterization, deactivation, dismantling) can be part of the organization, obtained through the larger organization matrix or contract.

Typical to have a separate department for work authorization and to ensure licensing adherence and safety is rigorous. This arms-length approach ensures organizational focus on both important missions. There are important support organizations that are required and typically are separate from the core decommissioning team. This includes licensing, environmental protection, waste management, procurement, safety, communications, finance, project controls and more. Build the decommissioning department early for best results.

Start with the end in mind, ask yourself some important questions:

- What is the required Physical – Radiological – Chemical end state targets?
- What is the plan for site re-use?
- What infrastructure will remain?

To build an effective decommissioning plan and reduce project risk, you must know your end state requirements. There are many considerations here. What are your waste streams and realistic disposal or storage options? This must consider all types of waste, radioactive, hazardous, re-usable, and recyclable. Who are the decision makers (owner, government, regulator)? Is there a state or regulatory policy, or better yet a clear national strategy? What international guidance may impact the project? There are plenty of projects underway that do not have clarity of final end state. The measure of how clean is clean has not been established. Where is the waste going is not fully vetted. What is the required post closure monitoring or other post-closure institutional requirements?

In the absence of a clear end state:

- Work done is at risk of re-work;
- Schedules and budgets are not reliable;
- You risk alienating the public by "changing gears".

Let me share a quick example of end state risk and loss of public confidence. In the 1990s the decommissioning strategy for one of our reactors was complete dismantling. The project prepared the planning and was close to starting the execution of work. Resulting from a change in the management model of the program, the desire to accelerate decommissioning work, and the absence of waste disposal options, the strategy was changed to partial dismantling and conversion of the facility into a permanent disposal site. The engineering and long-term modelling predicted safe performance with excellent isolation and containment of the waste. From a technical perspective, this made sense. But this change in strategy had immense public and Indigenous implications. Indigenous nations want all waste removed from their traditional territory. Former staff who worked their whole career on deep geologic disposal felt this was the "cheap approach" and the public "not in my back yard" sentiment was substantial. What started as a means to accelerate decommissioning and partly solve the waste dilemma has introduced substantial project schedule and cost implications.

So, you now have a clear, agreed upon end state! And you have a Decommissioning Organization staffed by motivated, bright people. Next is to develop a strategic plan to achieve the mission and the end state. Start by building a high-level plan. Break up the mission into a structure that is organized by project. Create a time phased strategy. What needs to be done first? How do facilities integrate with each other? Are there priority hazards to focus on? Following principles should be considered to address those questions:

- Build this into a schedule. Create a sustainable allocation of resources (money, people) to deliver smoothly;
- Utilize a rolling wave approach. Implement detail in the shorter term (~3 years) with a more strategic plan for longer range projects where planning is incomplete;
- Include stakeholders/technical support organizations for best accuracy and buy-in;
- Regularly review and adjust your plan.

Nuclear stigma persists and trust is low with the public and especially Indigenous Nations. The local community relies on nuclear facilities for good jobs, which decommissioning can be considered a threat. It is therefore critical to build relationships with external stakeholders, the public and Indigenous communities. Invite people to visit the site and see first-hand what is happening. This helps with relationships and works to diminish fear and stigma.

Areas to focus include environmental performance/monitoring, emergency management, end state, transportation, contracting. One of the pictures is an Indigenous citizen working with our environmental techs to collect traditional foods such as mushrooms that are sampled and analysed to show no impact by the site. This slowly rebuilds confidence in harvesting and other traditional activities around sites.

But it takes longer than you think to establish good relationships, and this is an important ongoing mission. It doesn't work to conduct a round of engagements and then stop until the end. Invest in resources to engage regularly.

Effective decommissioning is inextricably linked to a focused, engaged workforce. Every employee needs to identify their job with the mission, e.g., how they fit in.

Internal Communications are very important. At times it will feel repetitious and low value. Review plan regularly and adapt to keep it fresh. Staff are a very important external communicator. How they feel about their jobs and the overall mission is how they speak to their family and friends, creating a community view of the decommissioning organization.

At critical times such as operations shut down, turn-over of site management, or approaching end of decommissioning, create focused engagement plans. Morale can ebb and flow dramatically, but transparent and clear communications help. Leaders need custom staff engagement plans. Especially important for mixed on-site/off-site staff and where multiple sites exist. How do you stay in touch with staff and build relationships? Develop and implement transition plans, especially for new leaders from a different culture/site/country. Assumptions can be devastating.

Decommissioning is challenging task with many project risks. Due to long lengths of projects, unplanned changes to regulations can occur. What may have made sense early in the program, is no longer the case. Have a good trend (early warning) system to communicate potential for change. Employ a sound change management process. Utilize your engagement to inform stakeholders early. Most of all, be willing to change.

In the 1990s the decommissioning strategy at one site proposed in situ disposal of clay lined trenches containing operational waste. This was essentially authorized following the environmental assessment, but required a final safety case before could proceed. The project plan and necessary funding was developed. Fast forward a couple of decades to today. Regulatory policy changes have resulted in more substantial requirements for disposal in situ such as multiple engineered barriers, essentially removing this as a project alternative. To make things more complex, there is no alternative waste disposal option currently available. So have a good change management process and expect change will occur.

These are just some of the management issues that need to be considered and implemented for success in decommissioning projects. Enjoy the presentations throughout the day and take advantage of the experiences and lessons learned shared by our colleagues at projects around the world.

5.2. SESSION 6: PREPARATION FOR DECOMMISSIONING

While decommissioning-by-design concept is increasingly applied to newly built reactors, for the current aging nuclear fleet the transition period from operation is an essential time to prepare for decommissioning. The IAEA's Safety Report for 'Safety Considerations in the Transition from Operation to Decommissioning' [2] (SRS No.36) states that "the goal during the transition period is to achieve a significant reduction in radiological hazards through the safe termination of operational activities and removal of radioactive material, and to place the facility in a stable and safe condition until the decommissioning strategy is implemented. During this period, control of any remaining spent fuel, other radioactive material or nonradioactive hazardous material should be maintained, and the safety of the workers and the public, as well as protection of the environment, should be ensured".

In this session, the European Nuclear Installation Safety Standards (ENISS), which represents the nuclear utilities and operating companies from 16 European countries, highlighted the principles for developing transition from operation to decommissioning. ENISS stressed that the transition phase needs to be considered as a meta-phase covering the end of the operating phase until just beyond the start of the decommissioning. ENISS provides technical inputs based on the experience feedback from its members, which is the basis of its legitimacy. The following *FIG. 7* was presented to showcase the significant extent of the transition period.

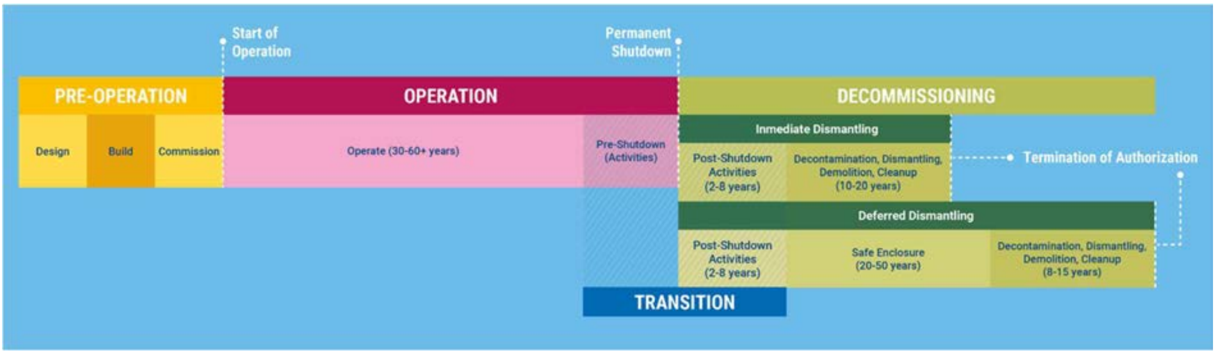

FIG. 7. Nuclear facility lifecycle

The focus of this work is on licensing and organizational change. To communicate the common position, they have developed four principles for a successful transition:

— Principle 1: Strategic direction is provided by the licensee to prepare for the decommissioning of a nuclear facility;
— Principle 2: Active preparation activities commence sufficiently ahead of the anticipated end of electricity production;
— Principle 3: The licensee engages early to develop an outcome focused environment with key stakeholders including the regulator, to achieve a reasonably practicable and proportionate risk informed transition strategy;
— Principle 4: Sufficient focus is given to the management of organizational change ahead of and during the transition period.

The second presentation showcased the work of another working group focused on the preparation for decommissioning: the WANO Transition to Decommissioning Industry Working Group (TTD I-WG). The WANO TTD I-WG also recognized the importance of the transition phase and its critical role in ensuring subsequent smooth decommissioning phase. As a complement to the principles offered by the ENISS, the WANO TTD I-WG presented a roadmap covering all the topics that should be considered by a licensee when shutting down a nuclear reactor. The structure of the roadmap shown in *FIG. 8*. The “Transition to Decommissioning Roadmap” [3] provides guidance for a safe and cost-effective transition phase from operation to decommissioning of NPPs while excluding the dismantling and restoration phase.

The other two presentations of this session exposed industrial examples of well-prepared decommissioning projects, one in Brazil and one in Japan. The presentation from Brazil explored the comprehensive planning required for the transition period of the Angra-1 nuclear power plant, focusing on achieving safety and efficiency from its permanent shutdown to safe enclosure. The example covered

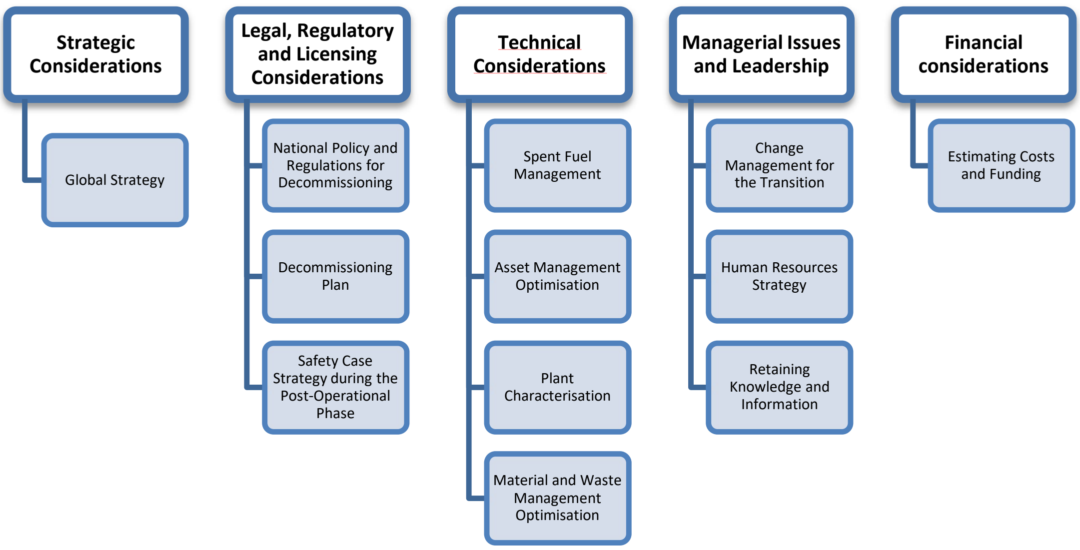

FIG. 8. Transition to Decommissioning roadmap contents: grouped in five topics.

a wide range of activities, regulatory requirements, safety assessments, and resource allocations, all aligned with the deferred dismantling strategy, considering the presence of two additional nuclear power plants on-site.

The presentation from Japan highlighted the findings of a study on the Japanese nuclear fleet. For sites with multiple units, the efficient use of interim storage enables the sequential decommissioning of multiple units.

To create an average decommissioning process, they selected 13 light water reactors (LWR) plants, excluding Fukushima Daini (2F), and similar cases. The average schedule plan is about 32 years. They considered the second stage as an adjustment period and reduced this 12-year phase to 10 years, thus making the total decommissioning duration 30 years.

— In Japan, longer safe storage periods increase the total cost as maintenance and management costs (labour costs) accumulate. There is a need to minimize these maintenance and management costs;
— Large maintenance costs are due to the retention of spent fuel, making the removal of spent fuel a top priority;
— Safe storage could reduce dismantling and disposal costs. Conversely, shortening the total process would increase costs, which would be offset by maintenance costs;
— There is no domestic disposal site for low-level radioactive waste generated from decommissioning. Given the current and expected number of years of operation, the process should be more than 25 years, and the early identification of disposal site's locations is necessary.

If an interim storage facility is prepared, even when its construction and maintenance costs are included, the total decommissioning cost is less than the increased costs due to the uncertainty of the disposal site location. Therefore, in Japan, an interim storage strategy makes economic sense if its location is better examined than that of a disposal site. This holds true even for multiple units or multiple sites. Finally, low-level interim storage facilities are well worth considering.

5.3. SESSION 7: PROGRAMME DEVELOPMENT AND IMPLEMENTATION

Experience from decommissioning projects suggests that the decommissioning of nuclear power plants could be made easier if it received greater consideration at the design stage and during the operation of the plants. Better forward planning for decommissioning results in lower worker doses and reduced costs. When appropriate design measures are not taken at an early stage, their introduction later in the project becomes increasingly difficult. Hence, early consideration may lead to smoother and more effective decommissioning. It is now common practice to provide a preliminary decommissioning plan as part of the application for a licence to operate a nuclear facility. This means, that decommissioning issues are considered during the design process. Although many design provisions aiming at improved operation and maintenance benefit decommissioning as well, designers also need to consider issues that are specific to decommissioning, such as developing sequential dismantling and providing adequate exit routes. These issues and more were discussed in this session that comprises from 8 presentations from Germany, Lithuania, Spain, the United States of America, Finland, the United Kingdom, Sweden and the Russian Federation, along with 7 posters.

Preparations for the Successful Dismantling of Ringhals 1&2 RVI and RPV were discussed. The Ringhals site (shown on *FIG. 9* below) is located on the Southwest coast of Sweden and hosts four nuclear reactors, 1 BWR and 3 PWR. The first two units were permanently shut down in 2019 (unit 2) and 2020 (unit 1). Ringhals unit 1 is an 881 MWe ASEA-ATOM BWR and unit 2 is an 852 MWe Westinghouse PWR. This project is challenging due to the presence of both BWR and PWR reactor types, and the segmentation includes both the internals and the RPVs. The Ringhals site has two reactors still in operation, which presents an additional challenge. The segmentation of the RPVs will be done dry and with a mix of thermal cutting with oxy-gasoline technology and mechanical cutting for some parts. Dry thermal cutting was chosen due to the schedule advantages provisions and is feasible because the RPVs are not as radioactive as the internals are. The scope also includes removal of the insulation around the RPVs, which in unit 1 contains asbestos and needs to be managed according to specialized

FIG. 9. The Ringhals Site (Courtesy of Westinghouse)

procedures. The sequence of the segmentation will be starting with the internals at unit 1, followed by the RPV at unit 1. Once the internals segmentation at unit 1 are complete, the segmentation of the internals at unit 2 will begin (in parallel with the RPV of unit 1) followed lastly with the RPV segmentation at unit 2. The planned site start of the project is in the autumn of 2023. The planning and preparation of the project implementation are already well underway with 3D models being developed and virtually cut to optimize the cutting and packaging plans. This also provides inputs for the designing the tools. The tools are being designed and manufactured in preparation for the Factory Acceptance Testing (FAT), ensuring everything is ready in the best possible way for the site implementation. The existing waste storage building at site will be used for interim storage of waste containers pending transport to the repositories for final disposal. The building will be upgraded and extended to handle the amount of waste created during decommissioning of the two units. The planning and preparation phase of the project, which is crucial for a successful implementation is presented together with the segmentation sequence and tools used for the different part of the project.

The Office of Environmental Management (EM) within the United States Department of Energy (DOE) is completing the safe clean-up of environmental legacy resulting from decades of nuclear weapons development and government-sponsored nuclear energy research. The Program Office is responsible for managing and directing the clean-up of contaminated nuclear weapons manufacturing and testing sites across the DOE complex. Integral to that responsibility is the need to safely D&D several thousand radiologically and chemically contaminated facilities no longer needed to support the Department of Energy's mission. With a large inventory of ageing nuclear and radiological facilities needing final disposition, EM's goal is to reduce the safety and environmental hazards, facility and infrastructure footprint, and the associated surveillance and maintenance costs by removing these facilities from the DOE inventory. EM's ageing infrastructure mitigation focuses on risks reduction activities that include characterization and abating high hazards, stabilizing buildings to reduce risks and future cost of maintenance and eventual decommissioning, establishing minimum maintenance requirements to place them in the lowest risk condition possible, and ultimately eliminating their risks by demolishing them and disposing of the resulting wastes. The removal of obsolete ageing structures as soon as possible following their shutdown is the best approach for reducing costs, minimizing risks, meeting mission needs, and maximizing programme opportunities. Over time, all enduring structures at EM sites that reach the end of their viable lifetimes will need to be removed. In the meantime, maintenance, whether preventive, predictive, or corrective, is performed to sustain facilities in a condition suitable for its designated purpose. EM implements a graded approach for surveillance and maintenance commensurate with the facility and utility system's condition, mission need, and schedule for decommissioning.

