IAEA Nuclear Energy Series

No. NG-T-2.3 (Rev. 1)

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# Training and Human Resource Considerations for Nuclear Facility Decommissioning

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# TRAINING AND HUMAN RESOURCE CONSIDERATIONS FOR NUCLEAR FACILITY DECOMMISSIONING

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA NUCLEAR ENERGY SERIES No. NG-T-2.3 (Rev. 1)

# TRAINING AND HUMAN RESOURCE CONSIDERATIONS FOR NUCLEAR FACILITY DECOMMISSIONING

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# FOREWORD

The IAEA's statutory role is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Among other functions, the IAEA is authorized to "foster the exchange of scientific and technical information on peaceful uses of atomic energy". One way this is achieved is through a range of technical publications including the IAEA Nuclear Energy Series.

The IAEA Nuclear Energy Series comprises publications designed to further the use of nuclear technologies in support of sustainable development, to advance nuclear science and technology, catalyse innovation and build capacity to support the existing and expanded use of nuclear power and nuclear science applications. The publications include information covering all policy, technological and management aspects of the definition and implementation of activities involving the peaceful use of nuclear technology.

The IAEA safety standards establish fundamental principles, requirements and recommendations to ensure nuclear safety and serve as a global reference for protecting people and the environment from harmful effects of ionizing radiation.

When IAEA Nuclear Energy Series publications address safety, it is ensured that the IAEA safety standards are referred to as the current boundary conditions for the application of nuclear technology.

This publication supersedes IAEA Nuclear Energy Series NG-T-2.3, Decommissioning of Nuclear Facilities: Training and Human Resource Considerations, which was published in 2008. The publication has been updated to provide information and examples of good practices in the training of personnel for the decommissioning phase of nuclear facilities, including guidance on the application of the systematic approach to training (SAT) methodology for decommissioning training. The supplementary files available on-line present additional examples.

Recent decades have witnessed significant increases in the number of decommissioning projects being undertaken globally, and the SAT methodology is now being applied to all types of nuclear facility for various phases of a nuclear facility's life cycle, including the operational and decommissioning phases. The technologies being used in decommissioning have also advanced during this period, driven in particular by innovations in the use of digitalization and robotics.

Appreciation is expressed to all Member States for their valuable contributions and to the experts involved in the drafting of this report. In particular, the IAEA is grateful for the contributions of F. Borrmann (Germany); S. Carroll (Sweden); J.-M. Chabeuf; M. Pieraccini (France); N. Messenger; D. Palmer (United Kingdom); R. Reid (United States of America); A. Rob (Canada); D. Serbanescu (Romania) and V. Szabó (Slovakia).

The IAEA officers responsible for this publication were P.J. O'Sullivan and C. Glorennec of the Division of Nuclear Fuel Cycle and Waste Technology and M. Ovanes of the Division of Planning, Information and Knowledge Management of the Department of Nuclear Energy.

# CONTENTS

# 1. INTRODUCTION

## 1.1. BACKGROUND

With the increasing number of nuclear power plants and other types of nuclear facilities entering into permanent shutdown, there is a need to review lessons learned and best practices relating to the decommissioning of such facilities. It is important that organizations which will be responsible for future decommissioning projects have a good understanding of what is needed for the development and implementation of human resource management practices, policies and training programmes, both for the facility and contractor personnel involved in the various phases of decommissioning activities. Ensuring the competence of personnel involved in decommissioning activities is a key prerequisite for successful decommissioning.

A sufficient number of competent and motivated personnel have to be available during all phases of the life cycle of a nuclear facility [1, 2]. IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [1], includes specific requirements for personnel involved in a decommissioning project. In particular, item 3.4 of these requirements requires that the responsibilities of the operating organization include:

> "Ensuring that properly trained, qualified and competent staff are available for the decommissioning project."

Item 4.4 requires that:

> "Provisions shall be made to ensure that institutional knowledge about the facility is obtained and made accessible and, as far as possible, that key staff from the facility are retained."

In light of the above, licensees are required to demonstrate that sufficient numbers of competent personnel are available until the facility is finally removed from regulatory control. However, there is an increasing nuclear decommissioning workload associated with an ageing fleet and there are concerns about the availability of the human resources needed to undertake decommissioning programmes.

This publication provides guidance on human resource and training considerations for the decommissioning of nuclear facilities. Competence building and knowledge management initiatives need to take into account the processes and technologies that are currently being used, as well as developments around the world and in other industries that may be applied to nuclear decommissioning.

## 1.2. OBJECTIVE

The objective of this publication is to disseminate good practices and make recommendations with regard to training and human resource management considerations for the personnel carrying decommissioning activities. The intent is to assist nuclear facility operating organizations in Member States in:

— Supporting the planning of resources and in acquiring the knowledge required to complete the various phases of a decommissioning project.
— Identifying the strategies and tools that support the retention and transfer of requisite knowledge to the various staff classifications to support a decommissioning project.
— Supporting Member States with practical examples of knowledge transfer techniques and considerations to facilitate the development of staff engaged in decommissioning activities.

## 1.3. SCOPE

This publication offers guidance to help organizations ensure the availability and competence of personnel involved in the decommissioning of nuclear facilities. It focuses on human resource and training considerations for those personnel involved in nuclear decommissioning programmes. It provides an overview of training requirements, knowledge transfer objectives and practices for all categories of personnel involved in decommissioning with a primary focus on the needs of training the workers who will be performing the work.

The information provided and the examples given are representative of the experience of decommissioning nuclear power plants and major nuclear fuel cycle facilities. However, the use of the systematic methodology and techniques described in this publication may be tailored to the development of training for all types of nuclear facilities undergoing decommissioning.

This publication is intended to be used by:

- Managers at organizations operating nuclear facilities;
- Managers of decommissioning projects;
- Contractor organizations wishing to develop specialized skills for their workforce;
- Personnel involved in human resource management in the nuclear facilities;
- Nuclear facility training staff;
- Regulatory body personnel;
- Staff of the training organizations;
- Developers of training programmes, training material and training tools in support of decommissioning projects;
- Managers and personnel involved in the improvement of human performance in decommissioning projects;
- Personnel involved in the establishment of management systems for the nuclear facilities preparing for or undertaking the decommissioning.

Reference is made to a number of other IAEA publications or activities in the following areas:

- Nuclear facility decommissioning;
- Training and qualification;
- Human resource management;
- Human performance improvement;
- Knowledge management;
- Information on status and trends in decommissioning, and associated facility databases;
- E-learning modules for decommissioning.

These will be individually referenced throughout this publication.

## 1.4. STRUCTURE

This publication includes 8 sections and 11 appendices. Section 2 discusses the different organizational approaches towards decommissioning and describes how the human resource requirements evolve during the various decommissioning phases from planning and preparation to conventional demolition and site release, including key functional areas, roles and responsibilities. Section 3 describes the transition from facility operations to decommissioning in terms of both the organizational transformation required and the activities to be undertaken during this period. Section 4 describes the broad range of human resource considerations in preparation for decommissioning, from workforce planning through to performance management. Section 5 discusses knowledge management in the context of the transition from operation to decommissioning, and how knowledge management requirements are adapted accordingly. It also outlines the importance of understanding knowledge loss risk management and knowledge and information management systems. Section 6 addresses the applicability of the SAT methodology for the development and implementation of training in the context of decommissioning. Section 7 outlines the different approaches to training and the facilities/equipment that can be utilized to improve the efficiency and effectiveness of decommissioning training and instructor training roles and responsibilities. Section 8 summarizes the conclusions of this publication. The appendices contain detailed information on aspects of the human resources considerations, knowledge management, and training issues discussed in this publication.

# 2. THE TRANSITION FROM FACILITY OPERATION TO DECOMMISSIONING

## 2.1. MOVING FROM FACILITY OPERATION TO DECOMMISSIONING

Following the permanent shutdown, a nuclear facility will normally be decommissioned, i.e. dismantled and the radiological contamination removed to such an extent that the facility may be released from regulatory control [1] (see Fig. 1). In a limited number of cases, sites may remain under regulatory control and be reused for other purposes involving radioactivity. During the period immediately following shutdown, while spent fuel remains in the facility, the ongoing regulatory controls are essentially analogous to those applied during operation. In due course active dismantling work is undertaken under an appropriate regulatory regime. Depending on the national legal regime, some form of regulatory authorization, or licence amendment, is typically needed before this phase of work can proceed.

As illustrated in Fig. 1, decommissioning a nuclear facility involves significant changes compared with operations in terms of organization, processes and objectives. After decades of routine operations with a stable organization, the facility transitions to a period of continuous change in terms of activities and tasks, which also involves a significant modification of the organizational structure. The organizational arrangements for decommissioning may begin during the period approaching the definitive shutdown of the facility. The immediate post-operational phase is typically concerned with activities to reduce the nuclear and radiation hazard, e.g. through removal of spent fuel, and in transformation of systems in preparation for immediate dismantling or safe enclosure. This transition is accompanied by an organizational transformation, as discussed below. Taking into account the roles and competences for decommissioning, this creates a requirement to define and deploy a new approach to managing human resources and training.

The differences between operation and decommissioning of nuclear facilities are highlighted in Table 1. Changes in knowledge management practices are also necessary with the change from facility operation to decommissioning. The nature of decommissioning, the increased logistical challenges and the numbers of structures, systems and components (SSCs) to be handled require the development of a knowledge management programme specifically focused on decommissioning.

The end of operation marks a distinct change in the status of a facility, and proper planning and preparation are central to the success of the subsequent decommissioning project. The transition from operation to decommissioning requires a transformation in the organization in order to be able to conduct decommissioning activities.

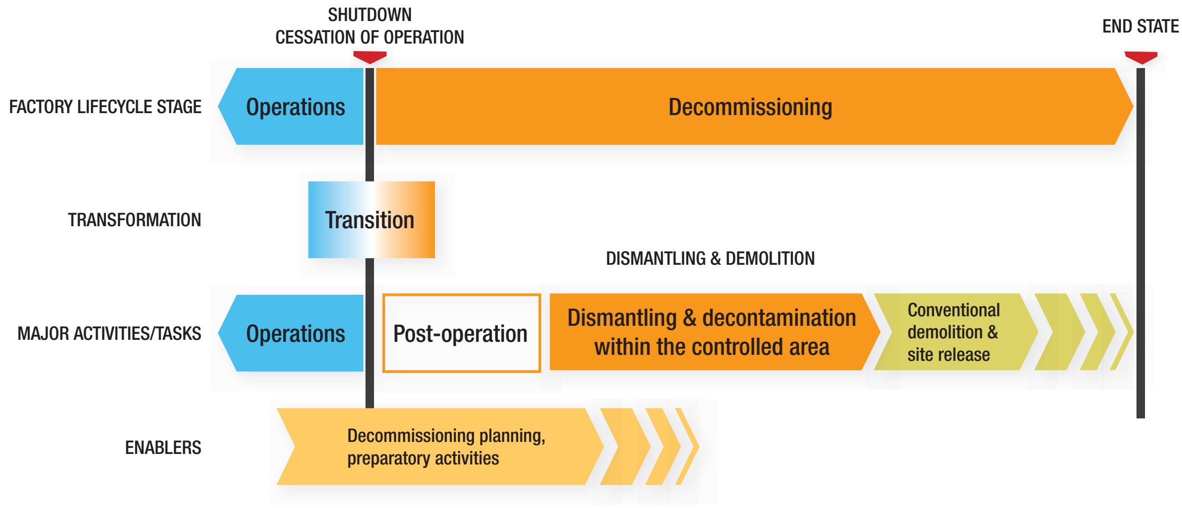


*FIG. 1. The change from facility operation to decommissioning.*

TABLE 1. DIFFERENCES BETWEEN FACILITY OPERATION AND DECOMMISSIONING

| Operation | Decommissioning |
|---|---|
| Cyclical programme, process driven with focus on production. | One way programme, project driven with focus on completion. |
| Income generating. | Cost generating. |
| Periodic modification, routine operations. | Constant modifications, varying tasks and activities. |
| Waste is a by-product, generated in quantities and involving logistics and movements that are well defined in advance. | Waste is the main product involving varied types and in considerable quantities, and requiring significant logistical considerations and movements. |
| Long term employment, stable workforce with routine objectives. | Visible end of employment, changing workforce, temporary tasks/activities. |
| Stable risk profile, emphasis on nuclear and radiological risks, nuclear trained personnel. | Changing risk profile, decreasing nuclear and radiological risks, industrial risk central, mixture of personnel with a range of backgrounds. |
| Routine communications with external parties. | New communication requirements. |

## 2.2. ORGANIZATIONAL APPROACHES TO DECOMMISSIONING

There is a range of approaches available to organizations to undertake decommissioning. These range from approaches relying primarily on: the use of operational personnel for decommissioning; external decommissioning expertise; or contractors. Approaches combining expertise from both organizational types are possible and would entail a division of responsibilities between an operator and the external decommissioning organization.

This is illustrated in Fig. 2, which represents the situation at the end of operation when a typical operating organization would have extensive facility knowledge and limited decommissioning expertise. Conversely, an external decommissioning organization would have considerable decommissioning expertise but limited knowledge of the specific facility. The main features of the different organizational approaches (A–D) are described in Table 2.

The choice of organizational approach has implications for managing human resources and training for decommissioning. For example, if decommissioning is to be undertaken by the operator with existing personnel, significant reorganization and retraining of the operating staff would be required. If decommissioning is to be undertaken by a specialist organization, the specialist decommissioning expertise would need to be complemented by specific facility knowledge. It is to be noted that, regardless of the approach followed, the historical knowledge of the plant retained by the operating staff needs to be made available for the decommissioning phase (see Section 5).


*FIG. 2. Distribution of expertise for different organizational approaches to implementation of decommissioning.*

TABLE 2. FEATURES OF THE DIFFERENT ORGANIZATIONAL APPROACHES TO DECOMMISSIONING

| Organizational approach | |
|---|---|
| Approach | Description |
| A — Operator undertakes decommissioning. | Approach may be suitable for one-off cases or in the context of nuclear phase-out scenarios. |
| B — Operator retains project control and delegates specific activities to decommissioning contractor(s). | Approach may be suitable where an owner/operator wishes to retain control or transfer of the licence is not wanted/allowed. |
| C — Operator and decommissioning contractor work in partnership. | Approach may be suitable where operator is not able to transfer the licence but does not wish to engage in nuclear decommissioning. |
| D — Operator transfers decommissioning responsibility to a specialist organization. | Approach may be suitable where the original owner/operator is able to transfer the licence and liabilities to a separate entity. |

## 2.3. ORGANIZATIONAL TRANSFORMATION

As the permanent shutdown date of a nuclear facility approaches, detailed preparations need to begin for the organizational transformation to facilitate the start of decommissioning [3, 4]. In particular:

— A transformation process to create an organization suitable for undertaking decommissioning;
— Actions related to specific phases of decommissioning, including post-operation activities and preparations for the start of decommissioning activities.

The approach to be followed to undertake decommissioning will typically be described in the decommissioning plan, which is maintained and updated throughout the lifetime of the facility. Regardless of the choice made, this will involve a process of transformation to establish the new organization required for decommissioning. At the heart of any such transformation will be change management.

Change management is the term given to the techniques and tools required to manage the human element of change to achieve the required business outcome. Change is an ongoing process in all organizations, but it is particularly important that nuclear facilities have a 'tried and trusted' methodology to ensure that change is implemented effectively, while remaining focused on safe reliable operation, and that nuclear safety risks are managed and controlled during the process. In some countries the regulator will insist organizations have adequate arrangements to manage any change to its organizational structure or resources which may affect nuclear safety.

The change process typically begins with identification of alternative organizational scenarios (also referred to as 'optioneering'), and consideration of the various strengths and weaknesses of each scenario. These strengths and weaknesses may be assessed against a number of pre-determined criteria to support the decision making in determining a preferred way forward.

For decommissioning, there are a number of external and internal factors that will determine the outcome of the new organization and workforce. These include, but are not limited to:

— Type of nuclear facility;
— The basic approach to be taken to decommissioning and whether this relies primarily on operational personnel or external decommissioning expertise, or a combination thereof;
— Government, political and socioeconomic factors;
— Regulatory factors;
— Commercial factors, including supply chain considerations;
— Financing and funding issues.

The organizational structure selected will be implemented through a change management plan. This plan will need to take into account a number of core considerations, in particular:

— Details of the change proposal (start point, end point, etc.);
— Stakeholder plan (including any consultations with trades unions, employee forums);
— Communication plan;
— Implementation plan (including counselling, retention of critical knowledge, redundancy and redeployment);
— Risks and countermeasures.

Once the change process starts, the transition from operation to decommissioning may have a substantial impact on the personnel present at the facility. The purpose and mission of the organization will change, as will the composition of the workforce. This will be the case regardless of whether the establishment of the new decommissioning organization is to be achieved by the modification of the previous operating organization, or by the introduction of external resources.

Staffing changes and role transformation are complex and case specific activities, which means that there is no one size fits all solution. In the case of nuclear power plants, even if the decommissioning staffing requirements are likely to be of the same order of magnitude for all similar types of plants, the workforce transition phase is likely to differ from plant to plant, even within a multifacility fleet within one organization.

Appendix I describes the transition from operation to decommissioning for the Ringhals 1 and 2 nuclear power plants in Sweden. Appendix II details the human resource challenges at the Ignalina nuclear plant in Lithuania. Appendix III provides a case study of the change management strategy and workforce transition at the former Rocky Flats nuclear weapons plant in Colorado, USA, which was remediated under the stewardship of the US Department of Energy. Appendix IV outlines the planning for decommissioning of the nuclear power plant in Armenia.

Figure 3 illustrates a basic change model for nuclear organizations, highlighting key questions and issues that need to be addressed.

## 2.4. ACTIVITIES FOLLOWING PERMANENT SHUTDOWN OF A NUCLEAR FACILITY

A range of activities need to be undertaken to support the transformation of the facility and to prepare for its decommissioning.

### 2.4.1. Post-operation activities

The main post-operation activities typically include the removal of all spent fuel from the reactor and spent fuel ponds, and post-operational cleanout of fuel cycle facilities. Other activities completed during the post-operation phase include the following:

— Drainage and drying of systems;
— Decontamination of closed systems if planned in the decommissioning scenario (for dose reduction, decommissioning optimization, waste management, etc.);
— Radiological inventory characterization to support detailed planning;
— Removal of system fluids, operational waste and redundant material;
— Reduction of all fire hazard materials;
— New construction (e.g. interim storage, waste treatment facilities, new ventilation, etc.);
— Anticipated dismantling work (if planned in the decommissioning scenario and authorized by the applicable licence).

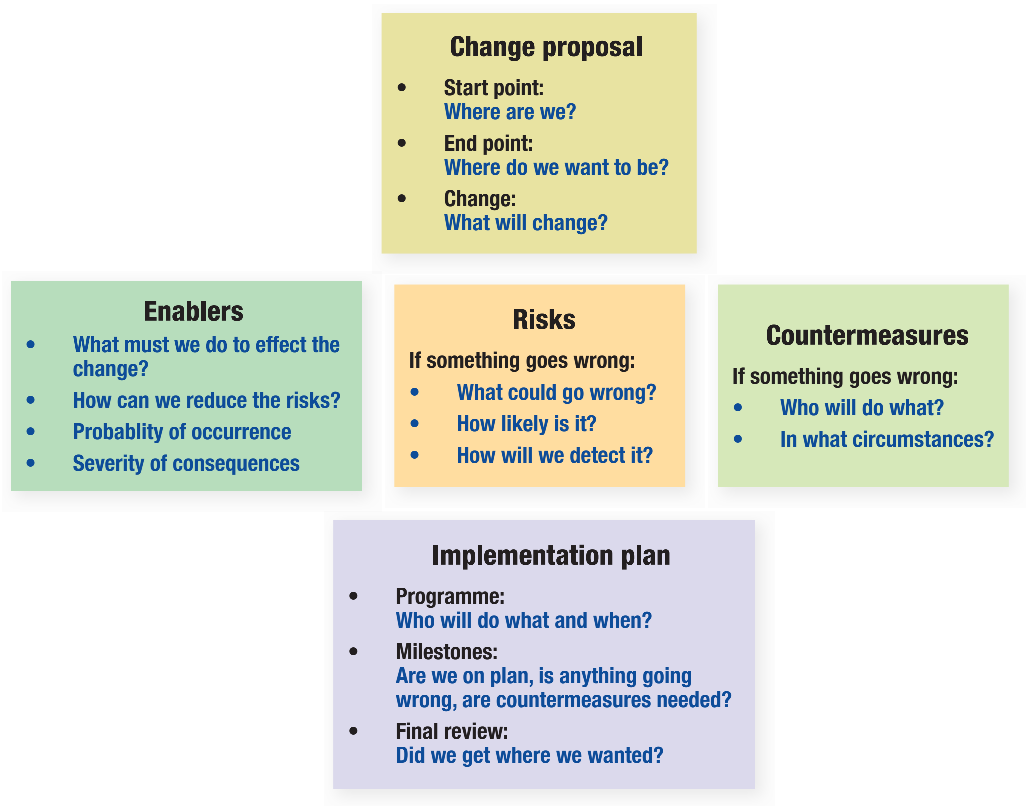


*FIG. 3. A basic change model for nuclear organizations.*

As the tasks carried out in this phase are similar to those during operation and during outages, the expertise required is similar to the operational stage of the facility's life cycle. Regardless of the planned organizational approach for decommissioning, post-operation activities have tended to be undertaken by the facility operation organization.