The paper from Germany addressed and highlighted the fleet approach for decommissioning utilities with multiple units across different sites (*FIG. 10*). Such an approach could be transferred to reactors of the same or similar design, even if they are operated by different utilities. This paper describes an ongoing fleet approach for dismantling of large radioactive components in commercial nuclear reactors

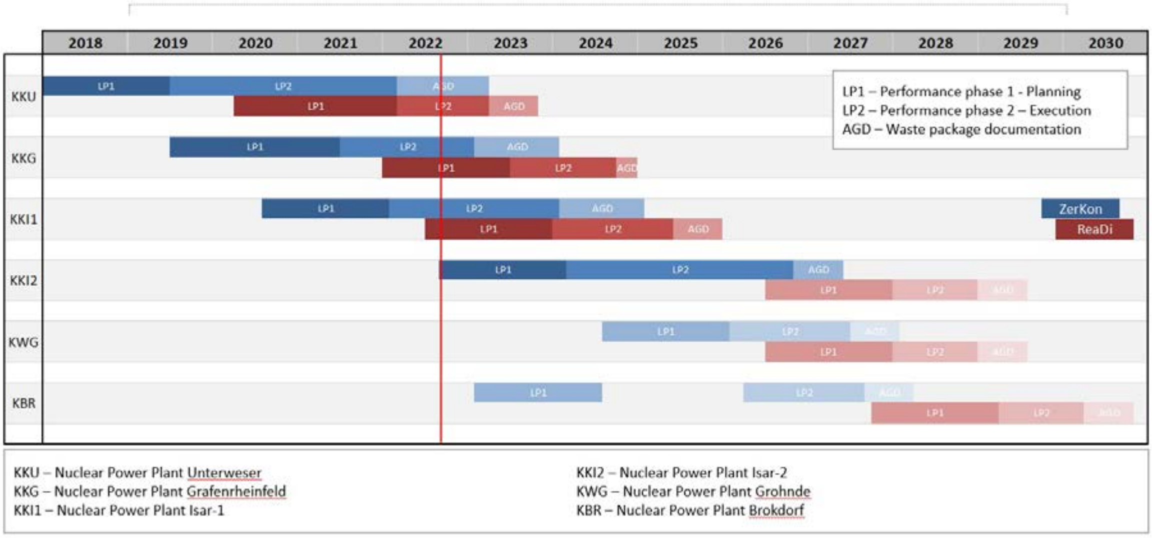

FIG. 10. Example for Multi-Project Management with Overlapping Schedules (Courtesy of GNS, Germany)

in Germany. It reflects on the technical, regulatory challenges and issues involved in this decommissioning implementation and showcase good practices in project management including managing project uncertainties and risks. Additionally, emphasis is placed on how learning from experience is gathered and fostered within the project organization to ensure continuous improvement and to create synergy effects, thereby strengthening the economic efficiency.

Fleet Project challenges are as follows:

- Federal structure – projects in different states have different responsible Ministry of the Environment and therefore nuclear supervisory authorities;
- Nuclear supervisory authorities are free to contract their expert organizations of choice;
- Different perception of satisfactory documents by expert organization;
- Different technical specification standards and safety requirements in between utilities and sites;
- Receipt of Decommissioning license depending on supervisory authority;
- Shifting or delay of parallel projects on the plant site;
- Functional tendering is the means of choice;
- Contractor should be aware of all technical conditions and requirements but also potential difficulties or deviations at the different locations.

An example from the United Kingdom is Dounreay site (North Scotland), which has provided gainful employment to the region since the mid-1950s. However, Dounreay is currently undergoing decommissioning, leading to anxiety within the community about the potential loss of employment once decommissioning is completed. Locally, opportunities for future regeneration have already been considered, including development of renewable energy, new nuclear applications, and a space port, among others. As the region is well positioned for development in the green energy sector, this paper, highlights the potential development of the hydrogen economy, focusing in particular on the fears, hopes, and needs of the local community and how these could be addressed. This analysis draws from primary data collected through interviews with local stakeholders. Lastly, this paper expands on the possibilities for other NPPs currently undergoing decommissioning suggesting solutions for the challenges faced by post-decommissioning communities. The conclusions are as follows:

- A preliminary analysis of the Caithness and North Sutherland Regeneration Partnership (CNSPR) area highlighted that the area could benefit from the large amount of renewable energy installed, which is currently curtailed;
- The opportunity for the CNSRP area is to use the excess energy produced by renewables (e.g., the wind farms) to produce green hydrogen and/or ammonia;
- Green hydrogen can tackle various global energy challenges, can help decarbonisation and can support reaching Net Zero;

— This preliminary investigation of the CNSRP area highlights that there are favourable conditions to establish North Coast Hydrogen Cluster (NCHC) within its boundaries, including the development of sustainable local economy, less dependent uniquely on Dounreay;
— However, there are also some risks and barriers that need to be tackled to guarantee the success of the NCHC, as local stakeholders underlined;
— The NCHC and the high visibility of hydrogen projects would bring the CNSRP area into the Green Industrial Revolution and to the forefront of an exciting emerging sector. This, together with other complementary projects, will support a sustainable economy in the region and a thriving "life after Dounreay".

In Lithuania, Ignalina nuclear power plant had two largest and most advanced water-cooled graphite-moderated channel-type power reactors - RBMK-1500. Unit 1 was launched in 1983, unit 2 in 1987. These were the most powerful nuclear reactors in the world at that time: the thermal capacity of a single unit was 4800 MW and the electricity generating capacity 1500 MW. Implementing the provisions of the agreement for its accession to the EU, Lithuania discontinued the production of electricity at Ignalina NPP. Unit 1 was finally shut down on 31 December 2004, and unit 2 on 31 December 2009. Ignalina NPP is implementing decommissioning works following immediate dismantling strategy. In accordance with the final decommissioning plan the decommissioning works at Ignalina NPP are expected to be completed in 2038. It is important to note that the original technical design of INPP, like many older designed and constructed nuclear power plants, did not account for decommissioning activities and was designed to never been decommissioned. Therefore, starting from the 2000s, planning and constructing decommissioning infrastructure essentially from scratch with international support and known practices was performed.

From Finland, a presentation on the reactor pressure vessel segmentation was delivered. This involved analysing the activity of the reactor pressure vessel, as well as its internals, using the MCNP code. Additionally, the nuclide-specific activity inventory was created, enabling the design necessary radiation protection measures based on dose rate assessments made with the MCNP-code. Due to the high activity levels of the components, utilizing computerized models as a basis for designs is deemed the safest and most cost-efficient approach. Under to the current decommissioning plan for the Loviisa units, the reactor pressure vessels and its internals will be decommissioned and disposed of as a whole, so that the reactor pressure vessels would be utilized as a release barrier required by the long-term safety. While a more common international practice involves segmenting and packing reactor components for final disposal. Based on MCNP-code and CAD-modelling all upsides and downsides of segmentation of RPV&RPVI are studied and the most efficient approach, cost, and dose wise, to be determined.

The Jose Cabrera NPP was the first power reactor developed in Spain, setting the foundation for future development and training. Construction of the reactor started in 1963, and it was commissioned by 1969. It was later shut down, entering the transitional stage by 2006. The transfer of responsibility to Enresa occurred in 2010 for the execution of the D&D stage. The reactor was a Westinghouse 1-Loop PWR with a thermal power of 510 MW and net electrical output of 160 MW. The fuel was UO2 enriched with 3,6% U-235. The containment was reinforced concrete with a carbon steel head. The decommissioning project was structured into several phases: (i) removal of fuel and preliminary work, (ii) preparatory activities for D&D, (iii) dismantling of major components, (iv) removal of auxiliary installations, decontamination, and demolition, (v) environmental restoration and final radiological survey. Currently, the project has reached an overall progress level of 98%, with all demolitions of the main radiological buildings from the operation phase completed. Final demolition activities are currently focused on the containment building below ground level and final soils excavations. Simultaneously, the final radiological site survey is in progress. Over the coming years, the remaining very-low level radioactive waste on-site will be shipped to the El Cabril disposal facility. Upon completion, the final radiological report of the site will be submitted to the regulatory body, and the declaration of closure will be requested once the site has been released from the radiological point of view.

Units No.3 and No.4 were built as the second phase on the Novovoronezh NPP site. These Units are powered with VVER-440 type reactors (design V-179) and were commissioned in 1971 and 1972. "Twin-units" configuration was used to design them. This configuration intends that reactor buildings are posed inside main building and many systems are used for two units concurrently. Similar VVER-440 type design units were constructed on NPP sites across the former Soviet Union countries, as well as in Western and Eastern Europe. Considerable experience has been gained in preparing for and executing the decommissioning for VVER-440 type reactors at several European NPPs. However, these experiences primarily entailed the immediate dismantling of these units, bypassing many configuration and technical challenges linked to their unique layout and design decisions during construction. The arrangement of Novovoronezh NPP Units 3 and Unit 4 preparing for decommissioning stage and carrying it out was adopted as an example of another approach. Design solutions were used during Novovoronezh NPP Units 3 and Unit 4 construction and their influence on decommissioning procedure will be analysed. The Novovoronezh NPP Unit 3, that was shut down in 2016, is currently undergoing the preparation for decommissioning, while some of its systems and equipment are repurposed to improve safety of Unit 4 and support its continued operation. The decommissioning strategy for these power units involves an immediate closure plan. However, the Unit 3 decommissioning activities have been staggered in time, delaying dismantling of its main process equipment until Unit 4 is finally shut down. This approach represents a compromise option that combines the deferred dismantling strategy for Unit 3 with an immediate dismantling strategy for Unit 4.

5.4. SESSION 8: COMPLETION OF DECOMMISSIONING

An increasing number of facilities are undergoing decommissioning, with significant number of decommissioning projects being completed or nearing completion. While there is considerable global experience on aspects related to defining and achieving decommissioning end state and in releasing sites from regulatory control, this knowledge is concentrated in a small number of countries. This topic is in the focus of many countries that are planning and/or implementing decommissioning projects.

This session aimed at (i) sharing experiences and good practices, (ii) discussing remaining challenges on completion decommissioning and site release.

The session included 4 oral presentations from the United Kingdom, France, the United States of America and Germany, along with 4 posters.

The contributions to the session highlighted a trend of “acceleration” of decommissioning in several countries, where initial decisions about applying deferred dismantling strategy have been changed towards immediate dismantling. This approach enables earlier completion of decommissioning projects and timely release of sites from regulatory control.

Planning and implementation of activities related to decommissioning end state, site clean-up and site release require an integrated consideration of wide spectrum of different aspects, including the radiological impact, industrial hazards, waste quantities generated during clean-up, waste transportation and disposal options, costs, plans for the future site reuse, expectations by interested parties, balancing risks to workers conducting the clean-up with risks to the future users of released sites, etc. This complexity usually requires a Multi-Attribute Decision Analysis (MADA).

There is usually a trade-off between the better clean-up and lower exposures to future site users on one side, and more waste generated, higher costs, more industrial risks, more transport, and higher exposures to the workers conducting the clean-up. An optimal balance between the two is always site specific. There is no single algorithm applicable to all situations.

Legacy sites from the early years of the nuclear industry and military present challenges, necessitating long-term restrictions in their decommissioning end states.

For sites release with restrictions, challenges persist in defining and assigning responsibilities for the post-decommissioning institutional controls, including institutions are to be responsible for surveillance, monitoring, land use restrictions, and planning for corrective actions, if needed.

Preparation of a consolidated guidance on the development and implementation of license termination plans for the nuclear power plants in the USA was presented. The document NEI 22-01, “License Termination Process,” (*FIG. 11*) was submitted to NRC for review and endorsement in February 2023. The purpose of this document is to distil the body of NRC’s guidance into a guidance that is most applicable to commercial reactor decommissioning.

FIG. 11. US Commercial Nuclear License Termination Process (Courtesy of Nuclear Energy Institute)

A presentation outlined the strategy and decision-making process adopted on the Nuclear Decommissioning Authority's sites in the United Kingdom to define site end states. The end state related decisions are based on risk-based safety assessments and sustainability considerations. Differing drivers across different sites and the available solutions were discussed and the application of the approach was illustrated through the example case of the Dounreay site in northern Scotland.

The presentation from Germany shared the country's experience in decommissioning of NPPs, highlighting a noticeable shift from adopting deferred dismantling strategy to the early projects towards immediate dismantling. The aim is to achieve unrestricted site release and clearance of up to 97% of the total material and waste.

An overview was provided of the approach, policies and guidelines of the French nuclear regulator ASN concerning the regulation and control of clean-up of structures and contaminated soil. This approach prioritises achieving a decommissioning end state and was illustrated by practical examples (*FIG. 12*).

Decommissioning of facilities ultimately aims at removal of radiological and other hazards and at release of the site from regulatory control, ensuring the site is safe for future use. Strong preference is given to unrestricted release of sites, so they can be reused for any purpose in the future.

Defining the decommissioning end state is a crucial aspect of the decommissioning planning process. It has different components, with the main ones being the radiological status of the site and any remaining

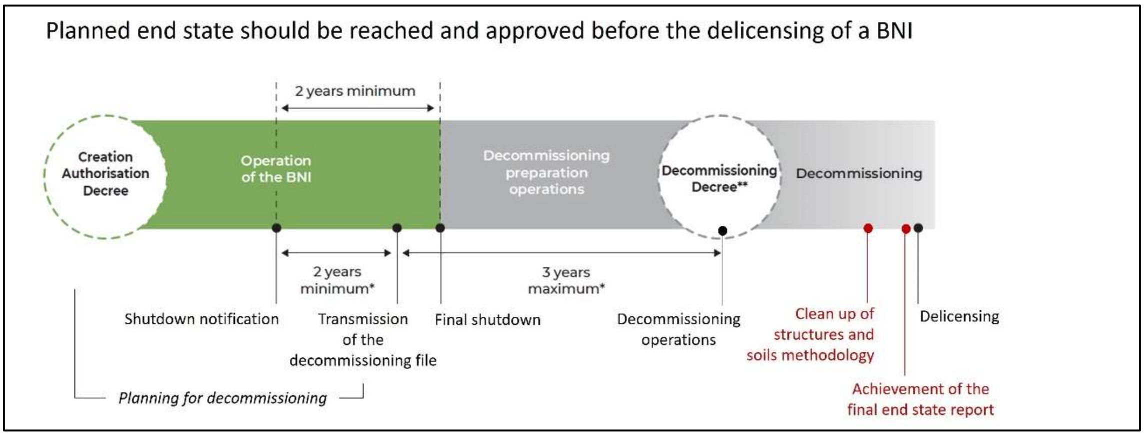

FIG. 12. French Decommissioning Regulatory Framework (Courtesy of ASN, France)

structures at the end of decommissioning, the physical status of the site and any remaining restrictions to the use of the site after decommissioning.

There exists a good international consensus on radiological criteria for site release, where dose constraints for the members of the public of the order of 100 μSv in a year are applied. Below this threshold, optimization of protection occurs, considering factors other than radiation protection.

Although the criteria are generally well harmonized, there are quite different approaches to the optimization process across different countries, addressing the reduction of the dose impact below the dose constraint and considering non-radiological factors, such as industrial risks and socio-economic aspects.

The discussions of decommissioning end states, clean-up actions and release of sites are increasingly incorporating sustainability consideration, alongside previously dominating safety and socio-economic aspects.

5.5. SESSION 9: DECOMMISSIONING OF NUCLEAR FUEL CYCLE FACILITIES

Fuel cycle facilities encompass a wide range of facility types, spanning activities associated with mining and processing of ores, uranium conversion and enrichment, fuel fabrication, spent fuel storage and spent fuel reprocessing and recycling. Major fuel cycle facilities typically comprise several subsidiary facilities, e.g., chemical processing and mechanical handling plants. This diversity, and the presence of significant chemical hazards alongside radioactivity, often presents unique and significant challenges during decommissioning. These challenges may include restrictions on the use of technologies due to the presence of chemical solvents, as well as the management of significant quantities of actinides that are typically dispersed around the facility.

The session included 8 oral presentations from France, Argentina, the United States of America, Germany, Canada, Brazil and the United Kingdom.

Decommissioning includes all activities leading to the release of the facility from regulatory control, including decontamination, dismantling and treatment of the resulting materials to enable their release from regulatory control oversight their placement in storage or disposal facilities. Depending on the regulatory framework in place, activities undertaken immediately following shutdown to reduce radiological and chemo-toxic hazards, such as operational and any legacy waste retrieval, may be considered as part of decommissioning or as part of facility operation.

While several fuel cycle facilities have already been successfully decommissioned, a significant proportion (>60%) of the global fleet of fuel cycle facilities is still in operation, with around 20% currently undergoing decommissioning (*FIG. 13*) [1]. Regulation of the fuel cycle facilities decommissioning typically follows a similar approach used for other nuclear facilities, adopting a graded approach considering the level of hazard.

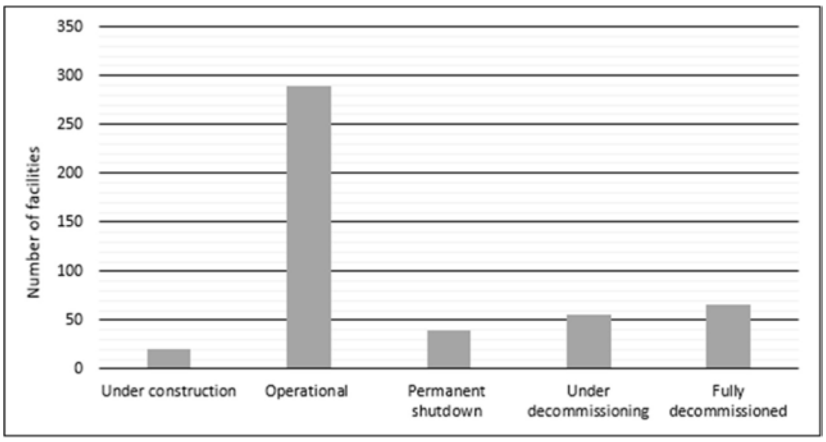

FIG. 13. Global status of nuclear fuel cycle facilities (excluding uranium mining and milling) (reproduced from Ref [1])

The decommissioning of spent fuel reprocessing facilities presents distinct challenges compared to other types of fuel cycle facilities. This is because of the diverse nature of facilities used to manage the wide range of radioisotopes that are separated, and often concentrated, during reprocessing or due to changes in state occurring during the operating lifecycle. The presence of radioactive deposits and contamination with actinides throughout the facility requires time-intensive removal efforts to maintain plant safety functions through the decommissioning. Typically, decommission a major reprocessing plant requires several decades, with costs potentially amounting several billions of dollars.