### 2.4.2. Preparing for the start of decommissioning activities

In addition to the process of transforming the organization into one suitable for decommissioning and completion of the post-operation activities, additional preparations are necessary following shutdown to facilitate the start of decommissioning work in order to:

- Minimize delays and undue costs;
- Optimize personnel and other resources;
- Initiate preparatory activities for decommissioning in a planned, timely and cost effective manner;
- Anticipate and optimize the decommissioning waste routes.

It will also be necessary to:

- Review/adapt strategic aspects;
- Optimize preparations for decommissioning;
- Optimize their implementation on-site while minimizing costs and delays;
- Manage any unexpected events and the consequential financial risk;
- Identify compulsory means and associated resources and personnel to be retained and the personnel to be redeployed or made redundant;
- Provide adequate training for operational staff who will be retained in the decommissioning phases;
- Maintain and develop communication with local stakeholders on the future planned activities.

# 3. HUMAN RESOURCES IN THE CONTEXT OF DECOMMISSIONING

## 3.1. HUMAN RESOURCE NEEDS FOR SPECIFIC PHASES OF DECOMMISSIONING

It is necessary to consider when particular human resource needs may arise, taking into account the timing of particular activities within the overall decommissioning programme. Certain tasks are associated with the planning and preparation for decommissioning. The decommissioning activities and tasks are grouped into several phases:

- Post-operation;
- Dismantling and decontamination within the controlled area, including any demolition of activated or contaminated structures;
- Conventional demolition, site remediation, where required, and site release.

In some cases, there is a deferral period which involves a delay before the start of the main dismantling and decontamination activities. In this situation, operational waste is typically removed and plant safety systems reconfigured to ensure ongoing safety of the facility during the deferral period. The phases are illustrated in Fig. 4.

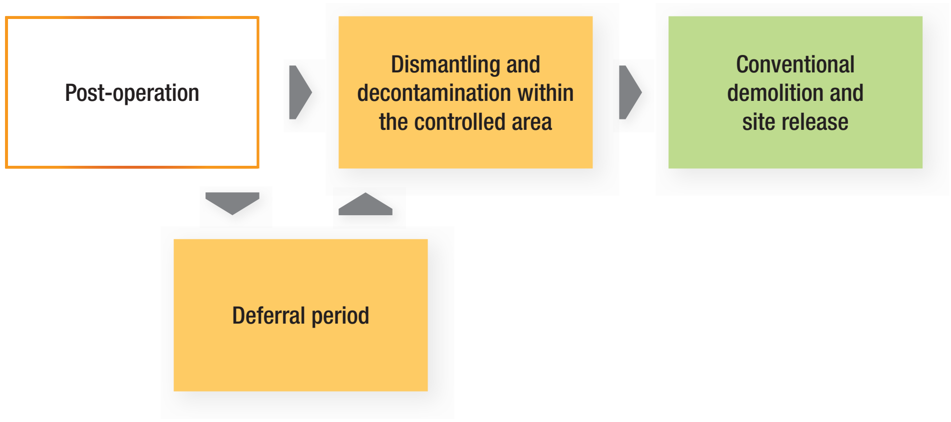


*FIG. 4. The main phases of a decommissioning programme.*

### 3.1.1. Planning and preparation

Organizations need to initiate planning well in advance of the end of operation to be prepared for the transition, to plan the work, and to be ready to initiate decommissioning in a structured, timely and cost effective manner.

Experience has shown that it is essential to begin planning and preparations for decommissioning at an early stage. Ideally, decommissioning considerations are incorporated during the design stage of the facility and planning for decommissioning are developed further during the operational phase. The growing number of nuclear facilities reaching the decommissioning stage emphasizes the need for intensified planning and preparation starting in the final years of planned operation. Typically, detailed planning for decommissioning a facility would be expected to begin three to five years before the planned closure. In addition, in practice, there is a need for ongoing preparatory activities associated with specific activities and tasks as the decommissioning programme progresses. Such activities are generally undertaken by personnel from the facility operator.

The principal activities typically performed during planning and preparation include the following:

— Decommissioning planning (including consideration of decommissioning scenarios);
— Initial characterization of the facility;
— Safety, security and environmental studies;
— Waste management planning (treatment, waste routes identification);
— Preparing applications for authorization(s) from the regulator(s);
— Preparing management group and contracting strategies and associated preparations.

This requires the involvement of project managers, project engineering staff, radiation and safety specialists, procurement personnel, licensing specialists, dismantling specialists and waste management specialists. Depending on the type, state and history of the facility additional expertise might be necessary.

### 3.1.2. Post-operation

Typical post-operation activities include the removal of all spent fuel from the reactor and spent fuel ponds, removal of waste remaining from the operational phase, and post-operational clean-out in the reactor and fuel cycle facilities. With the removal of the spent fuel, the nuclear hazard has been removed and the radiological hazard associated with the facility has been significantly reduced. Most legal regimes then allow amendment of licence conditions for the facility and permit organizational changes and potential corresponding staffing reductions.

Other activities completed during the post-operation phase include the drainage and drying of systems; decontamination of certain systems; characterization of the radiological inventory to support detailed planning; and other activities intended to facilitate the planned decommissioning activities.

As the tasks carried out in this phase are similar to those during operation and during outages, the expertise required is similar to the operational stage of the facility's life cycle. Accordingly, this work can be organized through staff in the departments involved with operation. There are some important differences between roles according to the skills required (some will be maintained at the same level, while others will decrease and new skills will need to be introduced). Typically, the number of staff for a single unit facility can be reduced from 100% of the operation level at the beginning of post-operation to around 50% at the end.

### 3.1.3. Deferral period (if applied)

If a deferral period is to be applied [4], the plant has to be put into a stable condition in preparation for an extended period of surveillance and maintenance. The deferral period for a nuclear power reactor typically lasts for 30–50 years or more.

The main activities typically performed include the following:

— Maintaining all plant systems required to support the stabilization configuration of the systems;
— Decontamination of the external surfaces of SSCs;
— Ensuring that all radioactive material remaining on-site is properly stored and any material to be permanently disposed of is removed;
— Reconfiguration of the site security boundary and landscaping to address the reduced plant configuration, where possible;
— Any required modifications to establish the physical security of site structures.

Deferral can be considered in two subphases: the first to achieve a status of safe storage and the second to maintain the plant in this condition until commencement of the final dismantling phase. During the first subphase, the staff numbers required may vary considerably, but will be reduced dramatically during the second subphase when the facility is in surveillance mode.

The expertise required in this phase are in the areas of management and administrative support, engineering, maintenance and work control, operations, oversight and nuclear safety, radiation protection, chemistry, regulatory/licensing, health and safety, security and craft labour. In the safe storage state, personnel will mainly be from the maintenance, security, craft labour, environment, health and safety and oversight areas.

### 3.1.4. Facility dismantling

During this phase, material and structures are removed from the plant so that the radioactivity is reduced to the levels required by applicable regulations to support termination of the radioactive material licence or to reach an agreed end state.

The duration of this phase varies considerably between facilities, organizations and countries. For a nuclear power reactor, the period ranges typically from 5 to 20 years. Key drivers for the duration include the plant type, the extent of radiological and hazardous material contamination on SSCs and environmental media, the desired end state to be achieved and the reuse, decontamination or disposal of buildings. It may be influenced by organization or country specific decisions to extend dismantling and demolition due to factors such as funding constraints, the availability of waste management and disposal infrastructure, or wider socioeconomic considerations, such as continued employment of personnel and impacts on local communities.

The main activities typically include the following:

— Final planning for dismantling activities and procurement of any required specialized equipment;
— Modification of SSCs as dismantling progresses (e.g. building cranes, ventilation systems, radioactive waste processing systems);
— Completion of contracting for specialty services (e.g. reactor vessel and internals segmentation, component segmentation);
— Removal of radiologically contaminated components and piping from the reactor systems;
— Decontamination of site structures for final removal or redeployment;
— Removal of hazardous material from plant SSCs;
— Characterization, packaging, conditioning and storage or disposal of all radioactive and hazardous waste;
— Removal of conventional waste and material from site;
— Clearance of material and declassification of buildings from the ‘controlled area’ to facilitate its conventional demolition;
— Finalization of the approach to licence termination with the regulator and stakeholders and preparation of associated documentation.

Due to the range of activities planned during this period there is a wide variation in the skills required and also an increased likelihood of shift working. The areas of expertise involved here comprise: management and administrative support, engineering, maintenance and work control, operations, oversight and nuclear safety, radiation protection, chemistry, regulatory/licensing, health and safety, and security. Engineering and related decommissioning operations (which increasingly involve the use of digitalization and robotics) will in most cases be carried out by contractors due to the extended period during which some of these operations will be performed in the case that the deferred decommissioning approach be chosen.

Most of the skills groups listed above are commonly available in Member States, and the core tasks are well understood. However, some overlap between the groups is necessary. The most common requirement in this respect is for a worker to undertake some waste handling or processing operations as part of dismantling or decontamination, i.e., for a worker to undertake both technical and operational activities. This hybrid role may be considered to be that of a decommissioning operator or decommissioning technician. The use of contractors to support this work can have implications on knowledge transfer and planning (see Section 5).

#### 3.1.5. Conventional demolition and site release

During this phase, the demolition of the decontaminated buildings, any necessary site cleanup and any final site restoration work to achieve the agreed site end state are undertaken. At the end of this phase, the site licence is terminated and all regulatory filings to support site release are made. This phase can take between one and ten years, depending on the regulatory requirements, the nature of the facility, and the extent of contamination.

The main activities typically include the following:

— Procurement of contracts for conventional dismantling and demolition;
— Conventional dismantling of systems and buildings outside the controlled area;
— Demolition of buildings from the formerly controlled area;
— Remediation according to the agreed end state of any residual contaminated environmental media (soil, ground and surface waters, sediment in discharge canals, or waste storage ponds);
— Final cleanup and landscaping of the site;
— Final survey of the site;
— Ongoing surveillance in the case of limited or restricted release of a site.

For demolition work after clearance of the structure, the required workforce mainly comprises safety, engineering personnel, the contractor's team and project management staff. For site clearance and restoration, technical staff carry out the necessary measurements, as well as the removal of material and landscaping.

Depending on the final licence termination conditions, the release of all security and emergency services staff is usually achieved with the completion of this phase and the owner's workforce often reverts to zero.

## 3.2. KEY FUNCTIONAL AREAS FOR DECOMMISSIONING

The nature of decommissioning activities will change throughout the duration of the decommissioning project. It is therefore important to ensure that there is a systematic approach that provides for the required skills and training to be available when needed to undertake decommissioning activities. Planning is needed to prepare staff with sufficient lead time to support the completion of training to the required standards and quality.

### 3.2.1. Programme management

Programme management is the management of a group of related projects in a coordinated way to obtain benefits and control not available from managing them individually. Programmes may include elements of related work outside the scope of the discrete projects in the programme.

In a nuclear decommissioning context, programme management can be an important contributor for effective delivery. Decommissioning a nuclear facility will typically involve a multitude of projects undertaken over an extended period of time. The programme approach can provide a coordinated platform for the deployment and management of the work. In addition, for those organizations having responsibility for the decommissioning of multiple facilities, a programmatic approach can facilitate the sharing of lessons learned from them and the incremental improvement of decommissioning over time.

In preparation for the decommissioning programme, it is important to include human resource requirements in the same way as financial and other requirements within the programme management system.

In planning the human resource and training requirements for the overall programme, it is important to consider the detailed social and economic context as well as the activities and time scales. The socioeconomic impact of decommissioning extends far beyond the site level[1] and can even impact a nation's economy and society [5–9]. Therefore, it may be necessary to enhance and strengthen communication channels with local authorities and communities, as well as other entities. Management of stakeholders can represent a significant part of the decommissioning programme effort and skills for this interface need to be recognized in the knowledge management plan.

### 3.2.2. Project management

Project management is the discipline of initiating, planning, executing, controlling, and concluding the work of a team to achieve specific goals and meet specific success criteria. It is the application of knowledge, skills, tools and techniques to activities to meet project requirements.

The decommissioning process may be likened to one of 'deconstruction', where construction management skills are utilized. It is not different from construction in that a series of individual tasks are required to be managed simultaneously such that the project can achieve its objectives in terms of cost,

[1] The socioeconomic impact of decommissioning with no further potential reuse of the site has led to various social policies and strategies for a number of sites, for example, Zion and San Onofre (United States of America); Dounreay (United Kingdom); Creys-Malville and Siloé (France); Greifswald (Germany); and Fukushima (Japan).

programme, safety and quality. The need for effective planning and preparation is, however, emphasized due to the unique challenges of the hazardous and radiological (and often unpredictable) environments in which the work is done. Whereas it may be relatively straightforward for a worker to cut into a masonry wall during construction, to repeat this task during decommissioning, where radiological and operating constraints exist, offers a completely different challenge.

Decommissioning programmes often use many subcontractors for specific dismantling tasks. Hence, there is a need to provide project management training, which includes detailed planning, risk assessment, contract and resource management. This is required to ensure that managers and supervisors have the knowledge and skills necessary to manage projects safely and effectively. The training may include knowledge about tasks to be contracted in order for project managers to act as informed customers. In addition, it is also necessary to ensure that subcontractors have, or are provided with, the necessary task specific training to safely and effectively complete work packages, and to coordinate safety provisions for contractors and operators.

### 3.2.3. Management of materials including radioactive waste

Management of material from decommissioning covers the entire chain of responsibility for handling, treatment and conditioning, storage and transport of the material arising during decommissioning [10]. In addition to radioactive material and waste, there is a variety of non-radioactive material, hazardous and inert.

Increasing effort is being devoted to ensuring that the 'waste hierarchy'[2] is applied in the context of decommissioning, and consequently greater attention is being given to ensuring that material is reused and recycled instead of being disposed of as waste [7]. In this context, material from decommissioning will ideally be sorted and segregated in order to maximize the quantity of material to be recycled in a cost effective and sustainable manner. At the same time, the quantity of radioactive waste to be sent for disposal is minimized to the level which is necessary for the safe management of this material and for protection of people and the environment. Specific attention has to be paid to proper conditioning to minimize the final number of packages, on sorting material by type, nature and radioactivity, and enhancing waste zoning or taking advantage of clearance arrangements, including recycling and reuse.

During the decommissioning process, hazardous non-radioactive material is generated and will need to be handled. In particular, conventional hazardous material such as asbestos and other mineral fibres, flame retardants, acids and lead, will be present. In some cases, these will be in combination with material or waste that presents a radiological hazard and will therefore need to be managed appropriately as radioactive.

In decommissioning, it is important that personnel are trained to work with a wide range of such hazardous material; often material hazardous in its own right is also radioactively contaminated. Additional training of personnel and the development of meticulous procedures is required to cope with these unfamiliar hazards or combinations of hazards.

It is important that personnel understand the requirements for radioactive waste management, and can apply radioactive waste management requirements, techniques and good practices to waste categorization, segregation, treatment (including ways of reuse and recycling), storage, disposition, and minimization of waste. For example, training is necessary in areas such as the safe operation of waste treatment systems and their associated quality assurance requirements. This training will ideally include the acceptance criteria for such waste in the particular disposal/storage facility concerned. Minimizing radioactive waste always has to be judged against the radiation doses received when carrying out the tasks (for example, size reduction or decontamination). This will mean an increase in the staff and programmes for radiation protection to ensure that the sorting, segregation, testing and protection of personnel involved in the work is managed appropriately.

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[2] The 'waste hierarchy' ranks waste management options according to what is best for the environment. It gives top priority to preventing waste in the first place. When this cannot be avoided, priority is given to preparing it for reuse, then recycling, then recovery, and last of all disposal (e.g. in landfills or repositories).

### 3.2.4. Management of safety

Due to the hazardous nature of the work, an emphasis on management of safety for all parties involved in the decommissioning programme is required, including the establishment of a working culture which regards safety as paramount [11]. Whereas the project management team can consider the task requirements and environment, and specify the working procedures, it is essential that the personnel supervising and completing the tasks are fully competent to complete the work in a safe manner. A sufficient number of personnel need to be qualified in plant operations (mechanical, electrical and instrumentation and control), firefighting and general industrial safety. They also need to be able to take mitigating actions for other hazards, e.g. explosion, flooding, etc.

The control of radiation exposure during decommissioning operations is as important as it is during maintenance operations. It relies on health physics personnel who are fully conversant with the likely exposures to be encountered and the exact nature of the work planned, and who are trained to specify the required protection measures. As stated the radiation protection measures may vary significantly from those during operations. This will also require the reorientation and retraining of radiation protection personnel already employed. In addition to the requirement to work routinely in areas with both high levels of contamination and radiation, there is a need to focus on standard industrial safety training associated largely with the construction industry. The requirement is essentially to train personnel such that they are able to apply specialized radiological safety skills alongside standard industrial safety practices.

The change in emphasis is also applicable to the personnel who manage facility and personnel safety issues. In decommissioning, managers require training to oversee the production of safety cases/analyses that may require many different tasks being completed simultaneously by different work groups. In a number of countries, such parallel work requires additional work–safety coordination. This is similar to the organization of maintenance operations being executed while operation and production is ongoing.

As systems are opened, there is also a requirement to introduce temporary auxiliary systems (e.g. confinement of contamination, or auxiliary ventilation and air filtration), and to train workers in the use of personnel protective equipment, to ensure their safety.

In the case of contractors, there is also a need to ensure that all workers involved in decommissioning activities have attained and maintain the relevant levels of competence and knowledge required. This is needed not only with regard to their decommissioning task, but also because of facility specifics (see Section 6).

Resources have to be allocated to develop and maintain an appropriate emergency response system for a plant under decommissioning. Immediately following shutdown, while nuclear fuel and special nuclear material remain on-site, emergency plans for the facility will likely remain substantially the same as during operation. These plans are likely to be adjusted as the fuel is removed and decommissioning progresses, where legislative and regulatory frameworks permit and as hazards decrease to levels found at typical industrial sites [12–15][3].

### 3.2.5. Environmental management

As facilities are progressively dismantled, changes occur in the way that material is handled and transferred off-site. The environmental challenges associated with decommissioning may not be the same as during routine operation. This may require modification of the environmental stressors and pathways, which need to be monitored and controlled. Personnel require training to ensure that the environmental impacts of decommissioning are carefully managed and minimized, and that there continues to be full compliance with all environmental licence conditions.

[3] The general aspects of emergency preparedness for which resources have to be considered include those in the emergency plans described in Refs [1, 12, 13].

### 3.2.6. Planning

An engineering plan is derived from the decommissioning strategy that has been developed. Decommissioning needs to be planned well in advance, ideally at the design phase [1, 16, 17]. The planning will be generic during the design phase and become more detailed with the approach of permanent shutdown. At the early stage, the operating organization is unlikely to have personnel specialized in decommissioning. More detailed planning at the later stages may require external expertise.