The approach generally adopted to decommissioning fuel cycle facilities involves prioritising the reduction or removal higher hazards, preventing cross-contamination, and enabling subsequent activities to be implemented with reduced risk. In practice, the approach taken is dependent on the specific situation and challenge, e.g., equipment such as installing lifting devices or upgrading safety functions prior to handling high activity items, is essential. Material and waste management activities play an important role throughout the project due to the large quantities of materials involved, ranging from radioactive waste with significant amounts of long-lived radionuclides, requiring geological disposal or long-term interim storage, to large quantities of lightly contaminated steel, suitable for decontamination, clearance or recycling through dedicated processes. An integrated decommissioning and waste management strategy is thus essential throughout the project.

An important prerequisite to dismantling a fuel cycle facility is the retrieval and conditioning of large amounts of operational or legacy waste, including sludges. In older facilities, the radiological and other characteristics of the materials may be uncertain, especially in cells with high levels of activity which may not have been entered for a considerable period of time. Establishing an access route to the cell is typically the first step, often requiring using remote means. A detailed characterization campaign to reduce uncertainty and to support the development of the waste retrieval and conditioning strategy follows. Large quantities of contaminated soils may also need to be managed as part of the process of demonstrating compliance with the defined end state of the facility.

Recent technologies in robotics and digitalization are already being applied to the development of strategies for characterization of plant and materials in difficult-to-access locations of the facility with high levels of activity. Recently developed technologies include:

- Portable cameras used to measure gamma and alpha radioactivity;
- LIDAR scanners which enable three dimensional digital representations of difficult-to-access locations;
- Snake-arm robots which may be used as carriers of scanning or laser cutting tools to such locations;
- Quadruped robots which may be used to inspect and clean active cells that would normally require workers to enter in air-fed protective suits;
- Use of digital information models to support simulation and visualization of possible dismantling scenarios.

Fuel cycle facilities are generally located on multifacility sites, often alongside facilities which may still be in operation, and are often situated away from urban centres. Attracting staff to work on decommissioning projects is often a significant challenge, particularly as younger professionals seek more mobility in their employment outlook than previous generations and may prefer the work opportunities offered by facilities still in operation or indeed may be reluctant to live in remote locations. Particular attention therefore needs to be paid to the development of staff recruitment and retention policies and to ensuring that staff are provided with interesting career development paths and training to promote mobility in the organization and ensure knowledge retention.

The session included presentations on a diverse range of topics relevant to fuel cycle facility decommissioning from seven national programmes ranging in size from large multifacility sites which included major reprocessing facility decommissioning projects (e.g., France, the United Kingdom) to single projects such as the decommissioning of a pipe conveyor on a uranium milling site in Germany.

An important theme of the session was the high level of project uncertainty and risk associated with large fuel cycle decommissioning projects due to the large variety of plant processes resulting in the challenges being faced are often unique (e.g., Canada, France, the United Kingdom and the United States of America). This uncertainty can result in cost overruns and delays in project completion. Addressing this uncertainty requires significant attention to facility characterization activities, including those undertaken prior to the retrieval of materials from the operating phase, some of which may have been stored in bulk and unsegregated over several years. Soil characterization and management following dismantling are also crucial elements in the license termination process (e.g., Germany).

The session highlighted the importance of adopting an integrated programme management approach, based on a comprehensive overall dismantling scenario, including optimization of the waste management strategy (e.g., by Brazil, Canada, France). The overall scenario should incorporate activity and cost schedules, and associated resource requirements, developed in sufficient detail to detect deviations early and adapt accordingly. Digital modelling and simulation are increasingly important tools for planning the decommissioning of fuel cycle facilities activities.

Recent technological developments in remote operations to support decommissioning were noted in several presentations, e.g., for waste and fuel debris retrieval and laser-based cutting systems. These technologies are driven in part by specific requirements resulting from post-accident clean-up activities on sites such as Fukushima and are now being applied to waste retrieval and decommissioning activities in fuel cycle facility. . Robotics remains a key area of ongoing research with the general aim of enabling tool operators to operate in a hazardous environment without physically being there, including enabling the operator to get the immediate physical feedback on how a tool is functioning. The importance of collaborative approaches to R&D to support decommissioning was emphasized (e.g., France, the United Kingdom).

Recruiting and retaining of personnel, along with competence development and knowledge management and transfer, were identified as an important challenge. Addressing these challenges included ensuring that knowledge gained during operation of facilities is captured and retained, ensuring that adequate numbers of personnel from the operating phase are retained in the decommissioning organization, and implementation of programmes for continuous staff training and development (e.g., Argentina, Canada and France).

5.6. SESSION 10: KNOWLEDGE MANAGEMENT

The application of knowledge management principles to decommissioning is a relatively contemporary discipline. The overall life cycle of a nuclear facility including sitting, design, construction, commissioning, operation, and decommissioning typically cover some 50 years potentially extending to over 100 years in some cases. This entails the involvement of several generations of nuclear scientists, engineers and related staff.

Given the increasing number of nuclear facilities approaching the end of their service life, it is crucial to consider the application of knowledge management principles into decommissioning practices. The absence of critical information and knowledge during decisions-making and executing phases of decommissioning might significantly increase the associated costs and risks. Establishing knowledge management systems in necessary to capture lessons learned and facilitate their use in decommissioning projects.

Knowledge management is therefore playing a key role in the smooth implementation of any decommissioning project, including issues such as:

— Preserving facility and site design knowledge and historical records;
— Sharing and capitalising on good decommissioning practices and lessons learned;
— Assuring the competence of personnel involved in decommissioning activities;
— Transferring knowledge to future generations, which is especially relevant in case where there is a need to establish long-term institutional controls over a facility and/or site.

The Knowledge management session comprised from eight presentation provided by the IAEA, France, Germany, Japan, the Russian Federation, Sweden and the United States of America.

General observations noted certain lack of expertise in field of nuclear decommissioning with sufficient knowledge to be widely shared and need to maintain sustainability in knowledge management as one of the most important aspects of the decommissioning process. Standardizing taxonomy and ontology in nuclear decommissioning has been encouraged for future projects and applications. Especially noted has been deferred dismantling that is deeply impacting the transfer of knowledge, increase the risk of loss of funds, experiences, and capabilities.

Distinct knowledge management requirements exist for the operational, transitional, and decommissioning phases of nuclear facility. The high turnover of the personnel during the decommissioning phase of the facility is a challenging task for keeping the knowledge and transfer of the experience.

Effective management of knowledge transfer could positively impact the capability building with sustainability considerations within the field. Implementing informative systems such as the decision support systems are recommended good practices in the field of decommissioning to support the planning, management of waste and optimisation of the processes.

Although data processing systems are under development in many countries and organisations, the common approach for the data processing seems to be clear, hence their common application remains limited. Sharing of information and hand over of the knowledge and experience is extremely important for gaining effective decommissioning in all perspectives e.g., costs, optimization, planning and scheduling. Advanced technologies, a lot discussed nowadays e.g., ChatGPT (Artificial Intelligence powered language model) and semantic learning technologies, are enhancing knowledge management practices. The progress in the technologies is unstoppable, will be applied soon or later and the acceptance and usage will become common.

Introductory presentation to this session provided outline of a collaborative exercise initiated by the IAEA, EC-JRC and OECD/NEA to facilitate organization of knowledge on the decommissioning of nuclear facilities and promote interoperability of knowledge organization systems. The foundations for such interoperability begin with the creation of a common taxonomy and the initiative aimed to propose such a taxonomy for nuclear decommissioning [5]. As in general known, decommissioning comprises a set of complex and interrelated activities. For the illustration it may be represented by a set of 'core' concepts that need to be considered for the purpose of establishing a decommissioning taxonomy – see *FIG. 14*.

Paper introduced by Japan focused on a Wiki-based database system prototype of a knowledge management tool to support decision-making for the decommissioning. It has been developed for decommissioning of the JAEA prototype reactor Fugen. It introduced a Wiki system on a trial basis and

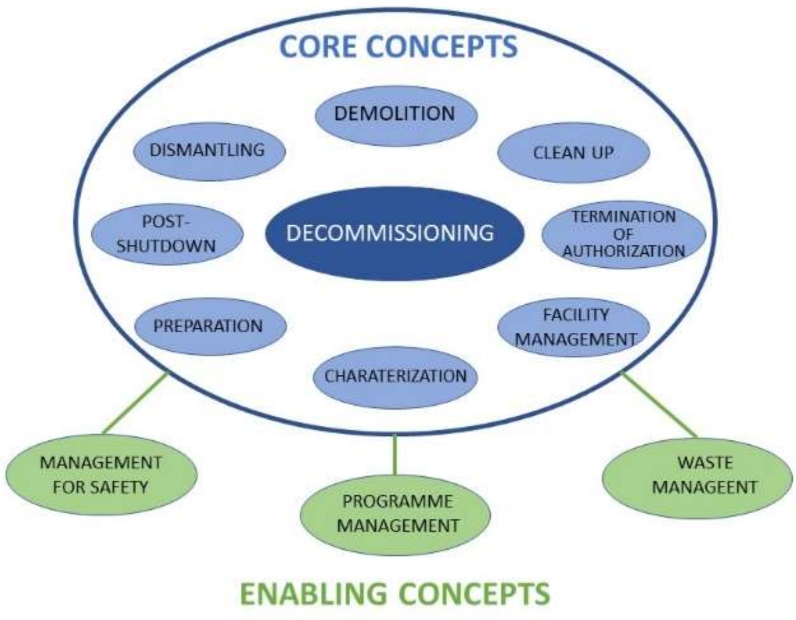

FIG. 14. Representation of core and enabling concepts (reproduced from Ref [5])

implement measures for the centralized information management. As a result, parallel work, and rapid information sharing, which are the merits of Wiki, became possible.

German authors presented the concept of “circular economy” that has become increasingly interesting for the nuclear industry, particularly during the decommissioning phase. While the focus has been on physical resources like materials, equipment, and land use, the principle can also be extended to the transfer of knowledge and competence. Maintaining and building competence in practical nuclear issues is a major challenge, and a possible solution could be to apply circular economy concepts to people and knowledge, finding a way to ensure at each new cycle and beginning that important knowledge isn’t lost with experts retiring.

French author presented utilizing collected decommissioning data in various ways, such as converted into a 3D model, calculation models, or to perform intervention studies and define dismantling scenarios. A holistic approach through simulation tools allows this data enhancement and a better control. By applying this approach from data acquisition to data modelling and data maintenance, global project risks might be managed. In that manner when using the ALARA or ALARP principles, costs and resources are optimised, risks in terms of exposure are mitigated and planning is controlled.

Presentations by authors from the Russian Federation provided a description of the history of knowledge management technologies and new digitalization challenges and interactions with Artificial Intelligence. They highlighted the development of applied ontologies as a basis for integrated management of national Nuclear Energy Programmes, experience of integrated programme management in Rosatom and overview of the logic of work that is changed from knowledge management in decommissioning projects to knowledge-based governance of decommissioning programmes. Another paper overviewed an analytical decision support systems specifically for decommissioning of radiation hazardous facilities, underscoring the importance of using such decision support systems for ensuring radiation safety of personnel, population, and environment at all stages of decommissioning.

Paper on NPP Oskarshamn discussed the decommissioning plan and new regulatory permit conditions that resulted in a safety demonstration relying on two major principles.: ensuring safety of the public, the personnel, and protection of the environment by defining limiting events that are analysed and consequences demonstrated to meet the acceptance criteria, and developing procedures to ensure available functions for all different decommissioning work packages.

The United States of America paper introduced Post-Defueling Monitored Storage (PDMS) of TMI-2 and related knowledge management challenges. Several years after entry into PDMS it was recognized that due to the increasing retirements of people knowledgeable of the plant the information originally preserved in the PDMS Safety Analysis Report was not sufficient. Therefore, a more robust knowledge management programme than originally developed was needed and several additional knowledge management initiatives were undertaken.

6. FRAMEWORK TO TECHNOLOGICAL ADVANCEMENTS

6.1. KEYNOTE ADDRESS OF THE VICE PRESIDENT

Mr. Kentaro FUNAKI, Executive Director, Fukushima R&D and International Affairs, Japan Atomic Energy Agency, Japan

Mr. Kentaro Funaki, Executive Director of Fukushima R&D and International Affairs, welcomed attendees and thanked the Programme Committee for giving him the opportunity to provide the keynote on technology advancements. Mr. Funaki noted that within last 20 years were a number of cases, in which technological advancements in nuclear decommissioning has progressed successfully and that major progress is being made in the advancement of more innovative technologies such as, digital transformation.

It is my great honour to have this opportunity for the keynote on technology advancements.

Today's discussion is an important follow-on to the last two day's outcomes as we consider "technology" as a key enabler. I am sure this discussion will bring useful suggestions and recommendations for potential areas of further activities and international collaboration and will be addressed in concluding discussions tomorrow.

Let me begin by looking back at history of technological advancements in nuclear decommissioning over the past 20 years. We have seen a considerable number of the cases, in which nuclear decommissioning was completed successfully. Use of remote-operation tools and robotics have enabled operations at contaminated facilities to protect workers by reducing exposure.

More recently, modern, and more sophisticated robotics system have become available and nuclear decommissioning projects have been making full use of them as common tools.

Major progress is being made in advancement of more innovative technologies such as, digital transformation (DX), technologies, to improve conventional application. Some technologies were already in use in other industry sectors, in particular manufacturing sectors. These advancements are only a small part of what we may see over the next 20 years and

I am looking forward to listening to, and learning from, the today's speakers.

A decommissioning process is often explained by staging into 5 processes, from characterization, decontamination, dismantling, waste management, to site restoration. Project management can be defined as another critical process for the success of effective and efficient decommissioning, as discussed in yesterday's session. Advanced technologies, such as robotics, drones, simulations, digital twins, extended reality, have already been applied to make each of decommissioning processes more effective and efficient. Growing use of advanced technologies will further increase the effectiveness and enhance safety.

These 5-stagesof the decommissioning process are basically common for all different type of nuclear installations. However, issues and priorities are different, as well as needs for advanced technologies and techniques will vary by facility.

In particular, for post-accident reactors and legacy facilities, as well as nuclear fuel cycle facilities, key priorities for decommissioning process are different from permanent shutdown reactors.

In these nuclear installations, large amounts of unsealed and unknown radiological contamination potentially remain during the initial step of the decommissioning process, priority is given to how safely and efficiently site characterization can be implemented without excessive exposure during post-operation phase which has led to needs for advanced technologies. Remotely operating in-situ characterization, advanced simulation and visualization of radiation source and dose mapping are some examples for this end and there are many other technologies in development.

More careful and extensive project management and rational planning are also needed for these installations with tough obstacles and hurdles. Application of advanced technology for project management is also key, and it will eventually benefit all other types of installations as use of these tools becomes more common.

To make project management effective, key is ensuring individual sub-projects be implemented successfully as planned. Applying simulation and modelling, and training activities are becoming more important parts of this project planning as induvial activities are mapped out.

In addition, holistic and integrated management is important. Data and information should be shared within organizations and among stakeholders involved/engaged, at both organizational- and experts-level. These include DX technologies, such as BIM (Building Information Modelling), AI-based knowledge management, and extend reality, which enable and maximize the benefits of these project management tools, in terms of risk mitigation, cost reduction, optimization, and waste management, among others.

Right now, many of these technologies are at the trial, testing, and demonstration phase. We need to ask what is required and how fast can these advanced technologies be applied and deployed? How to answer this question is one of the objectives of today's discussions.

It will be quite beneficial to learn from each other about some precedent best practices, application, and use of technology from other industries, and R&D efforts for potential applications. We also need to focus on issues and challenges we face in development and deployment, some of which have already been identified by users and supply chains:

To ensuring safety,

- Advance technologies can achieve even safer conditions?
- Any risk should be considered when applying new technologies?

To reduce cost,

- If/how we will/can achieve trade-off for total (or lifecycle) cost reduction?

As for user's readiness/acceptance,

- How can we foster innovation mind-set, motivation?
- How much training is needed?

During this session we will discuss how to overcome these challenges and how to accelerate the application of advanced technologies Stakeholders need to work together, to make innovative technologies applicable and deployable. Supply chain and R&D organizations should play a leading role, and operators as users of the technologies and regulators need to be involved at some point.

Waste management organizations responsible for waste disposal and those involved in licensing processes will need to be involved at an earlier stage to share goals and visions. We need to seek the best ways to encourage innovation and bringing new ideas and ensure everyone has an opportunity to contribute. The role of supply chain is going to be discussed at panel discussion this afternoon. I'd also like to highlight three more points as key considerations to address challenges, hoping that these will guide discussions for today.

The first point is to strengthen collaborations among those involved in different types of installation decommissioning, beyond a group of the same facility type. I am sure that every stakeholder involved in different installation will learn from each other, beyond the conventional boundaries. This is one of the objectives of this conference, as IAEA Director General Grossi stressed in his opening address.

For example, technologies, techniques, and project management to be applied to post-accident reactors and legacy facilities are usually specific to that facility or condition. However, we should expect that the technology, once adopted and confirmed, will bring huge benefit to decommissioning projects of other types of installations. The experience of research reactors as precedent, in which it is relatively easier to implement demonstration of any advanced technologies as it is smaller scale, will expectedly be shared with larger-scale reactors. And application to the design is important for SMR and smaller facilities for non-power application.

During the last two days, many distinguished speakers have already point out this issue. I was wondering if the terminology of "Decommissioning by Design" should be used to further foster awareness, as the Conference President Mme Piketty stated in her keynote address.

A number of SMR and advanced reactor design projects are ongoing in many Member states. Cost reduction in lifecycle-basis is a key to increasing the likelihood of future deployment. The new advanced reactors should be designed to facilitate decommissioning, resulting in less expensive, less time consuming, less hazardous, and much less volume of waste generated.

And DX technologies will bring further benefit through integrated data management for plant and site characterisation, and optimization of integrated approach between O&M and decommissioning. The next several years will determine the economic viability of SMR deployment and these technologies will support the extensive discussions among the stakeholders.

Finally, I'd like to provide my thoughts on how we can enhance the values of nuclear decommissioning, through further technology advancements. The goal of nuclear decommissioning can be represented by optimization, which include ensuring safety, pursuing efficiency, and reducing cost and time. The application of advanced technologies will ensure and enhance approaches to attain these goals, and will therefore bring values, in terms of increasing foreseeability of decommissioning completion, and whole lifecycle of nuclear facilities and reactors, and eventually sustainability of nuclear energy.

Furthermore, while we have seen several cases in which nuclear sector learned from experience in other industry sectors such as oil & gas and civil engineering. We would like to see any good practice of opposite direction case. Once we overcome tougher challenges with more advanced and sophisticated technologies in nuclear decommissioning and lifecycle facility management, such experience will become a good precedent to other sectors. This will lead to creating even higher value.

There are several activities and discussions already underway within the IAEA, OECD/NEA and others, which will expectedly be enhanced based upon the outcomes of this conference.

To conclude, I'd like to propose one thing: Let us highlight more the positive aspects of nuclear decommissioning, during the course of the discussions on technology advancements, and also at the concluding session tomorrow. I hope that we will be able to conclude this conference by fully recognizing the high value that decommissioning brings and to share advanced technologies will enable decommissioning more certain, earlier, and timely, and international collaboration will maximize the potential. Let us share and deliver such our positive message to those who was not able to make it to this conference, and all stakeholders involved in nuclear decommissioning. And let us inform younger generations who will play a key role in the future and draw more attention to join us and work together.

6.2. SESSION 11: DIGITALIZATION

Emerging digital technologies which are already helping to advance nuclear decommissioning projects worldwide, are set to play an increasingly key role in the sector, as more and more countries choose to immediately dismantle their retired nuclear facilities.

To help get the job done efficiently and reduce risks, including financial and radiological ones, countries are turning to high-tech tools like virtual reality and 3D simulations – a trend that looks set to intensify in the coming years as several ageing nuclear power plants and other nuclear facilities are phased into retirement.

In the session were presented 8 papers from Norway, Spain, Germany, France, the United States of America, Japan, and Canada.

It has been recognized that value propositions based on digitalization and robotics can be greatly improved through stronger integration of these technologies. National and international projects provide great opportunities to collaborate and implement digital technologies in decommissioning activities on a larger scale. The outcomes of several international projects (e.g., Euratom Share, Pleiades, Predis, etc.) have highlighted that digitalization and robotics are considered the two most prominent technologies foreseen to significantly enhance efficiency, safety, transparency, and circularity in nuclear decommissioning and waste management activities. Integrated modular multipurpose digital support (eco)systems, digitalization supporting a holistic/lifecycle approach, BIM (Building Information Management) and knowledge-centric plant information management systems have been identified as important transformative trends in digital transformation for the sector.

The Norwegian paper showcased various digital technologies tested and utilized for different activities. One of the internationally known 3D support systems with an integrated radiological analysis and visualization library is the VRdose. This system has also served as a basis for digital platforms integrated with mobile robot systems.

Nuclear decommissioning projects are generally large-scale projects with long durations and high complexity. Implementation of holistic planning and utilizing software supporting the optimization of the process are crucial for effective and efficient project realization. Various software solutions were presented during the session, offering a wide range of integration options. Identification of interdependencies between the various activities and development of the plan for proceeding with the tasks, options of processing material flow with displaying the impact on dismantling and decommissioning, and optimization of the project by resources utilization, are examples of the functions available in different software developed in Germany, Spain or Norway.

Presenters highlighted the use of Augmented Reality (AR) and Virtual Reality (VR) for training and managing workers' safety. The AR and VR would mitigate the potential damage to the environment and people surrounding, excluding the physical presence of employees at the site, it would assist also with any inspections done on sites. VR headsets create a virtual world where the user is immersed while AR adds to the reality, meaning the user views the environment as well as other information that they may want to include. The Mixed Reality (XR) could revolutionize the modern D&D processes allowing for reliable robotic systems that could be controlled and used remotely through these headsets. Unfortunately, the XR is sensitive to radioactivity and could experience some technical problems on-site, therefore additional research in this field is still required. The paper presented by a young professional from the United States of America provided results of activities realized within Florida International University Applied Research Centre. Research is oriented toward solving problems with the implementation of VR and AR in Decommissioning and Dismantling activities.

A work on localization and imaging of radioactive hot spots in 3D and in real-time using a single gamma camera was presented by France. The focus in on developing and implementing an algorithm utilizing triangulation to estimate the position of a hot spot in 3D from multiple gamma images taken from different positions. By using one single gamma camera, the costs and time required for the measurement can be significantly reduced compared to multi-camera systems.

Digital tools play crucial role in supporting the decommissioning of nuclear facilities post-accident. A paper on the estimation of radioactive source distributions inside reactor buildings was presented by Japan. Ability to prepare predictions of hot spots (*FIG. 15*) allows to reduce the radiation risk of personnel. A research and development project was initiated to identify hot spots using both air-dose rate measurement data and structural information. Machine learning method are integrated into a specific software developed by JAEA for this purpose. Further development of the user interface to smoothly execute and improve the data management process is expected.

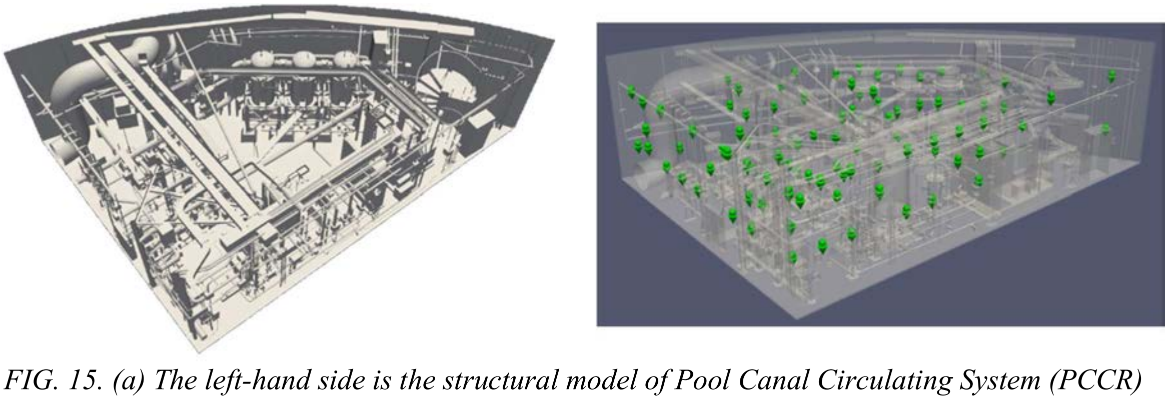

FIG. 15. (a) The left-hand side is the structural model of Pool Canal Circulating System (PCCR) of Japan Material Test Reactor (JMTR), and (b) the right one is the location points given by the developed measurement suggestion tool. (Courtesy of JAEA)

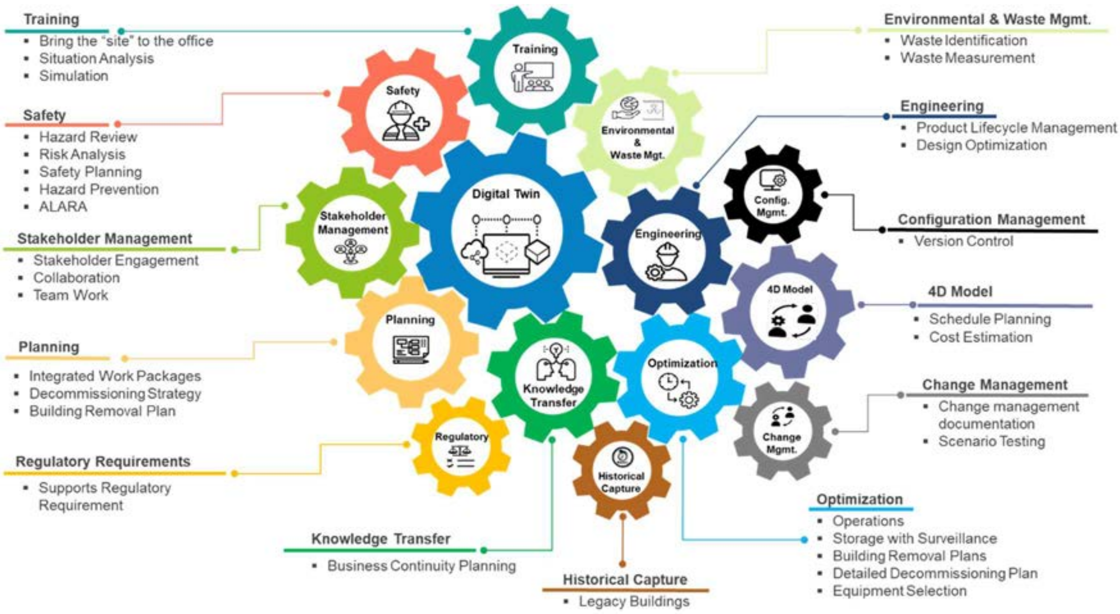

FIG. 16. Capabilities of Digital Twinning (Courtesy of Canadian Nuclear Laboratories)

Digital visualization is a powerful tool that can significantly improve the effectiveness and efficiency of decommissioning processes. Digital twin (DT) is a term that is common in other industrial fields, especially in new built. The advantages of digital twinning of a facility are several, the DT allows to explore different dismantling operations of nuclear facilities and study the ergonomics of various decommissioning tasks. Implementation of DT in legacy sites, despite the initial cost implications, could provide costs reduction, and increase the safety and efficiency of the decommissioning processes. The paper presented by Canadian Nuclear Laboratories showed and described different capabilities of Digital Twinning in nuclear decommissioning (*FIG. 16*). Safety enhancement, and hazardous operations such as handling, and procession of nuclear materials can be practiced using virtual environments. Improvement in training can lead to a reduction in accidents and near misses. Additionally, DT provides engineering support for nuclear activities throughout the lifetime of a project. The concept can be applied to create a digital knowledge management system that can be used as a centralized repository for all information and documentation related to the facility over the time. Planning is further enhanced with DT, resulting in improved efficiency, effectiveness, and safety of the decommissioning processes. Digital Twin not only visualize discussed concepts but also aids effective communication and visualization of activities to management and other stakeholders, facilitating better understanding of decision-making in nuclear decommissioning projects.

Different advanced digital solutions have been utilized to support the remotely operated and robotic development of a test programme for graphite removal and graphite handling of the graphite reactor fleets. The Industrial Demonstrator developed by Graphitech (an EDF and Veolia joint venture) will be used for testing and training of graphite decommissioning processes ensuring safe dismantling activities.

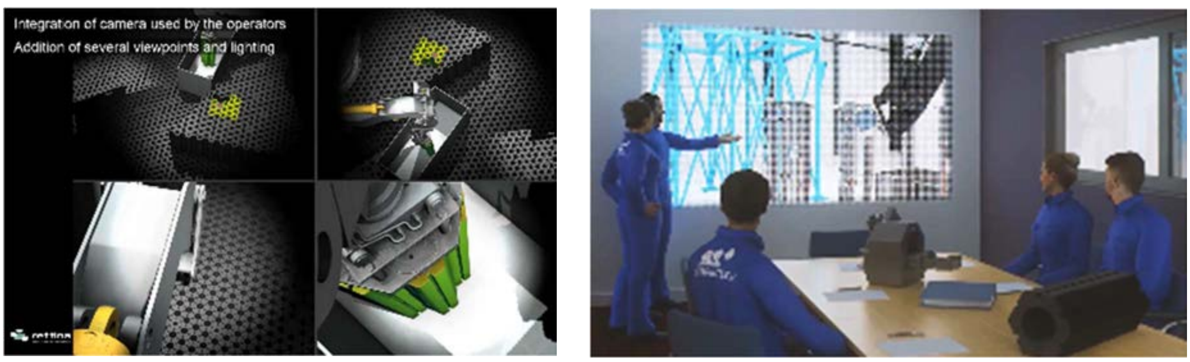

FIG. 17. 3D simulation of dismantling activities (left), Virtual reality use for operators training (right) (Courtesy of EDF)

The expected outcomes of these tests and developments will enable EDF to start the dismantling activities of the Chinon A2 graphite reactor by 2030. Software like DEMplus has been employed to simulate the dismantling scenario in 3D, optimizing modelling and analysing the impact of different alternatives of scenarios. These simulations could provide an estimation of the schedule and dismantling costs. The Demonstrator will offer training modules to learn more about graphite reactors decommissioning and remotely operated solutions. Virtual reality tools will be employed during in-class training sessions to further enhance learning experience in this regard (*FIG. 17*).

6.3. SESSION 12: ROBOTICS AND REMOTE OPERATION

Robotics and remote systems cover a broad and diverse collection of technologies that aim to reproduce and/or partially replace some manual human tasks. This makes them especially important in hazardous environments, such as the ones encountered in radioactive waste management, nuclear decommissioning, and legacy site remediation.

In the session were presented 7 papers from the United Kingdom, Germany, the United States of America, Sweden, and CERN.

The technologies in this field are rapidly evolving, offering a range of autonomy from basic repetitive motions with the assistance of a human operator, to the usage of artificial intelligence (AI). A new generation of smart robotic technologies with autonomous and AI capabilities is on the rise, expected to become strongly disruptive in future nuclear back-end activities. In the next two decades, likely, systems will still be controlled by a human, but with increasing amounts of AI assistance, exploiting semi-autonomous capabilities. This development will lead to additional complex challenges for evaluation and certification by nuclear safety officers and regulators.

General barriers to implementing robotics and remote systems include a reluctance towards adopting “first-of-a-kind” technologies and “paves-the-way” kinds of technology, as well as a lack of expert knowledge within end-user organizations. The use of the new technologies represents a challenge to demonstrate safety, effectiveness, and efficiency both for the decision process for end users and suppliers on one hand and for the regulatory processes on the other hand. Specific attention needs to be maintained on these aspects in addition to the challenge of good technological solutions.

Significant number of nuclear sites are planned to be shutdown worldwide in the future and a lot of measurements have to be acquired for material release and characterization. Radiation surveillance measurements are crucial for assessing the dismantling workload of a nuclear facility and conducting clearance measurements on various surfaces like walls, floors, and ceilings.

The Expert Group on the Application of Robotic and Remote Systems in the Nuclear Back-end (EGRRS) was established under the auspices of the Nuclear Energy Agency (NEA) Radioactive Waste Management Committee (RWMC) and the Committee on Decommissioning of Nuclear Installations and

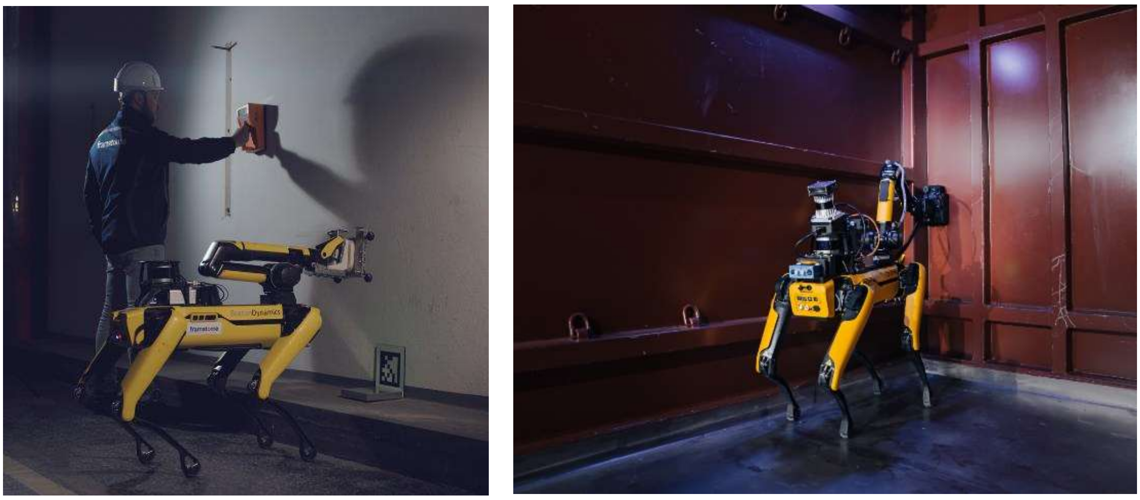

FIG. 18. (a) Left side - Operator and AMORAC both holding a contamination measurement device to make the clearance measurement of the wall. (b) Right side – AMORAC measurement of complex surface areas inside a 20ft container. (Courtesy of Framatome)

Legacy Management (CDLM) to assist the NEA member countries in optimizing the development of national radioactive waste management and decommissioning programmes through the application of robotics and remote systems.

A project was initiated to utilize the Spot from Boston Dynamics for automating α and β surface contamination measurements at close distances to the surface patches, emphasizing that the Autonomous Mobile Robot for Automated Clearance (AMORAC), using the Spot, demonstrates the potential for humans and robots to work side by side on a task (*FIG. 18*).

The development of special autonomous robotic devices that may be highly adaptable for different purposes in nuclear or non-nuclear facilities could reduce the manual labour, improve project schedules, and minimize radiation exposure of the workers.