## 3.3. ROLES AND RESPONSIBILITIES FOR DECOMMISSIONING

In order to complete the safe and efficient decommissioning of a facility, a wide range of disciplines and skill levels are required. In determining the necessary training needs, it is important to look at the typical functions which are required, along with the associated categories of workers. A number of key roles and responsibilities which are specific to decommissioning are described in the sections below.

### 3.3.1. Programme director

The programme director is responsible for managing a project at the strategic level. This person typically manages resources and oversees finances to ensure that the programme progresses on time and within the budget. The director reviews regular progress reports and makes staffing, financial, or other adjustments to align the developing programme with broader outcome goals [18]. Typically, the programme director oversees a team of project managers and project teams. In the case of a decommissioning programme, this can also be understood as multi-project — or portfolio — management and may involve decommissioning at several sites or facilities.

### 3.3.2. Project managers

Project managers are responsible for the planning, procurement and execution of a project in any undertaking that has a defined scope, defined start and finish. In organizational arrangements based on a matrix structure, project managers may not have direct hierarchical authority over personnel involved in project implementation. In such cases it is important that they have formal legitimacy to direct project activities, with decision making autonomy. The project manager also needs to understand the technical principles of the technologies being used to implement the decommissioning project to be in a position to oversee activities. They need not be experts in all of the technical issues they will encounter, but their legitimacy will be enhanced by their ability to make decisions concerning technical issues and questions.

### 3.3.3. Engineers

Engineers are responsible for the detailed planning and oversight of the decommissioning tasks, including preparing work procedures and checking compliance with them. This category includes operators responsible for the safe and efficient operation and control of plant and equipment. They report and investigate deviations from routine operating conditions and to deal with basic process deviations.

The type of facility operations required to be completed is dependent on the phase of decommissioning under way. There may be an advantage in using the operators engaged during the production phase of the facility for certain activities as they are fully familiar with the facility and the operational procedures. This is particularly relevant for the defueling phase of a reactor facility and the initial post-operation cleanout work associated with waste processing/reprocessing facilities. The operators performing this work will generally be qualified to complete the work by virtue of their previous operational experience and knowledge gained in a nuclear facility environment. Typical tasks undertaken include defueling, facility systems washout, safety surveillance, waste handling, waste processing, decontamination and process facility operations.

### 3.3.4. Technicians

This category typically includes staff who provide essential radiological monitoring and protection support services, as well as analytical and testing services, (e.g. chemical, bioassay and facility inspection). The technicians engaged in this work will generally be qualified by virtue of their competence in their particular discipline. In the case of radiological safety support, previous experience in a nuclear facility environment is essential.

### 3.3.5. Skilled trades

This category includes workers with engineering or construction trade skills who provide both engineering maintenance and technical support. It also includes the standard mechanical, electrical, and instrumentation and control technicians, as well as welders, pipe fitters and fabricators. On occasion, it would be necessary to deploy technicians from the building trades such as bricklayers and carpenters. The technicians in this area will generally be qualified to complete the work by virtue of their trade competence coupled with previous experience in a nuclear facility environment. Typical tasks include facility maintenance, construction and dismantling.

### 3.3.6. Specialist support

This category includes workers servicing the various support requirements that arise during the decommissioning process. Examples of these workers include scaffolding, lagging, concrete cutting and drilling specialists, remote handling equipment operators, underwater specialists, lift technician specialists, and demolition specialists (including explosive demolition). These individuals are deployed on an as required basis.

### 3.3.7. Supervisors

Supervisors oversee workforce teams to ensure that work is completed in a safe and efficient manner. The most important attribute a supervisor requires is the ability to manage the work such that it is completed in the manner intended, and to the required standards of safety and quality assurance. There is an advantage in using well trained, fully qualified and experienced supervisors with technical backgrounds related to the activity being supervised. The presence of such supervisors does not remove any of the obligations to ensure that all personnel being supervised are suitably trained and experienced to undertake the assigned tasks and duties.

### 3.3.8. Data managers

Data managers deal with the intersection of statistics, information technology and strategy. They create and administer the databases necessary for a dismantling project to be carried out satisfactorily. Data management is a relatively new and growing discipline arising from the huge increase in the quantity of data held by enterprises, which gives added value to information as digital resources.

### 3.3.9. Security and emergency response

The primary duties and responsibilities of security personnel are to execute the plant owner’s physical protection programme and coordinate emergency response until the regulatory requirements are changed commensurate with the reduction of nuclear risk as the facility progresses through the decommissioning programme. In the early phase of decommissioning, with spent nuclear fuel or special nuclear material present on-site, a higher level of security and emergency response will be necessary than in the later phases of decommissioning when the site security requirements may be the same as for general industrial sites. The resources required will vary accordingly as dismantling is being performed and the nature of the risks are evolving. The training requirements for security personnel will depend, to a large extent, on the decommissioning strategy selected by the plant owner.

### 3.4. IMPLICATIONS FOR STAFFING LEVELS

Human resource considerations for decommissioning are discussed in general terms in Section 4. In addition, the Annex includes some projections for personnel requirements, providing an indication of the implications for staffing levels required for the various phases of decommissioning.

# 4. MANAGEMENT OF HUMAN RESOURCES FOR DECOMMISSIONING

The satisfactory implementation of decommissioning programmes depends on various levels of involvement from all personnel, regardless of the type of nuclear facility and the management procedures employed. In addition, the national nuclear landscape, together with other ongoing infrastructure projects within a country and the organizational approach, will have a significant influence on the main human resource activities related to decommissioning.

The operating organization may have to recruit new personnel and establish new teams throughout the programme. The transition from operations to decommissioning may bring into focus some generic problems in human resource management in terms of skills, recruitment, leadership, training, performance management, and even psychosocial factors. The potential increased use of contractor staff may also lead to an externalization of important knowledge. This requires special attention to ensure successful integration into the knowledge management and human resource processes within the operating organization.

### 4.1. HUMAN RESOURCE MANAGEMENT STRATEGY

As mentioned earlier, the overall decommissioning strategy needs to be determined well in advance of the implementation of the organizational transformation discussed in Section 3. This will allow the human resource strategy, and the important associated communication strategy in the context of human resource management, to be developed (see Fig. 5).


*FIG. 5. Human resource and communications strategies for decommissioning.*

If the operator outsources responsibility for decommissioning, then the responsibility for human resources management will also transfer across and the contracting organization(s) will implement their own strategy. If the operator implements decommissioning, then all associated issues are addressed by the human resources management, including:

— Workforce planning;
— Recruitment;
— Diversity;
— Location and mobility;
— Employee engagement and retention;
— Leadership and leadership development;
— Succession and talent management;
— Performance management.

Knowledge management is discussed in Section 5 and training requirements and the application of the SAT is described in Section 6. The following sections look at each of the main elements of the human resources considerations pertaining to the preparation of decommissioning assuming the operator is retaining responsibility. If not, these responsibilities will transfer to the contractor organization.

## 4.2. WORKFORCE PLANNING

The workforce planning process is fundamental to the successful operation of a nuclear facility, but particularly during the transition from operations to decommissioning. Workforce planning is the systematic analysis of future needs in terms of the size, type and quality of the workforce to achieve its objectives [19]. It identifies the mix of experience and competencies needed and helps ensure that the decommissioning programme has the right number of people with the right skills in the right place at the right time. Furthermore, the term ‘workforce’ refers to all personnel, including contractors, involved in the decommissioning programme.

Workforce planning needs to be seen as an integral part of the decommissioning programme’s human resources strategy. It will ideally be aligned and integrated with other related activities and processes such as recruitment, succession, talent management and leadership development.

## 4.3. RECRUITMENT

Recruitment is ongoing throughout facility decommissioning; the nuclear industry competes with many other industries to attract appropriate personnel when required. There are concerns about potential shortages of suitably qualified and experienced people in the nuclear industry due to demographics and the general decline in recent years in the number of young people entering the industry. Decommissioning activities will need to attract new skills and competencies into the workforce in order to carry out the activities described in Section 2 (see also the Annex). It is important that personnel involved in decommissioning are given assistance in transitioning to other employment once their current work activity or project has been completed (e.g. see Appendix III).

An organization preparing for decommissioning may wish to carefully consider its strategy for attracting well qualified people and creating a ‘talent pipeline’. The increasing adoption of innovations, such as greater use of robotics and digital technologies, will help to support this effort [20]. The broad scope of activities in nuclear decommissioning and the possibility of making careers in this field are currently often obscured or are considered negatively by young professionals. Different ways to promote decommissioning among the younger generation will ideally be pursued, starting at the secondary school level through to universities.

Initiatives at local, regional and national levels which communicate the positive aspects of working in decommissioning may help to influence the perceptions of decommissioning. This communication needs to be targeted appropriately, depending on the needs of the decommissioning industry, at young people at different stages of their education as well as at those already at different career stages. Organizations planning for decommissioning need to dedicate resources and participate in such initiatives and, where required, develop their own methods of recruiting external talent, depending on their specific, projected needs.

Competition is particularly strong where organizations from outside the nuclear industry may compete for talent with non-nuclear experience, which frequently includes:

- Project management and controls.
- Engineering: electrical, mechanical and civil, as well as robotics in hostile environments.
- Senior managers in areas such as finance and operations.
- Construction management.
- Safety.

Competition for talent for decommissioning activities may also come from within the nuclear industry itself, with plant operations, lifetime extension and new build projects potentially being perceived as more exciting. This means that people with specific nuclear expertise may be attracted to other types of projects.

The sources of talent will vary, depending on the specific competencies that are being sought. Where non-nuclear experience is needed, the sources may include:

- Other parts of the organization, i.e. by developing and retaining existing talent;
- Directly from educational institutions (school leavers, apprentices, graduates);
- Other similar type of industries (e.g. aerospace, oil and gas);
- International sources, both within and outside the nuclear industry.

Conversely, the sources may be limited when considering very specific skill sets, such as radiation protection, waste characterization and management, radiological safety, some scientific disciplines, and technical areas. In both cases, competition can be intense and the approaches to being competitive will vary, depending on the situation.