A RoboDecom cooperative project, funded by the Norwegian Research Council, focused on practical scenario-based design and use cases for mobile robots in decommissioning. Customized mobile robots like nLink, Clearpath, Jackal, and Boston Dynamics Spot were employed to enhance the decommissioning scenarios, particularly in hazardous environments, both from radiological and other various unsafe conditions for human beings. Significant attention was given to the autonomy and self-navigation of these robots. The connection of the robot with the software and real synchronization of the locations enables to simulate potential radiation sources in the environment. A radiation analysis can be performed to show the levels of radiation on the robot following the synchronized pathway, real-world and simulated.

The United Kingdom started a demonstration, the Integrated Innovation in Nuclear Decommissioning (IIND) intending to find an integrated decommissioning system that is easily transferable to various scenarios, with the initial focus on removing the operator from hot cell decommissioning. The demonstration was focused on (i) remote characterization, (ii) visualization and implementation for planning, (iii) size reduction, (iv) waste sorting and segregation, and (v) waste packaging. A company,

FIG. 19. Current status of Barrnon Integrated Decommissioning System (BIDS) (Courtesy of Sellafield Ltd.)

local to the Sellafield site, developed the hydraulic-mechanic platform with a capability to deploy a range of quick-change tools (*FIG. 19*) to fit a variety of decommissioning scenarios. Characterization technologies provide a fully immersive Virtual Reality environment that can enable real-time decisions. Implementation of Commercial Off the Shelf technologies (COTS) innovatively can help solve the decommissioning challenges and help mitigate the project risks. Large scale demonstrations at Sellafield site are driven by learning from experience. In conclusion, the use of IIND and other technologies will provide equipment and the solutions that can be copied and transferred to different locations.

Successful dismantling of blowdown tanks using a remotely operated demolition robot was presented by Sweden. Identified challenges of the project as working in a confined space and limitations to restricting the operation area of the robot were managed within the project carefully. The main benefits of using the demolition remotely operated robot were gained efficiency and mitigation or elimination of the risk.

Remotely operated robots that carry radiation measurement and visualization tools are a priority area of research and development to help minimize the radiation exposure to site workers and to systematically advance the decommissioning in sites post-accident e.g., Fukushima Daiichi, Chernobyl NPP.

The use of advanced technologies is easier for the young generation; the attractiveness of the nuclear industry is increased by using and implementing more sophisticated robotics systems. Removal of humans away from harm and replacing them with robots to enable higher safety even if the cost-efficiency may not be proven.

6.4. SESSION 13: DECOMMISSIONING OF SMALL FACILITIES

Majority of nuclear and radiological facilities are smaller in size and complexity and may present a lower radiological risk in their decommissioning. Graded approach needs to be applied throughout planning and implementation of decommissioning, specifically of small nuclear facilities. Projects in implementation may benefit from other examples and lessons learned from decommissioning of similar facilities while some approaches and techniques tested in small-scale might be later considered for decommissioning of larger facilities. The main principles, such as careful planning, preparation of detailed characterization, use of proven technologies and availability of qualified staff etc. are important to consider and implement in practice.

In the session were presented 8 papers from Finland, Australia, Egypt, Romania, Indonesia, Poland, Thailand, and Serbia.

Lessons learned in planning, licensing, contracting and preparatory measures from shutdown until start of dismantling of FiR 1 (*FIG. 20*) research reactor in spring 2023 was presented by Finland. FiR 1 has been a key nuclear energy training and research facility for almost two generations. Now it serves as a pilot facility on decommissioning, being a forerunner in using virtual visits in the planning, detailed activity inventory characterization, radioactive waste management, and possible free release of materials, including methods to estimate difficult-to-measure nuclides. Technical plans of

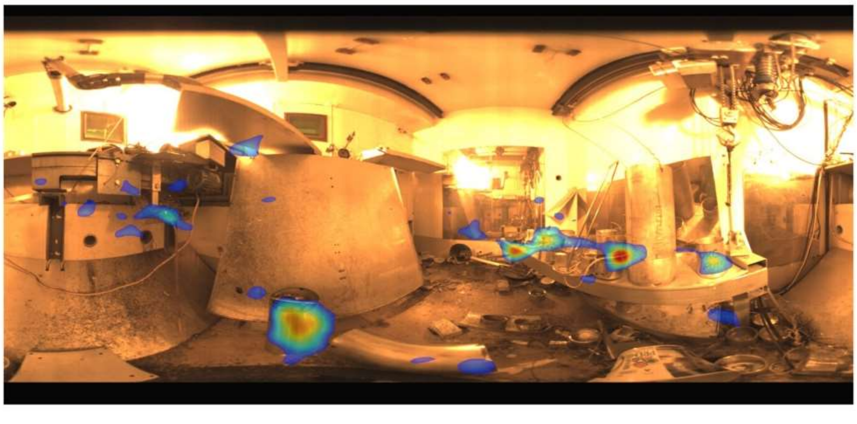

FIG. 20. FiR 1 as the first nuclear facility to be decommissioned in Finland. (Courtesy of VTT, Finland)

decommissioning are summarized in the final decommissioning plan. A final safety analysis report for decommissioning by VTT Technical Research Centre of Finland has been completed in 2022.

Paper from Australia described HIFAR research reactor and its operational characteristics. It also briefly described some of the more significant design and operational issues found during characterization of the facility, and which are predicted to present sizeable challenges during physical dismantlement. It addressed the stages of final shutdown of the HIFAR facility and identify some actions that would have been beneficial to the subsequent characterization and decommissioning projects (*FIG. 21*).

A paper from Egypt highlighted areas where early planning can significantly reduce the financial, safety and schedule process associated with the decommissioning activities for research reactors that are in the extended shutdown status. Moreover, some related technical aspects are introduced and discussed during the extended shutdown mode of operation. Three main particular decommissioning phases have been proposed. The first phase represents the pre-decommissioning activities in which the needed documents for whole decommissioning processes should be prepared in addition to the defueling activities. The second and the third phases are related to dismantling and decontamination activities. Moreover, work packages of the eventual decontamination and dismantling activities have been explained.

As part of decommissioning of VVR-S Romanian research reactor, the remained structures, and buildings after dismantling operations had been checked for contamination. The radiological survey was performed, procedures and used tools as well as techniques and statistics were described. The final decommissioning report developed by licensee explained how the end state criteria were met both for structures and buildings. This paper described the remaining buildings, structures and equipment which did not meet the release criteria and those which need release with restricted use. Abnormal events and incidents that occurred during decommissioning and summary of occupational and public doses received during the decommissioning were highlighted. Finally, the experience was overviewed on regulatory review of the radiological survey report as well as the final decommissioning report to support decision to release the facility from regulatory control.

The Radioactive Waste Treatment Installation (RWI), owned by Indonesia National Research and Innovation Agency (previously BATAN, now BRIN), is the only radioactive waste management facility in Indonesia operating since 1988. The RWI has a thermosiphon-type evaporator to treat and reduce liquid radioactive waste with a maximum capacity of 0,75 m^3/h. The evaporation method reduced the radioactive waste, mainly containing Cesium-137 and Cobalt-60, and the resulting concentrated effluent was solidified in cement. Since the RWI has to have a decommissioning program, including the decommissioning of the evaporator, as the requirement for its operating license, preliminary characterization of the evaporation system is carried out to predict contamination of components, systems, and structures. Free and fixed contamination can occur along the route of radioactive waste effluent, such as tanks, pipes, valves, pumps, evaporator vessels, heat exchangers, chillers, and others.

FIG. 21. Shutdown of HIFAR facility in Australia (Courtesy of ANSTO, Australia)

Based on the prediction of contamination, appropriate decontamination and dismantling methods can be recommended.

The decommissioning procedure of a medical cyclotron and Monte-Carlo simulation of the potential nuclear reactions has been performed in Bangladesh. The initial stage of the decommissioning procedure involves removing the simplest and hottest parts of the cyclotron as well as sampling and measuring the concrete wall and floor have been carried out. Concrete samples from the first 25 cm and from various depths were used for the sampling of the wall. Thermoluminescent dosimeters and digital dosimeters were used to monitor the doses of the workers who are involved in removal operations. For internal contamination, measurements were taken on samples of urine, spit, and nasal mucus. The residual activity of all samples was measured with a HpGe detector and liquid scintillation counting and compare with simulation data. During decommissioning or disposal of a cyclotron, the induced radioactivity in the structures and components of cyclotron were considered as radioactive waste. A report on the completion of decommissioning including the safe disposal of sources and any exposures to employees that occurred during decommissioning has been submitted to the competent authority of Bangladesh.

A case study from Thailand for the radioactive waste combustion system inside the radioactive waste management centre in Thailand Institute of Nuclear Technology (Public Organization) with a service life of more than 40 years, has deteriorated condition. The institute had to decommission the radioactive waste incineration system to ensure the safety of people and to prevent hazard from radioactive residues in the incinerator. Therefore, the decommissioning of the incineration system had to be carried out properly according to the international standards of the IAEA and to rehabilitate the area so that it can be used in the future.

In Serbia, the initial decommissioning plan presented the process of action for the future decommissioning of the radiation unit. The development of a decommissioning plan is an obligation of each institution licensed using ionizing radiation sources (Article 142 of the Law on Radiation and Nuclear Safety and Security of the Republic of Serbia). The presentation has described in detail all the elements of the initial decommissioning plan. Also, the structure of the plan was shown, and all necessary activities required for its implementation were listed.

The remediation concept at the Crossen site of Germany envisaged bringing the tailings pile masses, the demolition material from the facility premises and the excavated soil to the nearby industrial waste site Helmsdorf. The following points were discussed: (i) radiological surveys carried out prior to dismantling, (ii) the preparation of radiological environmental assessments as a basis for the approval procedures, (iii) the demolition and dismantling of the pipe conveyor (dismantling technologies, decontamination and evaluation of the resulting scrap batches using a special WISMUT in-situ measurement method), (iv) the radiological release of the resulting scrap for recycling, (v) the subsequent area assessment with sampling, (vi) measurements and release from radiation and mining law and (vii) lessons learned.

The session concluded by the presentation from Poland, a country with several research reactors with power less than 100 KW. As a part of research and preparation for construction of future planned large reactor, two facilities became full scale research reactors named EWA and MARIA. EWA research reactor is partially decommissioned, and MARIA is still in operation. Decommissioning of EWA research reactor was done between 1995 and 2000. Reactor with infrastructure was removed, but administrative buildings are in use and are under radiological monitoring. MARIA research reactor requires to present an updated decommissioning plan every five years as the requirement to be licensed. It is planned that the mentioned reactor will be in operation until 2050 and the last update of the decommissioning plan was done in 2020. The plan includes experience learned during decommissioning of EWA reactor. This work also covers information about commenced decommissioning and plan for the future of MARIA research reactor. Proposed were two scenarios – one to keep building safe and secured, and the second to achieve the brown field which could be used for future development of nuclear institute.

6.5. SESSION 14: TECHNOLOGICAL ADVANCES FOR CHARACTERIZATION AND DISMANTLING

Effective planning of waste management for large, activated components such as reactor internals and reactor pressure vessels is crucial for the decommissioning process. The waste management strategy for the fragments heavily relies on the accuracy of radiological characterization and a detailed sampling plan. Identification of the type and amount of waste packages depends on the results of the characterization. Characterization throughout all stages of decommissioning has proven to be vital during planning, execution, and clearance and/or removal of materials according to country regulations.

In this session 8 papers from Slovakia, Belgium, Japan, the United Kingdom, the United States of America, and Republic of Korea, and 4 posters were presented. Several methodologies, lessons learned, and advanced technologies were mentioned.

Extensive decommissioning activities have been performed in Slovakia, in Bohunice V1 NPP. The two reactors of Bohunice were the first VVER-440 type V-230 units in operation outside of the former Soviet Union. In this project the 3D modelling was used for several components, e.g., reactor internal structures, reactor vessels, steam generators, etc., to support segmentation and packaging simulation of individual fragments. For the segmentation of the components were established two new underwater workshops and other dry cutting workshops in the main reactor building and the turbine building. A challenging schedule required good planning and management of all the activities that were running simultaneously (*FIG. 22*). For segmentation of the steam generators was required to design, manufacture, and test new cutting tools. Segregation of the outer shell and the internal structures of the steam generators was performed. More than 75% of materials produced from the steam generators' segmentation were released from regulatory control for recycling directly after dismantling and post-dismantling decontamination or will be released after application of decay storage for several years.

Considering the segmentation of reactor pressure vessels and reactor internal structures, the induced activation source term provides a major contribution to dose commitment, the quantity of waste generated during decommissioning activities, and the radiological content of the waste. A precise methodology for sampling and monitoring the components prior to the segmentation was defined and executed. Radiological characterization and verification of the calculated data during the project implementation resulted in the modification and optimization of the packaging plan. Separation of low-level fragments from the intermediate-level fragments was done.

The BR3 pilot PWR in Belgium's decommissioning strategy was based on the best practices and international guidelines. Reactor internals and vessel segmentation have been performed using different cutting techniques, the activated parts were segmented mostly underwater or remotely using mechanical

FIG. 22. Bohunice V1 reactor building during dismantling works (Courtesy of JAVYS)

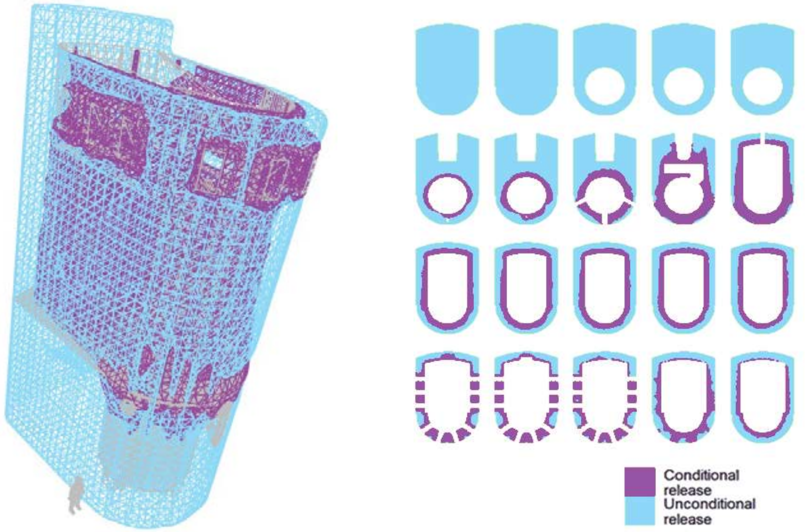

FIG. 23. Model visualizing volumes of removal over the entire height of the biological shield. (Courtesy of SCK CEN, Belgium

techniques. Removal of the concrete biological shield represents a vast amount of radioactive material from the project. The characterization has been based on data analysis and sampling strategy which resulted in a 3D model for the activity distribution in the concrete structure (*FIG. 23*). Removal of the concrete was performed according to the prepared map of contamination. A remotely operated pneumatic hammering demolition robot has been used for the removal of the concrete in layers.

The characterization of radiologically hazardous environments is one of the most significant challenges associated with the effective planning and execution of nuclear decommissioning strategies.

Technology to understand the distribution of dose equivalent rates and radiation sources at the decommissioning site of Fukushima Daiichi Nuclear Power Station is important for reducing workers' exposure and developing a detailed workplan. Development of a system that uses a commercially available VR head-mounted display to virtually experience a 3D model of the work environment was presented by the author of the paper from Japan. The aim of the work is a development of a method to estimate radioactivity from images of hot spots acquired by the Compton camera and to calculate dose rates in the surrounding areas using a radiation transport calculation code. This advanced technology will be able to estimate the radioactivity of hot spots in the Fukushima Daiichi NPP using a gamma-ray imager and to estimate the dose rate distribution using radiation transport calculations.

Effective characterization of unknown environments provides vital knowledge of hazardous locations within a plant and enables calculation of operator dose uptake when planning work in high radiation areas, reducing unnecessary risk and exposure. NV-Explore is designed as a portable radiometric payload that can be mounted to any remote device. The NV-Explore is considering the challenges

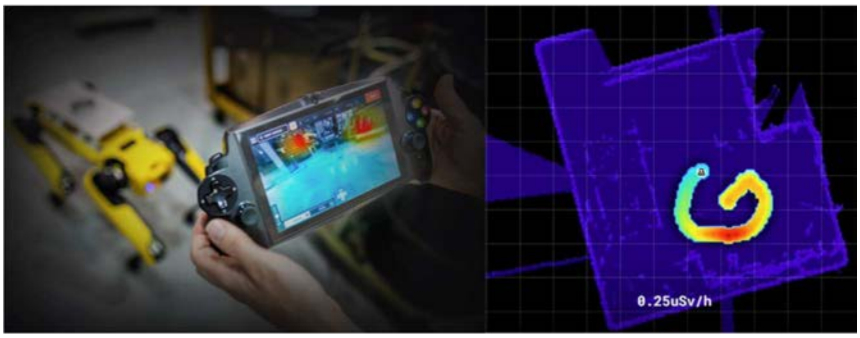

FIG. 24. Example of views of both the source of radiation (left) overlaid onto the spot camera and the dose measurements overlaid onto the building map (right) as real time outputs on the spot controller. (Courtesy of Createc, UK)

associated with contamination, that is impacting the characterization of nuclear environments. Utilization of such technology across the power generating facilities and sites of nuclear accidents or former research facilities supports the decommissioning process to be more safe, effective, and efficient (*FIG. 24*).

7. CLOSING SESSION

7.1. REPORTS OF THE CONFERENCE VICE PRESIDENTS

7.1.1. Vice-President's Summary Outcome of the Framework to Enable Effective Nuclear Decommissioning

Dr. Marta ŽIAKOVÁ, Chairperson, Nuclear Regulatory Authority of the Slovak Republic, Slovakia

We have successfully reached the point at which we will conclude and evaluate the second day's sessions of the Conference. Before outlining some of the high-level conclusions and outcomes, I would like to thank all those who contributed to a successful day dedicated to establishing a framework for the effective decommissioning of nuclear installations. In particular, the chairs of the individual sessions, the moderators and chairs of the side events and the panel discussions, authors of posters and finally all of you who contributed to the smooth running of the second day with your active participation.

Over the four sessions, we have engaged in insightful discussions and shared invaluable experiences on the policy, legal and regulatory framework for the decommissioning of nuclear installations, competence development, decommissioning and waste management, including on EURATOM HORIZON 2020.

Besides the sessions were complemented by two side events: (i) on improving the safety of radioactive waste management from Ignalina NPP and on IAEA Decommissioning Collaborating Centres, (ii) one panel discussion on stakeholder engagement and repurposing of sites. During the poster session, Member States shared their experiences, ideas, and forged connections that will undoubtedly shape the future of nuclear decommissioning.

The 3rd session on Policy, Governmental and Regulatory Framework demonstrated that some decommissioning projects are very complex and therefore, we need to change our approach, moving away from a prescriptive model to a dynamic one. The importance of creating space for an open dialogue, transparent communication, and trust have emerged as key pillars for success in this critical area. On one hand, it is important for nuclear power plants to prioritize safety, while on the other hand, they should be designed to be "decommissionable". In this regard, the significance of circular economy aspects is growing, particularly in terms of reusing facilities or the sites.

With the growing number of decommissioning projects reaching their final stage, there is an increasing demand for guidance regarding site clean-up and the verification procedures required for the release of the site from regulatory control.

We noted for example that in Italy, there is an open portal for stakeholders to communicate with the public on the results of monitoring. In the United States of America, the NRC is updating and developing guidance on site remediation and on survey and dosimetry considerations for discrete radioactive particles to streamline the decommissioning process. A novel approach has been formulated by the ASN in France, featuring a revised regulatory framework, the use of visual tools, the implementation of regulatory project inspections and, lastly, the encouragement of a positive mind-set and behaviours.

What are the take-aways? Recognizing the need for addressing the sustainability of decommissioning is important as we are moving towards a more circular economy. Flexibility in decommissioning planning is essential, with a need of a shift in focus from demolition to decommissioning. It also leads us to put a greater emphasis on the potential reuse or recycle of equipment, as well as systems and components.

The regulatory body should comprehend the critical path of decommissioning projects and strive to issue authorizations in a timely manner, thus facilitating efficient decommissioning essential for ensuring long-term sustainability. In addition to long-term management, continuous monitoring, maintenance, and implementation of institutional controls are crucial, especially in cases involving restricted releases. Drawing lessons from both successful and unsuccessful past experiences, can provide valuable insights, best practices, and lessons learned, contributing to continuous improvement in future decommissioning endeavours.

The 4th session on Competence Development addressed the three main leadership roles in decommissioning in Indonesia. These involve designing various products and the establishment of process for implementing of policies and necessary documentation to initiate and manage decommissioning activities. It further includes, ensuring the availability of necessary resources and their effective management, facilitating dialogue and mediation between stakeholders, and cultivating a strong safety culture among implementers. A recommendation from this Conference is to conduct further confirmatory studies to explore the nature of leadership in decommissioning, using primary data sources, such as surveys and interviews. Examples of competency development programmes at the national level (Rosatom, RF) and international level (IAEA and EU cooperation) were also provided.

In the Session on Waste Management, it was generally observed that a comprehensive characterization plays an important role in filling knowledge gaps, facilitating effective dismantling or decontamination, as well as helping with the selection of optimal waste management strategies. In decommissioning planning, stakeholder involvement addresses relevant public concerns and increases public acceptance of decommissioning projects. Emphasis should be given to operations at the designing and construction phases of decommissioning planning. Waste management integration is an important element to promote effective decommissioning. Optimization of waste management can promote waste volume reduction as well as waste re-classification to lower categories, and therefore, waste management integration is an important element in the overall decommissioning processes.

Given the lack of final disposal solutions, radioactive waste management remains the main challenge for most nuclear countries. Countries with clearly defined radioactive waste management policies facilitate more efficient decommissioning activities.

Challenges concerning characterization rest on obtaining reliable and high-quality characterization data, particularly noticeable in the context of legacy waste. Enhanced remote and in-situ characterization capabilities prove to be beneficial for both the initial and long-term waste characterization processes.

The challenge in segmentation and dismantling lies in the availability of technologies for safe and cost-effective dismantling. Currently, existing technologies tend to be labour-intensive, thereby increasing workers' exposure to radiation. Detailed planning, monitoring and oversight of activities are essential to minimize the risk of accident and injury, ensuring industrial safety and radiological protection.

Examples have been given in support of national waste management programmes. In the United Kingdom, there is a national identification of challenges (e.g., characterization capabilities) that need to be addressed. R&D and incubation of new and innovative technologies, including the involvement of larger stakeholders are used in France to drive innovation. In Germany, landfills support disposal of very low level waste (VLLW) given higher acceptance criteria compared to unconditional clearance. Stakeholder engagement and federal support can promote waste disposal. In China, early establishment of regulatory principles, requirements, and classification standards for waste minimization, including a roadmap of challenges can improve future decommissioning and waste management demand.

In the field of waste management, we can take away valuable lessons: (i) to consider focusing management resources on wastes that present the greatest environmental risk; (ii) to incorporate early waste characterization and record keeping into the decommissioning planning process. This can assist in decision-making on management methods (e.g. sorting/segregating/decontamination, etc.) and support the implementation of the waste management hierarchy; (iii) to overcome limitations in facility design, especially in legacy nuclear sites, by automation and modularity of handling / sorting / decontamination, especially for legacy nuclear sites; (iv) to support the implementation and progress of national programmes for waste management and provide opportunities for international cooperation; (v) to develop both less energy-intensive and less invasive treatment methods for facilitating more efficient remediation and environment protection.

The Special Session on Euratom Horizon 2020 Research and Innovation Programme reported the progress of several collaborative projects related to waste management and decommissioning and emphasized both needs and benefits of the research and innovation activities.

Collaborative projects, such as ANUBIS project, the MICADO project, the PREDIS project and the international PLEIADES project, were also presented.

In addition, a three-year EURATOM HARPERS Project focuses on the establishment and clarification of the benefits and added value of harmonized regulations, practices, and standards in decommissioning and radioactive waste management, including possibilities for shared processing, storage, and disposal facilities between Member States.

During day 2 a panel discussion on Engaging Stakeholders and Repurposing Sites was held and a side event was held on the Joint Effort on Implementing the Decommissioning Project as a Collaboration between Lithuania, Norway, and the IAEA. The event presented a good example of successful international cooperation, leading to improvement of plans and enhancement of safety of radioactive waste management at the Ignalina NPP in Lithuania.

The day 2 of the conference concluded with a side event on IAEA Collaborating Centres on Decommissioning, where a re-designation signing ceremony was held for the Collaboration Agreement between the IAEA and the Institute for Energy Technology (IFE) from Norway. The IFE became the next IAEA collaborating centre on decommissioning, together with SOGIN (Italy), JAVYS (Slovakia), EDF-DP2D (France), JAEA (Japan) and perspective KINGS (Republic of Korea). Each collaborating centres provided a comprehensive overview of their current activities and plans for future cooperation and assistance within the IAEA programme on decommissioning.

In closing, I would like to extend my heartfelt gratitude to all of you for your active participation and contribution towards advancing nuclear decommissioning. I hope that we will remain committed to the principles we have affirmed here and take away the ideas and lessons learned from past experience that will enable the effective decommissioning of nuclear installations.

7.1.2. Vice-President’s Summary Outcome of the Framework to Manage Nuclear Decommissioning

Mr. Brian WILCOX, Director of Reactor Decommissioning, Canadian Nuclear Laboratories, Canada

The programme on day 3 for the Planning of Decommissioning was fantastic. My deep appreciation for all the presenters for sharing their work.

Presenters shared their roadmaps and experiences for transitioning to decommissioning from operations. It was clear that optimization of the projects was a constant theme throughout the day. The programme on decommissioning fuel cycle facilities presented excellent technical information and methods to mitigate hazards and project risks. This is a very useful experience that can be applied to other projects. Acceleration of projects continues to be incentivized. Facilities are decades old and operational knowledge, which is critical to planning, is eroding.

As a summary, the integration between decommissioning and waste management continues to be the most important partnership to ensure optimal management of waste arising and the avoidance of repacking or multiple handling.

Optimization is an important trend in decommissioning to deliver work on both large and small projects more efficiently, making best use of resources. The fleet approach to build once and deploy several times was presented by several countries and organizations.

Decommissioning teams are adopting new technology, especially visualization tools, to improve collaboration and planning. The use of digital twin models is making the work safer and more efficient, especially to assist in material handling, mock trials, and to guide workers in the field to avoid hazards.

I’d like to share some of my key take-aways from the conference:

Decommissioning is a waste-driven process. In other words, the waste produced (type and rate) and the ability to manage it can be a constraint to efficient decommissioning. The waste infrastructure to handle waste produced is a critical resource to decommissioning. This is probably the largest challenge facing decommissioning projects in most countries. The waste management infrastructure has not kept its pace with the decommissioning work.

Integration between decommissioning and waste management is important in these areas:

— Clear roles and responsibilities;

— Up front characterization and resulting waste plans;
— Clear waste processes on packaging requirements, including field technical support;
— Provision of containers and documentation;
— Avoidance of multiple handling and moving of waste;
— Waste receiving, storage and disposal options.

A decommissioning challenge experienced by many projects continues to be timely and adequate characterization data. Planning, to execution, to waste management relies heavily on reliable characterization. Characterization data is fundamental to support safety systems and the determination of which safety systems are needed and the timing of removing them from service. Advice from presenters was to characterize early, especially when operators are still at the site and can use their operational and historical knowledge, which benefits the characterization results.

Optimization and Sequencing of projects was another significant topic at the conference. This is especially so for large missions that have numerous sites in a country or sites with many facilities. Managing a fleet of sites or fleet of reactors, presenters provided excellent advice. Presenters discussed methods and analysis to best achieve efficiency in decommissioning programmes.

Decommissioning, like any business, has to effectively manage funds and prioritize the work to align with budgets. Projects should develop a licensing and technical blueprint (plan) for one site/calandria/core, and then re-use it multiple times. Projects are making very good progress, and we are seeing completion of decommissioning occurring.

The conference theme is Addressing the Past, Ensuring the Future. The work that my organization is doing is a perfect example. I would like to share what is happening at one of our sites, Chalk River Labs in Canada, where we are renewing the site for future of nuclear science and technology. Called Vision2030, we are designing and building new nuclear facilities to enable the continued delivery of science and technology as Canada's national lab. This based on 3 key priorities:

— Restoring and Protecting the Environment;
— Advancing Clean Energy;
— Contributing to the Health of Canadians.

The vision will convert a very old 1940s site into a modern, sustainable campus, designed to enhance collaboration. Equipped with modern research facilities, it is our intention to attract excellent employees and important collaborations.

Examples of our new, most important initiatives include cutting edge cancer treatment using targeted alpha therapy. CNL is also enabling the demonstration of SMRs, by being the host and support to organizations and private sector vendors.

None of this is possible without our very large decommissioning programme. To enable Vision2030 we need to safely decommission over 200 buildings and facilities, many of which were built in the 1940s, 50s, and 60s. We are halfway there, and new facilities are being constructed in the footprints of decommissioned and demolished buildings. It is a very busy site!

The staff at the IAEA have done a wonderful job this week, along with the many hours of hard work in the months that preceded. This truly was an international decommissioning conference, with all continents (well maybe not Antarctica) represented. It has been a great mix of the big, multi-site country projects and the smaller, unique projects. It was also great to see youth participating and the important discussion on how to attract and retain young people to our industry. It has been my deep honour to be Vice President for the Management of Decommissioning day. I hope you are taking away new business contacts and fresh information. I certainly found the week very productive.

Thank you very much!

7.1.3. Vice-President's Summary Outcome of the Framework to Technological Advancements

Kentaro FUNAKI, Executive Director, Fukushima R&D and International Affairs, Japan Atomic Energy Agency, Japan

An exciting week is coming to an end. The focus of day 4 of the conference was on technological aspects of decommissioning, and we learnt that impressive progress is being made in the implementation of advanced technologies in this field. Allow me first to thank all the presenters, posters presenters, speakers from the panel discussions and the participants of the Conference for their active attendance in the technical sessions and panel discussions.

Yesterday's sessions focused on digitalization, robotics, and remote operation, decommissioning of small facilities and on technological advances for characterization and dismantling: 36 oral presentations were provided, including a panel discussion on the role of the supply chain in fostering innovation. There was also a poster session with 16 posters being presented.

Given the rapid developments currently taking place in the fields of digitalization and robotics, and considering the number of nuclear power plants, research reactors and other nuclear facilities expected to be under decommissioning over the next 1-2 decades, it is inevitable that the role of these technologies will increase substantially. The increasing use of robotics brings the obvious benefit of removing workers from a hazardous environment, resulting in increased safety. It is very likely that there will also be increases in efficiency, resulting from reductions in the duration of activities and associated reductions in cost.

Digitalization also brings many benefits, which are linked to the ability to represent physical systems in a digital form. Digital models, especially if they include radiation data, enable different dismantling strategies to be simulated and therefore optimized. In this way they also support detailed work planning and training, e.g., by enabling a worker to 'virtually' enter a facility and therefore become familiar with the layout and environment within the facility, including the hazards that will be encountered.

Subsequently, having entered a facility location to undertake the planned activity, the worker may be assisted by technologies based on extended reality, whereby the worker receives information about the characteristics of the surrounding environment directly through headsets, such as information about radiation levels. This brings a clear safety benefit.

Detailed three dimensional BIM-type models provide a framework for bringing together information about the system from many different sources. The process of collection and refinement of data is being enhanced by the use of remotely operated vehicles, especially drones, for data collection and the use of digital systems for its preservation and sharing. This development will have a significant impact on the process of collection and management of data as part of the characterization process, which is currently often extremely time consuming and expensive.

The possibility of visualization of facilities and of different dismantling scenarios also support interactions with regulators and indeed with other stakeholders such as supply chain and the general public.

The increasing adoption of digitalization and robotics brings the additional important benefit of increasing the attractiveness of decommissioning for young people – because of their natural interest in new technologies. As was mentioned several times during the conference, encouraging young people to work in the decommissioning field remains one of the most important challenges facing the decommissioning industry.

Key points from the session on digitalization

- Despite significant number of digital tools for mapping and displaying of radiological conditions available on the market, the implementation at large scale is at a relatively low level. Development of tools for radiological characterization of buildings and materials is still underway;

— Digital Twin modelling could be an extremely useful tool for the project implementation when planning various work packages however the cost should be considered as a long-term investment.
— Planning with digital tools leads to enhancing the physical walkdowns and reducing time. Digital tools for smart planning are bringing new options for more optimal and accurate planning and preparing of activities in decommissioning.

Key points from the session on robotics and remote operation

— The adoption of robotics for decommissioning activities is still at relatively low levels and is still largely based on master-slave manipulator systems;
— New robotic systems have reached maturity in recent years – for mapping, navigating, grasping, cutting etc. – and are likely to be increasingly adopted in the coming years;
— Cost benefits of increased adoption of robotics and remote handling are more evident if a long-term vision is taken, i.e., it is often difficult to show a cost benefit in the short term unless an ‘of-the-shelf’ technology is being used;
— An important barrier to greater adoption tends to result from lack of knowledge about the specific technology and on experiences gained with its usage;
— The importance of early engagement with the regulatory authorities was emphasised and it was noted that regulators can be an important catalyst for using technologies that provide demonstrable safety benefits.

Key points from the session on small facilities decommissioning:

— Just as with larger facilities, developing a good characterization plan at the outset facilitates the effective characterization of a facility and supports the subsequent dismantling work and management of the resulting materials and radioactive waste;
— Small facilities are often unique and therefore it is generally more cost effective to use well known and mature technologies for implementation of decommissioning.

Key points from the session on advances in using technology for characterization and dismantling:

— Important current areas of development are concerned with dose rate measurement and identification of hot spots, together with the creation of radiological maps;
— Characterization (radiological and physical) is an essential element for planning decommissioning activities and waste processing and disposal;
— Integration of diverse source of information in a common digital model is a very powerful tool to increase the understanding of the situation and also creating unintended opportunities;
— Innovations may create a need to adapt the regulatory framework. So early exchange with the safety authority is important.

Conclusions:

Greater use of robotics and digitalization is inevitable in decommissioning, particularly for larger and more complex facilities. In this sense decommissioning is no different than other major projects. But the extent and pace of their adoption depends on a number of factors which are still being addressed, including regulatory acceptance, demonstration of cost benefits to users, and extent to which they are taken up by the supply chain involved in project implementation.

It is important to have a long-term perspective when considering cost benefits, given the difficulty is demonstrating an immediate cost benefit with the use of any new or emerging technology. Adopting a ‘wait and see’ approach will always be a general barrier to progress, i.e., someone has to make the first move if progress is to be made. Collaboration between organizations working in this field is therefore crucial, both to address this aspect and to avoid the situation of unnecessary duplication of development work.

7.2. REPORT OF THE CONFERENCE PRESIDENT

Laurence PIKETTY, Deputy CEO, CEA – Alternative Energies and Atomic Energy Commission, France

We have reached the final session of the IAEA Decommissioning Conference Decom2023 and I would like to express my great appreciation to you all – speakers, attendees, exhibitors and the IAEA staff for your support and active participation in the technical oral and poster sessions, panel discussions and side events. The global interest in nuclear decommissioning has been demonstrated by the following:

— Total number of officially designated (registered) participants: 460
— Total number of invited speakers: 46
— Member States participating: 69
— Number of international organizations participating: 6

Number of oral presentations: 109 in the main programme including VP keynotes (3), and President and VPs presentations on Friday (4) & number of posters: 42.

Four panel discussions and four side events were held during the Conference.

The theme of this conference was "Addressing the Past and Ensuring the Future" and I think the IAEA Director General captured our sense of urgency when he said that "as we look into the future, the past is catching up with us."