When faced with competition, organizations need to consider the attractiveness of the careers that they offer to candidates, typically described as ‘employer branding’[4]. Elements to consider in terms of employer branding that will improve competitiveness include:

- Flexibility, with respect to working hours and conditions;
- Demonstrating a willingness to invest in ongoing training and development;
- Financial incentives;
- Offering a demonstrable career path;
- Offering a sense of purpose in the available work;
- Portability of skills, experience and qualifications.

## 4.4. DIVERSITY

The globalization of nuclear power has led to different people and cultures working together, and therefore promoting and supporting gender and cultural diversity in the workplace is an important

[4] This is related to the reputation of an employer and its value proposition (what it has to offer) to prospective and existing employees.

aspect of good leadership and people management. It is about valuing everyone in the organization as an individual.

Diversity needs also be considered in terms of education and experience already gained. While operational personnel are often specialized in one field, decommissioning is an area where, for example, environmental engineering and other more generic roles can offer career opportunities and bring in the specific skills required for decommissioning.

In an industry where there is an anticipation of a skills shortage, considering more diverse options can extend the talent pool. Currently, the nuclear workforce is significantly biased towards men between the ages of 40 and 60. Addressing future needs is likely to require the recruitment of young engineers and scientists, female engineers and scientists in general[5] as well as foreign nationals, particularly in countries where there are no future plans for nuclear programmes. To realize the benefits of a diverse workforce, it is important to develop an inclusive environment where everyone is motivated to participate and fully apply their abilities.

### 4.5. LOCATION AND MOBILITY

Nuclear facilities are often situated away from large population centres, which can create challenges and affect the attractiveness of a career in decommissioning for potential employees and their families. One of the consequences of the decision to move from the operation phase to decommissioning is that employees will be aware that the future of the plant is limited. This may bring about a movement of staff from the area and, with it, the knowledge gained over decades. An approach which is sensitive to the future of the local community will help to avoid this outcome, as will measures to support mobility by being supportive of redeployment and/or relocation. This can potentially increase the resource pool available for the duration of the decommissioning project (see Appendix II).

A relocation decision may be daunting for employees and their families, so organizations may need to engage with not only the candidate, but also with family members in order to maximize the attractiveness of the relocation. Providing information on the location and access to other people who have already made a similar move can be an effective way of supporting the candidate[6].

### 4.6. EMPLOYEE ENGAGEMENT AND RETENTION

Many organizations measure employee engagement through an annual survey. They use the feedback to understand the areas where employees may be less happy than other areas and develop and implement suitable changes to bring about improvements. Ultimately, it is in the interest of each organization to create a workplace which allows employees to deliver their best performance, be committed to the organization's goals and values, and motivated to contribute to organizational success, with an enhanced sense of their own well-being.

Any change situation brings about uncertainty and therefore it is important that the organization, human resources and communication strategy are developed and delivered in a coherent and timely manner. Engaging with employees in the change process will help to reduce as much uncertainty as possible. This may be done, for example, through trade unions, employee forums and line managers.

Establishing the right culture for employee engagement will help in supporting the retention of suitably qualified and experienced personnel, especially those with nuclear specific skills and knowledge.

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[5] Member States may engage with organizations such as Women in Nuclear Global (WiN Global), which is a worldwide non-profit association of women working professionally in various fields of nuclear energy and radiation applications.

[6] A web site was created to help people support prospective employees when moving to the Canadian Nuclear Laboratories site at Chalk River in Canada, see: https://keysource-thomas-thor-renfrew-county.ca.

A retention strategy, similar to a diversity strategy, can be promoted at an industry level and developed and implemented at an individual organization level. Providing clear and motivating career paths, international opportunities, healthy workplace environments, competitive remuneration and benefits packages, and high quality training and development are all features of a good retention strategy. Retention is inextricably linked to motivation [21] (Appendix III).

## 4.7. LEADERSHIP AND LEADERSHIP DEVELOPMENT

Leadership for decommissioning is an organizational development challenge. The organizational configuration and the technical knowledge and experience for the leadership team are quite different from that of an operational facility. Decommissioning is an industrial project taking place in a dynamic environment rather than a process type operation with little daily fluctuation in work activities. Leaders may require enhanced skills in areas such as stakeholder management (including regulatory strategy, regulator and public interface, and stakeholder relations). They may also require enhanced communication and interpersonal skills. If required, leadership development programmes could be developed using SAT [22], depending on the size and context of the decommissioning organization and programme.

There are significant cultural differences internationally in leadership styles and approaches. However, the following principles are relevant:

— A clearly articulated mission and purpose;
— Clear and appropriate communication;
— Relevant domain knowledge and experience;
— Leadership by actions and examples.

Leaders may be individuals with substantial experience in their specific organization or may join from other organizations or industries. Continuing professional development and support of these individuals are recognized as key foundations for their effectiveness. This can come in many forms, such as:

— Mentoring (either by senior colleagues or by third parties with specific, relevant experience).
— Commercially available executive education.
— Industry specific leadership and educational opportunities; they may be available through the IAEA.

In addition, leadership skills can benefit from the development of techniques and motivation methods to improve performance in the organization. These types of courses are required to address some of the human resource management and communication issues within the project. For example, Ref. [23] contains information on the selection and development of managerial skills; Ref. [24] details the approaches to improving staff performance.

## 4.8. SUCCESSION AND TALENT MANAGEMENT

Succession planning may assist in deciding which people are suitable to move to roles within the new decommissioning organization, may be allowed to leave through redundancy arrangements or be redeployed into new roles following a formal counselling process (see Appendix III). It has to be borne in mind that, given the finite timeframe of a decommissioning project, some employees will take up alternative opportunities as they present themselves during the course of the project.

It is important to be aware of both the existing and emerging talent within the organization as this is where retention and redeployment strategies are likely to be focused. Some employees will have been on a well defined and agreed career path which may eventually become obsolete with organizational change.

Understanding and agreeing alternative career paths within the new organization is an important factor in retaining well qualified personnel.

### 4.9. PERFORMANCE MANAGEMENT

Performance management aims to maintain and improve employee performance in line with an organization's objectives. Broadly, performance management relies upon regular, effective feedback on progress towards achieving employee objectives. With the transition to decommissioning, these objectives are going to change and therefore discussion and engagement with employees is important.

Discussions between line manager and employee usually take place on an annual cycle whereby objectives are set at the beginning of the year followed by an interim review of progress after six months and a final review at the end of the year. The process can also include discussions on career progression and training and development.

Within nuclear organizations performance management is a useful mechanism for understanding an employee’s suitability and intentions. When discussing the transition from operation to decommissioning, discussions may focus on the following options:

— Current and future expectations concerning objectives;
— Suitability for roles within the decommissioning organization;
— Preparation and discussion of possible alternatives if no obvious role;
— Possible redeployment;
— Possible exit.

These discussions are important and help line managers to understand an employee’s future intentions at an early stage but do not supersede the formal counselling process.

## 5. KNOWLEDGE MANAGEMENT FOR DECOMMISSIONING

Knowledge management has been defined as:

> “An integrated, systematic approach to identifying, acquiring, transforming, developing, disseminating, using, sharing, and preserving knowledge, relevant to achieving specified objectives”. [25]

Significant differences between facility operation and decommissioning have been outlined previously in this publication. With the change from operation to decommissioning, it will also be necessary to adapt the knowledge management programme.

The flow of information, relevant to decommissioning, during the life cycle of a nuclear facility is summarized in Fig. 6. Important bodies of knowledge include: design knowledge from the construction phase; knowledge of plant behaviour gained during operation, and decommissioning knowledge partially obtained from the supply chain. Knowledge of the contents and composition of waste packages and remaining contamination need to be retained beyond the ultimate disposition of materials, waste and the achievement of the site end state. This knowledge may also be necessary when taking into account actions on waste packages or the site (e.g. usage restrictions).

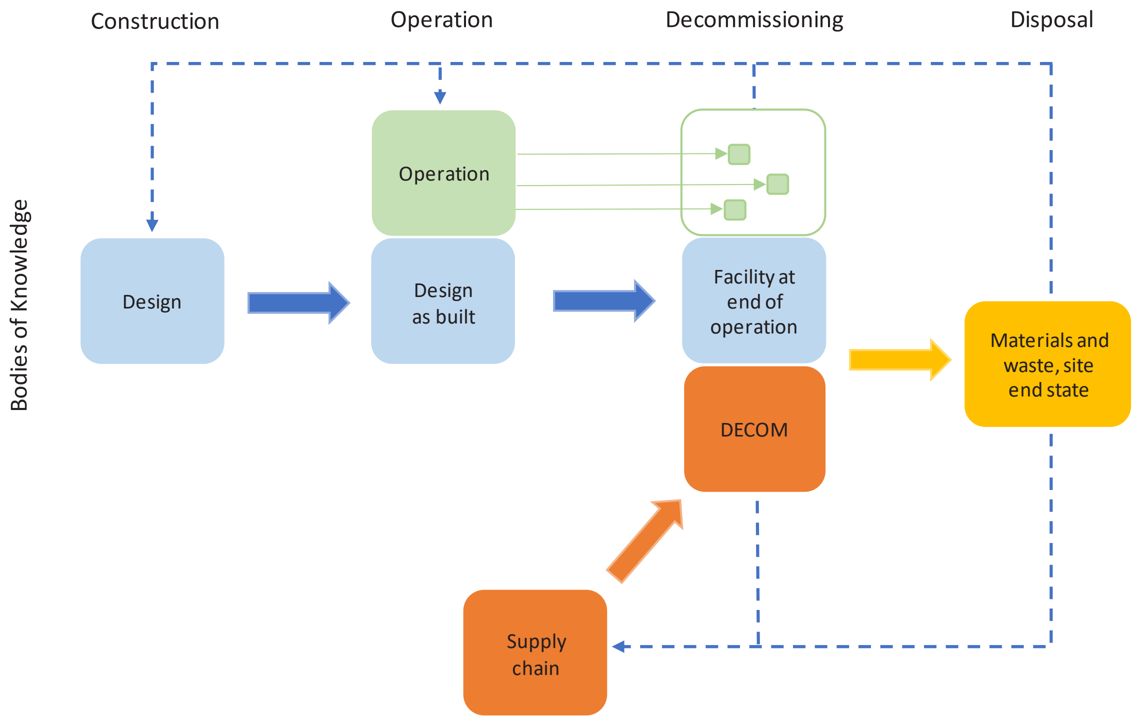


*FIG. 6. Flow of information during a nuclear facility's life cycle, including possible knowledge feedback loops (dashed lines) to design and construction, operation and the decommissioning supply chain DECOM = decommissioning.*

### 5.1. KNOWLEDGE MANAGEMENT REQUIREMENTS FOR DECOMMISSIONING

In this publication, knowledge management is considered mainly from the perspective of a nuclear power plant operator [24–26]. Similar considerations apply to other facilities, to multi-facility sites and other types of organizations, with necessary adjustments taking into account the specificities of these different facilities.