It is true, we face new and complex challenges as we see the global expansion of nuclear energy and technology applications. We recognize that nearly half of the current over 400 power reactors will be in decommissioning by 2050. While reactor decommissioning draws the most attention, the number of fuel cycle facilities, research reactors, medical isotope and other facilities are far more numerous and also require attention. But the challenge we face are that very few of these facilities were designed with decommissioning in mind. Applying the principles of circular economy to optimize reuse and recycling of material and minimizing waste will be difficult. But these challenges also present opportunity for developing new technologies and processes, and perhaps more importantly, attract a new generation of talented specialists to careers in decommissioning.

In this regard I would like to note the IAEA project on Global Status of Decommissioning of Nuclear Installations presents outcomes of a collaborative study to analyse the status of nuclear decommissioning activities around the world, as well as considers future evolution in this professional area. Structure of this Decommissioning conference to some extent reflects considerations summarized in the project report and further built on them.

The first IAEA international conference on decommissioning was held in Berlin in 2002 and this week illustrates what progress has been achieved in the nuclear decommissioning programmes over the world. By way of comparison, we presented a few charts to show the decommissioning developments for power reactors, research reactors and fuel cycle facilities. These charts can be found in the Global Status of Decommissioning of Nuclear Installations.

While these charts may show the growth in demand and need, the facts are that nuclear decommissioning is not a simple clean-up or demolition. It is a complex set of interrelated tasks to be implemented safely by well trained staff based on the advanced technologies, solid engineering design, effective project management, and supported by comprehensive waste management programs. To an outside observer of this conference, perhaps this is the most important take away message.

Let me now to summarize the main outcomes, issues, good practices, and remaining tasks for the future as per key topics presented and discussed this week:

Framework to Enable Effective Nuclear Decommissioning:

— Need to change the regulatory approaches for decommissioning from prescriptive ones to dynamic and more flexible ones has been recognized in several countries and actions are underway to establish new approaches, supported by visual communication tools, taking into account the views of stakeholders.

— More and more decommissioning projects are reaching their final stages, and guidance on site clean-up and final surveys for site release are gaining interest. Release of sites with restrictions remains a challenge. Additional clarifications of the concept and regulatory guidance are necessary in many countries, for example in relation to the release criteria and to the definition and implementation of post-decommissioning institutional controls.
— In the current global economic and financial situation, a need was recognized for prudent safekeeping and protection of decommissioning funds.
— The main challenge for advancement of decommissioning projects in many countries is still the lack of disposal facilities for radioactive waste and lack of plans for the disposal. The practices show that countries with clearly defined radioactive waste management policies facilitate their decommissioning activities more effectively. Continuous efforts are necessary to advance the establishment of national policies and strategies for decommissioning and waste management, including aspects of waste disposal.
— The ageing of the nuclear facilities worldwide and the increase of the number of decommissioning projects require continuous efforts on competence development in many countries. These efforts would benefit greatly from enhanced international cooperation.
— The conference recognized and welcomed the progress of several international research and innovation projects related to waste management and decommissioning and emphasized the needs for and benefits of the research and innovation activities, in particular those related to characterization, dismantling technologies and waste management.

Framework to Managing Nuclear Decommissioning:

— The integration between decommissioning and waste management continues to be the most important partnership to ensure optimal management of waste arising and the avoidance of repacking or multiple handling.
— Optimization is an important trend in decommissioning to deliver work on both large and small projects more efficiently, making best use of resources. The fleet approach to build once and deploy several times was presented by several countries and organizations.
— Decommissioning teams are adopting new technology, especially visualization tools, to improve collaboration and planning. The use of digital twin models is making the work safer and more efficient, especially to assist in material handling, mock trials, and to guide workers in the field to avoid hazards.

Framework to Technological Advancements

— Application of advanced technologies in the decommissioning process is enhancing efficiency and effectiveness in all stages. Planning with digital tools leads to enhancing the physical walkdowns and reducing time. Digital tools for smart planning are bringing new options for more optimal and accurate planning and preparing of activities in decommissioning.
— Application of advanced technologies in small nuclear facilities and research reactors is an opportunity to implement activities in small-scale and later to develop into full-scale applications in nuclear power plant. Capturing the lessons learned and updating the systems with the new emerging technologies is necessary along the full decommissioning process.
— The development in the field of robotics and remotely operated tools is in advanced stage in many countries. The sharing and international cooperation is necessary to accelerate the development and applications in the nuclear field. Looking to other type of industries to gain from the applications of advanced technologies brings the benefit in usage of proven and workable technology.
— Cost benefit analysis is driving the decision process for deployment of the advance technology into the project. The higher costs for the technology development in first sight may impact the implementation if correct cost benefit analysis is not performed. The increased initial costs are often worth the price as optimization of the waste production or human effort is significantly decreased.
— Despite significant amount of remotely operated and digital tools for mapping and displaying of radiological conditions available on the market, the implementation in large scale is not that common. Development of tools for radiological characterization of building and materials is still underway.

- Training of personnel using extended reality, or virtual reality is under development in many countries, while application of the tools was so far not yet commonly used and expensive. International cooperation on this topic would be beneficial for the accelerated implementation.
- Remotely operated technologies are largely used in different sites. The collaborative approach on sharing the technologies for the same or similar design of reactors may be beneficial.

The last time we convened this conference was in 2016 in Madrid. Many of the challenges and issues identified seven years ago remain but there have been successes as well. While seven years is a short time period, I think it is clear from the presentations and discussions held here this week that there are changes worth noting.

First, is the expanded awareness of the global challenge of climate change. In 2018, the United Nations' Intergovernmental Panel on Climate Change (IPCC) report called for limiting the global temperature rise to 1,5°C. Subsequent reports from numerous scientific and governmental agencies began to recognize the importance of nuclear energy as a contributor to a clean energy portfolio and sustainable development goals. This has given rise to the interest to the rapid deployment of advanced and small modular reactors, expanded construction of large NPP, and extending the life cycle of current reactors.

Second, is the need for an expanded workforce trained in nuclear technologies and decommissioning. Over the next 25 years there are likely to be in excess of 200+ power reactors and many other facilities undergoing decommissioning. At the same time, the human resources needed for the global expansion of nuclear energy will compete for many of the same talented and trained individuals needed for decommissioning. Maintaining competence at decommissioning sites is already a challenge and likely to grow worse unless efforts are made now to increase the pipeline of talent. The IAEA might strengthen its support to Member States with further training initiatives, including establishing the Leadership and Management Decommissioning School.

Third, are the challenges of waste management and the growing recognition by Member States and organizations that cost effective solutions for implementing decommissioning and environmental remediation will require changes in approaches to waste management. Concepts such as applying circular economy to decommissioning and waste management will require the innovative use of less energy-intensive intrusive treatment technologies, establishment of recycle pathways etc. The IAEA should follow this trend and should emphasize circular economy principles into its activities.

Going forward, what are our opportunities? I think it is clear that decommissioning by design is becoming a fact. While we may not be able to apply this to most of the current NPP fleet, the new generation of reactors and facilities should have this as part of their design basis. This is an evolving process. As we begin to apply concepts of sustainability and circular economy, new standards will need to be developed. This will also require new approaches and methods for addressing life-cycle costs and decommissioning funds. New reactors are designed for at least 60 years of operation and likely 80 years. Financial plans and investment of decommissioning funds over such an extended period requires new approaches to financial planning and regulatory oversight. The IAEA is expected to continue knowledge-sharing, networking and benchmarking initiatives addressing these challenges.

It is also clear that the trend is for earlier dismantling and termination of licence which will support potential beneficial reuse of the land and facilities at decommissioned sites. Characterization and record keeping integrated into the decommissioning planning process can assist in decision making. We expect the IAEA continue supporting knowledge-sharing and training activities in this respect.

With the increase in decommissioning, one change we are seeing is an increased awareness of the need for regulatory approaches which are risk informed. Regulations must be commensurate with the risk and prescriptive formulas often reduce the opportunity for beneficial re-use. This requires stakeholder engagement beyond risk communication. Decommissioning plans should address future uses and limitations and engagement by stakeholder in decision processes. While the regulatory framework drives toward license termination, the opportunity for beneficial reuse will drive social acceptance of decommissioning plans. In this respect we are welcoming the IAEA conference on stakeholder engagement to be held in 2025.

Vision of the future of decommissioning was well presented in the Conference session on Thursday – point mapping, digital twins, virtual reality, remote mapping, data integration, artificial intelligence, and autonomous robots. All these technologies are transforming decommissioning, reducing human intervention, radiation exposure and removing unknowns. The decommissioning of a large NPP used to take two to three years for characterization and planning. These new technologies are substantially reducing both time and cost. When we convene this conference again in five years, I can only imagine what new advances will have been made. Perhaps we should reserve a speaking role for Spot the Robot Dog who is already deployed in many decommissioning projects around the world.

In closing, I want to again express my thanks to the DDG, thanks to Minister Ms Van der Straeten and all three Vice-presidents – Ms Marta Ziakova, Mr Kentaro Funaki and Mr Brian Wilcox. Great appreciation to the Decom2023 Programme Committee including Olena and Vladan as Scientific Secretaries as well as to all involved IAEA staff.

The future of nuclear decommissioning is brighter because of you. Thank you for all you have done, and I look forward to following your accomplishments in the future. Safe journeys to all of you until we meet again.

7.3. CONFERENCE CLOSING REMARKS

Mikhail Chudakov, Deputy Director General, Department of Nuclear Energy

Madame President, dear Vice-Presidents, distinguished delegates, ladies and gentlemen,

I would like to thank you for taking part in the International Conference on Nuclear Decommissioning: Addressing the Past and Ensuring the Future. The focus of the conference was on identifying the main current challenges for decommissioning and on sharing information on strategies for how these might be addressed. It is now seven years since the last IAEA Conference on decommissioning, which took place in Madrid (Spain) in May 2016 – and so, this has been an important opportunity to take stock of developments since then.

As I hold the honour and privilege to be the final speaker of the Conference, I would like to provide you now with my closing remarks.

The background and theme of the Conference was established in the Opening Session by the IAEA Director General, the Minister of Energy of Belgium and the Conference President. The Director General emphasized the important role that nuclear energy can play in helping address the challenges presented by climate change and, in turn, the important part played by decommissioning in making nuclear power a sustainable energy option.

The addresses during the opening session emphasized the importance of planning for decommissioning from the very outset, at the design stage of a nuclear facility, and the associated need to make appropriate financial provisions for the decommissioning work and for management of the resulting waste. Good preparation also includes consideration of human and technological resource needs, including establishing research and development programmes where necessary. Establishing an appropriate spent fuel and radioactive waste management infrastructure is also a fundamental requirement.

The opening day of the Conference also considered the current status of decommissioning programmes and the main current challenges. These challenges, and how they are being addressed, have just been outlined in the reports by the Conference President and Vice-Presidents so I will not repeat them again. I would like to note however that nuclear programmes have now been in existence in several countries for seven decades or more, and therefore many nuclear facilities are reaching the end of the lives and will need to be decommissioned. Sustainability considerations demand that these liabilities be addressed at the earliest reasonable opportunity and not passed on to future generations.

The Conference comprised of 15 Sessions, complemented by 5 panel discussions, 6 poster sessions, 3 Side Events and a Special Session devoted to the Euratom Horizon 2020 research and innovation programme. The Conference technical sessions focused on three major themes – Enabling Factors for Decommissioning (Day 2); Management of Decommissioning (Day 3) and Technological Innovations (Day 4). The Conference President and Vice-Presidents have just provided a very comprehensive overview of the outcomes of these sessions so I will not repeat them, except to note that all sessions were very well attended, with a high level of active participation.

In addition to already provided statistics of participants (460 registered and invited, over 350 attended in person), Member States (69) and international organizations (6), I would like to highlight that that the gender balance and role of women in decommissioning have been well promoted during the conference and that Female to Male ratio of sessions' chairpersons was about half to half. We also have many young professionals on board with us. A special panel discussion on attracting the Young Generation to nuclear decommissioning provided very good perspectives on motivation of young people from different parts of the world to be involved in the decommissioning activities.

I would like to offer a few observations on some of the major 'cross-cutting' themes which emerged, beginning with the issue of human resource needs. Decommissioning remains a predominantly male industry, though this is changing. Indeed, this was evident from the level of female participation in this Conference. Nonetheless, greater efforts are needed to ensure that decommissioning is an attractive career option of women, including promoting women as role models for young people. Similar considerations apply to making decommissioning attractive for young people. Presenting decommissioning in an overall context of sustainability and concern for the environment will help in this regard.

A second topic which arose on several occasions during the week was the benefit to be gained from collaboration. This is most obvious in the case of accident damaged facilities such as at Chornobyl and Fukushima Daiichi. In the latter case, the Conference heard of several examples where the technologies being applied to diverse problems such as retrieval of fuel debris and treatment of contaminated water are benefiting from collaboration. But the benefits to be gained from collaboration apply throughout the industry. IAEA and the other international organizations participating at the Conference see this as a key part of their role and are committed to ensuring this happens, including taking advantage of emerging technologies to enhance knowledge sharing.

The final topic which I would like to mention specifically is the growing role of digitalization and robotics in decommissioning. This is one of the areas where developments since the Madrid Conference have been most rapid. The Conference included several presentations showing these advances, showing, for example, that a facility having high levels of radiation can now be scanned remotely and three-dimensional models of the scanned area can be developed which show both the physical layouts and the levels of radioactivity. The benefits for planning and eventually executing the dismantling activities are obvious, including better approaches to training of workers who will undertake the work. Remote technologies allow tools to be introduced to the work face in high radiation areas. These changes are ongoing and are likely to have a major impact on how future decommissioning is implemented.

Ladies and gentlemen, this past week has offered us exciting opportunities to gain a better understanding of current challenges facing decommissioning and on current good practices being applied to address them.

I would like to take this opportunity to express my thanks to all of you, and especially Ms Piketty for her support as President of the Conference and her engagement throughout the entire event. I also want to acknowledge the important role played by the three Vice-Presidents – Ms Marta Ziakova, Mr Brian Wilcox and Mr Kentaro Funaki. Of course, I also want to highlight the enormous effort made by the International Scientific Programme Committee who evaluated about 200 abstracts and helped design the overall programme. Please allow me to also thank all Chairpersons from technical sessions, panel sessions and side events and our wonderful conference clerks who kept the Symposium running smoothly. And of course, my sincere thanks go to the Scientific Secretaries, Olena Mykolaichuk and Vladan Ljubenov.

In addition to appreciation of the top-level supporters of this Conference, I would like to also express my thanks to Vladimir Michal and his team – Ben Bertaux, Patrick O'Sullivan, Helena Mrazova, Masahiro Yagi, Jovan Catovic, Nichola Cannavan, Iris Kridtner as well as to Irena Chatzis and others involved. I highly appreciate the hard work of the Conference Service Section, in particular the great leadership of Mr Tom Danaher.

I wish you all pleasant and safe travels back to your home countries and all the best in your future activities.

With this, I declare the IAEA Decommissioning conference Decom2023 adjourned.

8. SUMMARY OF THE PANEL DISCUSSIONS

8.1. PANEL DISCUSSION: INTERNATIONAL COOPERATION TO ADVANCE DECOMMISSIONING PROJECTS

At the beginning of the panel, HE Ms Van der Straeten (Minister of Energy, Belgium) provided opening remarks to highlight importance of the international cooperation.

Ms Yuki Tanabe (Ministry of Economy, Trade and Industry, Japan) promoted bilateral collaboration to advance decommissioning projects. Mr Con Lyras (Australian Nuclear Science and Technology Organization) introduced the IAEA International Decommissioning Network. Ms Haimanot Yilma (NEA/OECD) informed about NEA activities on nuclear decommissioning. Ms Anna Clark (IAEA Department of Nuclear Safety and Security) introduced the IAEA ARTEMIS Peer Review Services offered to Member States on the back-end management framework. Mr Carmina Jimenez Velasco (IAEA Department of Technical Cooperation) provided an overview of the IAEA support to Member States implementing decommissioning projects. Mr Valentin Seider (European Bank for Reconstruction and Development) overviewed the activities on nuclear decommissioning in the Europe and Asia regions. The session was concluded by Q&A with multiple questions and feedback by the Conference participants.

8.2. PANEL DISCUSSION: ENGAGING STAKEHOLDERS, REPURPOSING SITES

The Panel discussion included opening statements by panellists, some of them supported by few slides, and follow-up discussion on the topic. Opening remarks were provided by representative of Slovakian JAVYS. Nuclear Damage Compensation and Decommissioning Facilitation Corporation of Japan (NDF) presented Fukushima Decommissioning Programme: Engaging Stakeholders. Representative of IFE and Halden Municipality (Norway) introduces newly created Decommissioning Cluster. Office of Environmental Management of US DOE and representative of Roane County, Tennessee, presented collaboration with local communities on the site repurposing.

It has been widely discussed that stakeholder engagement in repurposing is a continuous process. Important is to engage diversified stakeholders including local residents, and younger generations for visioning future and for tackling the long-term venture. Reconfirmed was the importance of transparency, trust, and accountability. To provide accurate and understandable information is essential. Setting up information centres with digital technologies that can support communications with stakeholders is beneficial.

8.3. PANEL DISCUSSION: ROLE OF THE SUPPLY CHAIN AND TECHNOLOGICAL INNOVATION

Opening remarks to the Panel were provided by the top-level Spanish commissioner on regulatory perspectives on the supply chain and technological innovations. Representative of the United Kingdom Nuclear Decommissioning Authority explained their approach to delivering technological innovation for decommissioning through supply chain collaboration. Expert from Ignalina NPP described Lithuanian experience with supply chain and technological innovations to address needs of large graphite reactors decommissioning, as an example from country without recent nuclear power development. Representative of Bulgarian State Enterprise Radioactive Waste (SERAW) focused on supply chain and technological innovation at the site with ongoing decommissioning and nuclear power programmes in parallel.