During preparation for decommissioning, it is necessary to define the critical knowledge[7], skills and competences, either generated internally or acquired externally, to be transferred from operation. This process needs also to consider the critical knowledge required for the subsequent steps, such as waste treatment, storage and disposal.

Transforming the knowledge management programme from operation to decommissioning, as well as developing the additional skills and competencies required, requires a significant investment of effort and time. This process needs consideration well in advance of the start of decommissioning and will typically be an integral element of decommissioning planning, proceeding in parallel and at similar levels of detail.

The knowledge management programme for decommissioning can be established by beginning from a consideration, first, of the desired end state and then the steps needed in order to reach this objective from the start of decommissioning. In practice, once the end states are defined (e.g. by the relevant waste acceptance criteria for disposal of the decommissioning waste or the site end state), the associated critical knowledge can be defined from the processes to be conducted to safely reach this end state or the defined transition states in between.

[7] Knowledge that is deemed imperative to possess before proceeding to perform certain activities independently

The knowledge management programme will need to take account of the following considerations:

— Clear understanding of the physical status of various systems and the knowledge needed to safely complete the tasks;
— Existing financial and organizational limitations that may have an impact on managing knowledge generation and preservation, as well as the numbers and deployment of personnel within the organization;
— Existing knowledge management programmes, including management skills and competencies, outsourcing and human resource development plans;
— Development of a specific body of knowledge for decommissioning.

Appendix V is a case study on the retention of knowledge from the implementation of decommissioning projects.

Table 3 emphasizes that the knowledge management strategy depends heavily on the organizational scenario for implementing decommissioning.

At the organizational level, a significant amount of new knowledge will be created during decommissioning, and therefore the management system [27] needs to provide the basis for the knowledge management programme by ensuring that knowledge preservation and transfer are properly organized and controlled. The knowledge management programme for decommissioning will include decommissioning strategies, plans for project management and control, decommissioning technologies, waste treatment, packaging and interim storage. The management system needs to ensure that the processes for the identification, acquisition or generation, application and deployment of the knowledge necessary for decommissioning and the subsequent steps are properly set up, executed and controlled. Changes in the management system itself (i.e. vision, mission, policies and aims) will be initiated during the transition from operation to decommissioning and these changes may also influence the knowledge management programme.

The knowledge management programme processes and procedures generally need to be reviewed to ensure they are suitable for decommissioning. Any changes will focus more on the number and frequency of certain tasks (e.g. the amount of individual knowledge capture and transfer planning for persons leaving at the end of operation) than on changing the general procedures.

The knowledge management elements that typically need to be revised for decommissioning include:

— Plant policies and procedures, e.g. safety policies and procedures (both nuclear and industrial) and technical procedures and instructions. The change of objectives impacts both procedures and instructions.
— Configuration management, e.g. plant status control and plant modification and change control. To cope with the frequency and extent of configuration changes, the configuration management procedures and systems may have to be adapted.
— Learning from past (or other) experience, e.g. events on similar installations or environments. Change of focus to decommissioning sites, change of focus to work safety.
— Corrective action tracking, e.g. identification of existing deficiencies, their planned resolution and status of resolution, inclusion of contractors in corrective actions.
— Training and qualification, e.g. approved training materials and training and qualification records. Change of focus to decommissioning, enhance work safety aspects.
— Data and information access, e.g. although information safety and privacy are important topics, the balance may shift from a strict ‘need to know’ basis to a more open approach taking into account that decommissioning is logistics and data driven.
— Human resource management, e.g. workforce planning for the organization. Recruitment plans, integration of internal and external resources and contracted personnel.

TABLE 3. ADVANTAGES AND DISADVANTAGES OF DIFFERENT ORGANIZATIONAL KNOWLEDGE MANAGEMENT APPROACHES

| Organizational approach | Advantages | Disadvantages |
|---|---|---|
| A — Operator undertakes decommissioning. | — Plant and organizational knowledge is retained.<br>— Minimal transition required (continuity from operating to decommissioning phase). | — Operator not likely to have all skills and competences required.<br>— Redeployment and retraining required.<br>— Acquisition of new capabilities necessary.<br>— Plant personnel may have operational mindset[a].<br>— Missing experience in decommissioning. |
| B — Operator retains project control and delegates specific activities to contractor(s). | — Plant knowledge is retained.<br>— Specialist contractors bring in competencies and knowledge of their own. | — Some decommissioning competence for operator necessary (informed customer).<br>— Competencies and qualification of contractors require evaluation.<br>— Knowledge transfer between several contractors and operator may be necessary; intellectual property issues may arise.<br>— Operator only acquires decommissioning knowledge as a customer. |
| C — Operator and contractor working in partnership. | — Combines plant knowledge of operator with decommissioning knowledge of contractor.<br>— Operator will acquire decommissioning knowledge. | — Compatibility of cultures, data and systems required.<br>— Mindsets of personnel from operational and decommissioning backgrounds are typically very different.<br>— Intellectual property issues may arise.<br>— Long term association between contractor and operator needed. |
| D — Operator transfers decommissioning to a specialist organization. | — Specialist organization may have significant knowledge of decommissioning.<br>— Specialist organization will have an adequate supply chain. | — High risk of loss of knowledge during transition.<br>— No decommissioning knowledge backflow to operator.<br>— Access to detailed facility specific data may be limited. |

[a] Mindset refers to the attitudes and behaviour, the way of thinking, and the influence of values on it. The mindset may greatly influence the ability to cope with a highly controlled, more repetitive line management task in operation or a continuously changing environment in the project environment for decommissioning.

## 5.2. ADAPTING THE KNOWLEDGE MANAGEMENT PROGRAMME TO DECOMMISSIONING

The knowledge management programme has to be adapted to the selected decommissioning strategy. Depending on the chosen strategy and approach (see Table 2), this may require significant planning and reorganization.

All plant life cycles give rise to specific features of knowledge acquisition and transfer, and technical expertise. Most of the knowledge relevant to future decommissioning is acquired during design, siting, planning, construction and operation before shutdown. However, there are some challenges to the knowledge management process, such as delayed decommissioning in the case of operational life extensions, and the retention of existing skills and competencies for periods over 50 years. The amount of new knowledge that is generated is substantial, as is the degree of effort required for the acquisition of external knowledge. In addition, processes to remove obsolete knowledge from files and systems (‘forgetting’) are necessary to streamline the body of knowledge and align with the particular status of the facility.

Important considerations related to knowledge management during the transition from operation to decommissioning include:

— Knowledge transfer from operation to decommissioning may be lost in various ways, e.g. experienced staff leaving, new hires requiring training;
— A significant body of knowledge may be present from operational experience that is not needed during decommissioning and later;
— Some important information may not have been adequately captured during operation;
— The management system and its preparedness for the transition to decommissioning need to be modified and updated, and then reviewed;
— There may be a need to adapt or recon figure data and information gathered during operation in order to make it more readily accessible for decommissioning;
— There may be a need to review who has access to what type of data.

Accordingly, preparation for decommissioning needs to include:

— Identification of the critical knowledge to be preserved and possibly adapted when transitioning from operation to decommissioning;
— Identification of the gaps in information required for decommissioning and how to obtain the necessary information;
— Development of specific knowledge management procedures suitable for decommissioning;
— Identification of the plant configuration during various stages, and the knowledge required to perform operation/maintenance activities on them during the transition from operation to decommissioning;
— Development and implementation processes to identify information that is no longer required as decommissioning work progresses, e.g. as the facility changes or systems are removed;
— Identification of knowledge that can be made obsolete by organizational, technical or other developments, e.g. replacement of nuclear specific equipment by standard industrial equipment.

## 5.3. KNOWLEDGE LOSS RISK MANAGEMENT

The unintentional loss of knowledge may have safety and financial implications. The likelihood of knowledge loss increases over time (i.e. from the time the knowledge was generated to the time it is required, especially for tacit knowledge[8]). Information may be lost due to its deterioration or outdated electronic support (documentation, old electronic formats, etc.). Knowledge may also be lost due to the retirement of qualified and knowledgeable facility staff, or because of the loss or error during the transmission of information from one person to another [28].

The problem can be mitigated by recognizing the importance of systematically identifying and capturing critical knowledge for decommissioning during operation. This requires organizations to consider decommissioning as a stage in the life cycle of a nuclear facility and to preserve during operations the knowledge, records and information that might be useful after shutdown.

[8] Tacit knowledge is held by individuals and is difficult or impossible to articulate (e.g. skills, insight, intuition and judgement). In contrast, explicit knowledge is written down. In the middle there is implicit knowledge, also held by individuals, which could be systematically elicited and transferred to others.

A systematic approach is required for identifying areas where there is a risk of loss of information of importance to decommissioning, and to implement mitigating actions, including:

— Acknowledgement and management of the differences between operation and decommissioning during the planning phase;
— Development of a knowledge management programme for the facility’s life cycle, including decommissioning;
— Application of project management best practices which incorporate knowledge management processes;
— Consideration of the important aspects of operation, such as various plant operating states (POSs), including after shutdown;
— Awareness of current maintenance, as well as extensive refurbishment activities which are part of the operation phase;
— Taking into account the significant differences in operation and decommissioning, and hence the training differences;
— Management of human resources for all stages of the facility’s life cycle;
— Management of information in various databases and systems, and from knowledge based plant information systems[9];
— Application of SAT (see Section 6) throughout stages of the facility’s life cycle.