Follow-up discussion was centred on the operational supply chain that need to provide practical basis for decommissioning implementation and support deployment and effective use of innovative technologies and approaches. Noted was also role of technological supply chain, such as national laboratories, universities, and industries, that is ready to develop and offer innovative technologies and solutions of the issues that decommissioning projects are facing.

8.4. PANEL DISCUSSION: HOW TO ATTRACT THE YOUNG GENERATION TO NUCLEAR DECOMMISSIONING

The event was moderated by Laurent Jerrige, the Director Nuclear Decommissioning and Waste Management at the European Commission Joint Research Centre. The panel focused on the importance of attracting young engineers and technicians to the decommissioning sector, given its technical challenges, use of new technologies, and complexity. Challenges in attracting the younger generation include social acceptance, the image of decommissioning, and competition from new construction projects.

It is difficult to attract young generation to work in remote areas where nuclear facilities are often located. However, robotics and climate change challenge were identified as key drivers for increasing the attractiveness of the industry for the young generations. Using existing skills while adopting modern project management methods and cultural change is essential in the development of the industry to be more interesting compared to other industries.

9. SUMMARY OF SIDE EVENTS

9.1. SIDE EVENT: WOMEN IN DECOMMISSIONING

The event was moderated by Ben Bertaux, member of Women in Nuclear (WiN) of IAEA and Decommissioning and Environmental Remediation Section (DERS) consultant. He reminded, by being the moderator of this panel, that this is not only the responsibility of women to address gender equality, diversity, and inclusion.

In the panel were participating high-level professionals, HE Tinne Van der Straeten (Federal Minister of Energy, Belgium), Laurence Piketty (Deputy CEO of CEA, France), Marta Ziakova (Head of NRA, Slovakia), Nadia Helal (Director of NRSRC-EAEA, Egypt) and Theresa Dekker (OPG, Canada), that shared their views and opinions on women participation in the decommissioning field.

Narratives around the role-models were identified as key to encourage more young women to join the field. It was recognized that even though we are getting closer to gender parity in terms of numbers, there is still a long way ahead of us to get rid of the gender stereotypes deeply rooted in our societies.

It was stated that the diversity and inclusion are gaining in importance and the benefits are numerous: diverse teams are performing better, and it creates various and wider approaches to challenges. All talents, men, and women are needed in the decommissioning field.

9.2. SIDE EVENT: SAFETY ENHANCEMENT OF IGNALINA RADIOACTIVE WASTE MANAGEMENT

Through the European Economic Area (EEA) Agreement, Norway contributes to the European internal market through a unique financial mechanism, the EEA and Norway Grants. The Grants have two goals – to contribute to a more equal Europe, both socially and economically – and to strengthen the relations between Iceland, Liechtenstein, and Norway, and the 15 Beneficiary States in Europe. The objective of the Grants is to reduce social and economic disparities and strengthen bilateral relations.

During the IAEA's International Conference on Nuclear Decommissioning, the Norwegian Radiation and Nuclear Safety Authority had the pleasure of hosting a Side Event for our project with Ignalina NPP, aimed at improving management, control, and prevention of negative impact of radioactive materials stored on the environment and population, financed through the EEA Norway Grants. The IAEA has been a valuable partner whose technical contributions have greatly aided the outcome of the project, which is set to conclude in 2024.

The purpose of the event was to showcase the Ignalina NPP project and the Grant's function, impact, and future potential. Norway's permanent representative to the IAEA, HE Susan Eckey held the opening statement, accompanied by the IAEA's representative Mr Gerard Bruno. They both highlighted the importance of close, international cooperation within nuclear decommissioning, and commended all involved parties on their efforts.

Following the presentations by DSA on the EEA and Norway Grants financial mechanisms, by Norwegian Nuclear Decommissioning on the Norwegian decommissioning venture, by Ignalina NPP and by the Lithuanian regulator VATESI, the DSA representative chaired a panel discussion. The subject for the discussion was one of the key elements to successful decommissioning: international cooperation and knowledge exchange.

DSA would like to thank to the IAEA staff, Chief Inspector VATESI, Mr Zybartas Patasius, Project Manager IAE, Mr Andrius Vysniauskas and Head of Decommissioning at NND, Ms Lene Rexten.

As the current project period (2020 – 2024) is coming to an end, DSA now welcomes dialogue with other donor countries wishing to explore potential project proposals.

9.3. SIDE EVENT: IAEA COLLABORATING CENTRES ON DECOMMISSIONING

This side event was open by Mr Mikhail Chudakov, Head of the Department of Nuclear Energy, followed by the introduction to the IAEA Collaborating Centres, highlighting collaborative approach and recent status.

Representative of Norwegian Institute for Energy Technology provided presentation of the holistic approach to digitalisation and robotics for sustainable nuclear decommissioning. Speaker from Italian decommissioning and radioactive waste management organization Sogin introduced advancements on nuclear decommissioning in Italy. Representative of Slovakian decommissioning and radioactive waste management organization JAVYS provided overview of implemented innovative technologies and approaches supporting effective implementation of decommissioning. Speaker from French EDF/DP2D explained status and activities of the Graphite Reactor Decommissioning Demonstrator. Representative of JAEA informed about activities on radiological characterization of research reactors in support of decommissioning. Executive Dean of the Korean Kepco International Nuclear Graduate School (KINGS) provided overview of perspective collaborating centre on enhanced training opportunities in NPP decommissioning and associated radioactive waste and spent fuel management.

At the concluding part of the side event was held signing ceremony of re-designation agreement between the IAEA and Norwegian IFE as the IAEA Collaborating centre on decommissioning for additional 4 years.

9.4. SIDE EVENT: UPDATE ON FUKUSHIMA DAIICHI DECOMMISSIONING

Japan organized the side event on “Reconstruction and Decommissioning in Fukushima”.

Twelve years after the accident, steady progress is being made toward the decommissioning of the Fukushima Daiichi Nuclear Power Plant, with the restoration of the surrounding environment involving local residents.

This side event, moderated by Mr Jean-Michel Chabeuf (ORANO, France), focused on sharing the latest status of the restoration and decommissioning of Fukushima.

Ms Yuki Tanabe (Ministry of Economy, Trade and Industry, Japan) delivered a presentation titled “Progress of Reconstruction in the Surrounding Area”. She noted that the evacuation zone has been significantly reduced due to tremendous efforts, including the removal of contaminated soil. She also introduced efforts to support the return of those who were forced to leave their hometowns due to the Great East Japan Earthquake and the Fukushima Daiichi Nuclear Power Plant accident, and to increase the number of newcomers to the areas surrounding the plant by promoting new industries amid the decline in the country's overall population.

Mr Akira Ono (Tokyo Electric Power Company, Japan) gave an overview of the accident at the Fukushima Daiichi Nuclear Power Plant, efforts to date to decommission the plant, and future challenges. In particular, he introduced preparations for the offshore discharge of Advanced Liquid

Processing System (ALPS) treated water and outlined what is known so far about the fuel debris in the reactors and the planned test retrieval of debris.

Ms Nancy Buschman (Department of Energy, US) and Mr James Byrne (Byrne & Associates, LLC, US) provided their observations and perspectives, based on their own decommissioning experience.

Mr Jean-Michel Chabeuf closed the side event by pointing out the critical importance of gaining public acceptance for the decommissioning of Fukushima Daiichi NPP as explained by Japan in the previous day's session, and the need to share information and encourage dialogue to gain understanding among people of all ages and demographics.

10. CONTENT OF THE SUPPLEMENTARY FILES

The on-line supplementary files for this publication can be found on its individual web page at www.iaea.org/publications. For ease of reference the content is organized in the following folders. Session 1 featured the opening remarks of the conference; therefore, no supplementary files are available. Session 2 included key presentations on the Global Status of Decommissioning, with the associated papers featured in Chapter 3 of this publication.

Conference Programme

Poster Sessions

Session 3

Session 4

Session 5

Session 6

Session 7

Session 8

Session 9

Session 10

Session 11

Session 12

Session 13

Session 14

Special Session

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Global Status of Decommissioning of Nuclear Installations, IAEA Nuclear Energy Series No. NW-T-2.16, IAEA, Vienna (2023)

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations in the Transition from Operation to Decommissioning, IAEA Safety Report Series No. 36, IAEA, Vienna (2004)

[3] WORLD ASSOCIATION OF NUCLEAR OPERATORS, TRANSITION TO DECOMMISSIONING INDUSTRY WORKING GROUP, Transition to Decommissioning Roadmap: Roadmap to guide operators through the transition to decommissioning, WANO, (2022)

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Systematic Approach to Training for Nuclear Facility Personnel: Processes, Methodology and Practices, IAEA Nuclear Energy Series No. NG-T-2.8, IAEA, Vienna (2021).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, A Taxonomy for the Decommissioning of Nuclear Facilities, IAEA-TECddoc-2029, Vienna (2023)

ANNEX I. CONFERENCE STATISTICAL DATA

Organized by	IAEA Department of Nuclear Energy	
Location	IAEA Headquarters, M Building, Vienna Austria,	
Total No. of participants and observers	460 (28% female, 72% male)	
Total No. of Member States	69	
Total No. of Invited Organizations	6	
Total No. of Invited Persons	46	
No. of presentations and others:	Sessions	15 (incl. opening and closing)
	Panel discussions	4
	Side events	4
	Presentations	128 (incl. panel discussions, side events, opening and closing session)
	Posters	45
Scientific Secretaries (IAEA)	O. Mykolaichuk (NEFW) V. Ljubenov (NSRW)	
Scientific administrative support (IAEA)	V. Michal (NEFW) P. O'Sullivan (NEFW) B. Bertaux (NEFW) H. Mrazova (NEFW)	
Administrative support (IAEA)	I. Kridtner (NEFW) J. Catovic (NEFW) N. Cannavan (NEFW)	
Conference Coordination (IAEA)	T. Danaher (MTCD)	
Conference website:	https://www.iaea.org/events/decom2023	

No. of participants by Member State: 449 from 60 Member States

Albania	1	Georgia	2	Romania	7
Argentina	3	Germany	28	Russian Federation	25
Armenia	1	Ghana	9	Saudi Arabia	1
Australia	3	Greece	2	Serbia	3
Austria	1	India	2	Slovakia	19
Bahrain	2	Indonesia	9	Spain	18
Bangladesh	1	Iran, Islamic Republic of	3	Sweden	10
Belgium	21	Iraq	1	Switzerland	3
Benin	3	Israel	1	Syrian Arab Republic	1
Bosnia and Herzegovina	1	Italy	8	Tajikistan	1
Brazil	4	Japan	22	Thailand	6
Bulgaria	5	Kazakhstan	3	Türkiye	3
Canada	12	Kenya	2	Uganda	1
Central African Republic	2	Korea, Republic of	14	Ukraine	4
Chad	2	Libya	1	United Kingdom	32
China	11	Lithuania	11	United Republic of Tanzania	3
Colombia	1	Malawi	1	United States of America	18
Congo	2	Mauritania	1	Yemen	1
Croatia	2	Montenegro	1	Zambia	1
Czech Republic	7	Netherlands	3		
Denmark	1	Nigeria	6		
Egypt	8	Norway	14		
Ethiopia	6	Pakistan	3		
Finland	8	Paraguay	1		
France	29	Poland	1		

ANNEX II. LIST OF PAPERS

Session	Paper	Presenter	Country	Paper Title
2	001	O. Mykolaichuk	IAEA	Overview of Global Challenges and Trends in Decommissioning
2	N/A	O. Novikov	Ukraine	Chornobyl NPP Decommissioning: Prospects and Challenges
10	003	E. Klochkova	Russian Federation	Analytical decision support system for safe decommissioning of radiation hazardous facilities
6	007	Y. Iguchi	Japan	Case study for the optimization of the decommissioning project of nuclear power plants in Japan
3	014	S. Kadhum	Iraq	Lessons learned and challenges in the Decommissioning of former Iraqi nuclear facilities
10	015	T. Rakitskaya	Russian Federation	Knowledge Management on Decommissioning in Russian Federation. From Knowledge Management in Decommissioning projects to Knowledge-based Governance of Decommissioning programs
4	017	R. Alamsyah	Indonesia	The Roles of Leadership in Decommissioning Management of Nuclear Facilities
11	018	M. K. Sotolongo	United States of America	Using augmented reality (AR) and virtual reality (VR) for nuclear decommissioning
9	019	F. Lopez Canton	Argentina	Decommissioning of a uranium dioxide production facility in Argentina
7	020	T. Eichhorn	Germany	Fleet approach for dismantling of large, activated components in commercial nuclear reactors
9	022	G. Jones	United States of America	Identifying and Understanding Technical Challenges to Mitigate the Physical and Project Risk during Decommissioning
12	023	J. Sant	United Kingdom	Implementing transferable technology for remote cell decommissioning
5	026	B. Frasca	France	Optimization of radioactive waste decommissioning management through a French national innovative program

Session	Paper	Presenter	Country	Paper Title
2	027	B. Watson	United States of America	An Overview of the U. S. Nuclear Regulatory Commission Decommissioning Program
9	028	O. Vougny	France	Risk & Opportunity analysis to optimize lifecycle cost of decommissioning
4	029	J. M. Chabeuf	France	Competence development to support decommissioning
9	030	J. M. Chabeuf	France	Common challenges in decommissioning research facilities and reprocessing plants
10	031	Y. Taruta	Japan	Nuclear Knowledge Management in Decommissioning Using Wiki System as Text Database
3	033	S. Carroll	Sweden	Sustainability considerations in nuclear decommissioning – improving practices and reframing the issues
4	034	J. Repussard Y. Guntzburger	France	Nuclear Decommissioning: Project Management and Leadership for Safety Education
7	035	N. Buschman	United States of America	Managing Aging Infrastructure at DOE Facilities Prior to Decommissioning
13	038	D. Gurau	Romania	Radiological Characterization Laboratory – past and future
5	040	L. K. Vajpyee	India	Development of Solid Radioactive Waste Monitoring System for Clearance Level of Gamma Emitters during Decommissioning of Nuclear Reactors
2	041	C. Naze	Belgium	Decommissioning of Belgian Reactor: The journey begins
4	043	D. Daubaraite	Russian Federation	Integrated system of personnel training for decommissioning
13	044	R. Sumarbagiono	Indonesia	Decommissioning Strategy of Evaporator at Radioactive Waste Treatment Installation (RWI) in Indonesia: Preliminary Study
3	047	J. B. Salazar	Argentina	Considerations and Reflections for the Development of New Strategies in the Design of Nuclear Power Plants
Special Session	049	A. Rozko	Ukraine	Attractive solutions for the encapsulation of ashes after thermal treatment of ion-exchange resins

Session	Paper	Presenter	Country	Paper Title
14	051	K. Kristofova	Slovakia	Planning and implementation of large activated components decommissioning
5	052	T. Poehlsen	Germany	Specific Clearance of Materials for Disposal on Landfills
8	055	S. Schneider	Germany	Completion of Decommissioning of German Nuclear Power Plants - Factors influencing duration and finalisation
Special Session	056	A. Puhach	Ukraine	Plasma gasification of solid organic radioactive waste
13	057	L. Bak	Poland	Decommissioning of Polish Research Reactors - Lessons Learned and the Future
3	059	C. Barr	United States of America	US Nuclear Regulatory Commission Decommissioning Guidance and Research Initiatives
6	060	B. Estanqueira Pinho	Brazil	Proposal for an Initial Plan for the Transition Period of Angra-1 Brazilian Nuclear Power Plant
7	061	D. Jekaterinichev	Lithuania	Ignalina Nuclear Power Plant Decommissioning Projects
3	064	S. Luque	Spain	Jose Cabrera NPP Decommissioning: Past, Present and Lessons Learned.
13	065	I. Vujcic	Serbia	Initial decommissioning plan for gamma irradiation facilities: Example of the Radiation Unit at the Vinca Institute, Serbia
Side event	066	M. Kochiyama	Japan	Development of radiological characterization method for research reactor decommissioning in JAEA
7	072	V. Oinonen	Finland	Modelling and optimization of RPV segmentation
3	074	F. Kaloustian	France	French Nuclear Safety Authority (ASN) is developing a new approach to more effectively regulate shut-down nuclear facilities
8	075	D. Tafani	France	Cleaning up and achieving the final state in France
10	077	J. Byrne	United States of America	Three Mile Island Unit 2 Knowledge Management
9	078	Y. L. Maia	Brazil	Nuclear-powered submarines decommissioning in Brazil, Challenges and Perspectives

Session	Paper	Presenter	Country	Paper Title
7	079	N. Bergh M. Sivula	Sweden	Preparations for Successful Dismantling of Ringhals 1&2 RVI and RPV
Side event	081	T. Kukan	Slovakia	Innovative technologies and procedures supporting effective decommissioning of materials utilised by company JAVYS
Special session	083	N. Weyens	Belgium	ANUBIS: Advancing NUclear dismantling in Belgium through Improving Sustainability
7	086	D. Invernizzi	United Kingdom	Planning for regeneration after decommissioning: the case of North Scotland
6	090	A. Ensuque	ENISS	Principles for developing the transition from operations to decommissioning
11	091	L. Thenault	France	EDF's Industrial Demonstrator: A way to mitigate risks and ensure safe decommissioning activities
14	092	M. Zachar S. Mila	Slovakia Spain	Successful Dismantling of the Bohunice V1 Reactor Coolant System
9	093	N. Kinal	Germany	Successful decommissioning of a pipe-conveyor within the remediation of the Crossen uranium milling site (Germany)
14	094	Y. Sato	Japan	Development of portable VR system for radiation work environment using 3-D environmental map visualizing radiation information as input data
5	095	A. Rooses	France	Development of waste treatment technologies
7	097	A. Pekshev	Russian Federation	Novovoronezh NPP Units No.3 and No.4 decommissioning strategy
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