Similar measures of knowledge loss risk management are required to those applied during operation, while ensuring a decommissioning focus. It is important to retain personnel with critical knowledge (e.g. operators and maintenance technicians for critical infrastructure, waste management specialists, safety engineers) and to develop a programme for the transfer of such knowledge within the organization. The knowledge management programme needs to incorporate documentation management. Particular attention may be needed to ensure the retention of tacit knowledge that might otherwise be lost, using the most appropriate knowledge management processes and tools.

## 5.4. KNOWLEDGE AND INFORMATION MANAGEMENT SYSTEMS

Knowledge and information management systems can be used to help facilitate the timely availability and accessibility of appropriate knowledge and information in the right form. This helps personnel at all levels within the organization, whether making operational judgements or involved with strategic decision making.

Knowledge centred plant information systems have also been developed to facilitate this and were the focus of an international conference in 2016 [29]. Aspects of virtual reality (VR), augmented reality (AR) and 3-D modelling have been demonstrated in a number of international meetings [30] and training activities [31]. However, personnel may need training in the appropriate use of knowledge and information management systems .

The application of knowledge organization schemes (KOSs)[10] facilitates the combination of information from different sources and of different types, given the complex nature of decommissioning and the challenge of different regulatory environments.

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[9] For example, digital twins of plants or parts of it, the use of VR, AR and other technical assistance systems can be used not only for engineering, but also for training and education. Combinations with semantic systems may be necessary to allow integration of information from these different sources into the knowledge management system.

[10] The IAEA uses a semantic based system to support knowledge exchange for the International Decommissioning Network.

# 6. TRAINING REQUIREMENTS AND THE APPLICATION OF SAT

## 6.1. INTRODUCTION

The previous sections described the different approaches to decommissioning and their requirements in terms of roles. Whichever approach is taken, these roles will need to have different skills and competencies, and therefore associated training plans and programmes will be required. To help define them, the use of SAT methodology may be used as part of the process to achieve and maintain a competent workforce. A graded approach to the application of SAT methodology is recommended, taking into account health and safety priorities. The use of this approach in the application of SAT is justified by the availability of existing methods and tools. The aim is to secure a motivated, readily available, pool of suitably qualified and experienced personnel to ensure that the decommissioning programme can be implemented efficiently and effectively.

Many of the personnel identified in the categories involved in decommissioning phases will have been trained and qualified during the operational phase, and a significant portion of their earlier training is directly applicable to the decommissioning phase. In addition, a significant portion of existing training programme material is normally used for continuing training and for training new employees. Also, as the decommissioning process progresses, increasing numbers of the total workforce will be contractor personnel. These contractors may not possess specific knowledge of the facility being decommissioned, but they may have been selected due to their previous experience of similar work at other facilities or their own specialist skills. Alternatively, they may have been employed simply to satisfy resource requirements and have little or no previous relevant training.

Some other prerequisites are essential in achieving the successful implementation of the training programme:

- Leadership and vision from the senior management to drive the change;
- Commitment from line managers to deliver and improve the training as a continuous process;
- Motivation of the personnel to commit to the training.

This section describes the methodology for training, but the prerequisites described above will ideally be part of the management system, aligning with human resource policy and communications as part of the decommissioning programme strategy.

## 6.2. SYSTEMATIC APPROACH TO TRAINING

SAT is recognized worldwide as the international best practice for attaining and maintaining the qualification and competence required for nuclear facility personnel [32]. With a systematic approach to training, the competence requirements for personnel involved in the decommissioning programme can be established, validated, and met in an objective manner. An overview of the SAT process is given in Fig. 7.

SAT consists of five interrelated phases:

- *Analysis:* This phase comprises the identification of training needs and the competencies (knowledge, skills, and attitudes) required to perform a particular job.
- *Design:* In this phase, competencies are converted into measurable training objectives. These objectives are organized into a training plan.
- *Development:* This phase comprises preparation of all training materials so that the training objectives can be achieved.

— *Implementation:* In this phase, training is conducted by using the training materials developed.
— *Evaluation:* During this phase, all aspects of training programmes are evaluated on the basis of the data collected from the other phases. This is followed by suitable feedback leading to improvements in the training programme and facility.

In the following sections, an overview of each phase of the SAT approach is given. As an example, a case study will follow the development of a training roadmap for the role of a waste technician for each SAT phase.

During decommissioning, a waste technician has the responsibility for:

— Providing advice to all waste producers regarding waste packaging options and requirements;
— Controlling the waste packages produced and the associated documentation to ensure they comply with the employer's waste acceptance criteria, validating their transfer for storage, treatment in a dedicated facility, or shipment to a repository;
— Evaluating the waste producer's culture and providing guidance for improvement.

### 6.2.1. SAT analysis phase

Depending on the situation and the impact of the transition of personnel during the move from operation to decommissioning, it is necessary to analyse and update the required competencies for all positions in the future organizational structure.

The expected outcomes at the end of this phase include:

— A series of key performance indicators (KPIs) relating to human resource needs, safety, process improvement, finance, etc;
— A description of currently available competencies of the workforce, those competencies that will be required to perform the decommissioning (e.g. in terms of knowledge, skills and abilities), and the training effort that is required to meet future needs.

This phase will not ideally be considered a 'one-off'. It is an iterative process, regularly updated to integrate the latest enhancements and needs throughout the entire decommissioning programme. Two techniques often used to determine training needs are job and task analysis and job competency analysis. The work to be undertaken is analysed and the requirements, in terms of the actual tasks to be completed and the competencies required to undertake these tasks respectively, are listed.

Figure 8 depicts a simplified representation of what the analysis could look like for the role of a waste technician. From the existing roles during operation, three have been included in Fig. 8: plant operator; maintenance technician; and health physics technician. The blue rectangle illustrates the level of difficulty of training an employee from the beginning to the final role of waste technician. In this example, training is most difficult (red rectangle) for plant operators because they are unlikely to have

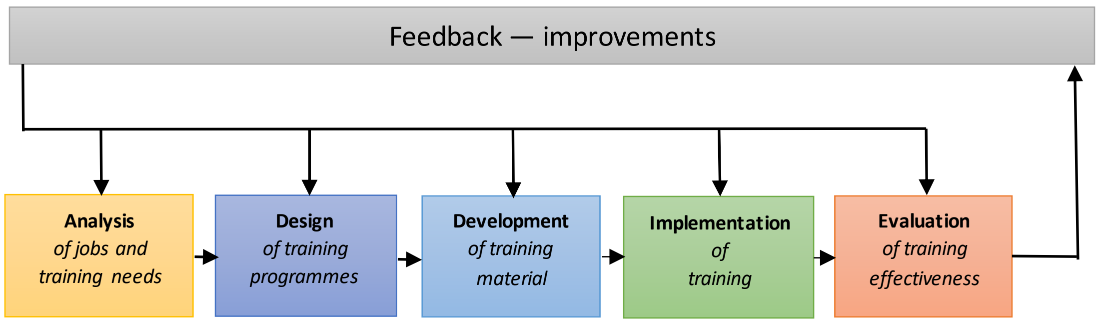


*FIG. 7. Overview of the SAT process.*

any prior knowledge in the areas required for a waste technician. The effort will be less for a maintenance technician (yellow rectangle) who is involved in producing waste during their activities, and who has some knowledge and sensitivity towards radiological concerns. The final example, health physics technicians, (green rectangle) will require even less effort as they regularly perform nuclear and waste measurements on a regular basis.

The training programme details the total number of waste technicians to be trained and the total number of available staff in the starting (or previous operational) roles.

### 6.2.2. SAT design phase

The definition of the design phase relies on both the availability of existing tools, methods and facilities and the investment in training that the owner/operator is ready to consider. Indeed, the range of possible design options for the operator will depend on the training infrastructure and methodologies available to the owner/operator. The main outputs from the design phase are grouped and sequenced training objectives, test items and a description of the training programme.

The development of methods and tools for training related to decommissioning preparation is concerned with the following, each of which offers a range of possible options in terms of the programme design:

— Instructors and trainers;
— Digital solutions and VR;
— Realistic mock-ups.

Section 7, and the appendices associated with it, describe in detail the training tools and methods available to perform the design phase. The objective of this phase is to define for each future skill requirement:

— A generic training programme (training and qualification descriptions specific to particular roles);
— A flexible approach that can be tailored for each person, recognizing that individuals will have a unique background in terms of training and qualifications; and taking into account the needs of the organization.

This phase relies on information on the following three factors:

(1) The type of role and profile for which training is needed;
(2) The targeted level of competence to be attained;
(3) The profile of the employee envisaged to fulfil the role.

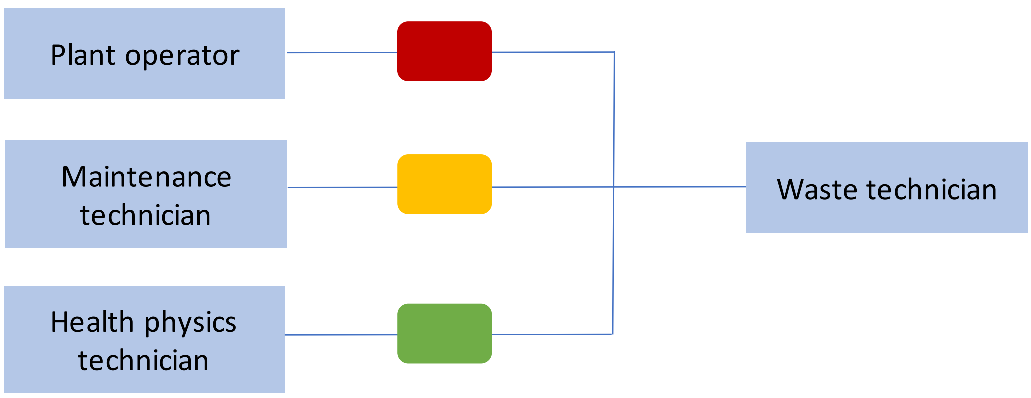


*FIG. 8. Analysis of transitioning options from the operating workforce to decommissioning (example of a waste technician).*

It is important for training programmes to be designed so that they can be used both to train workers who possess relevant experience and those who have little or no experience in those areas. In the case of the former, the task is to confirm existing knowledge and to identify and address any shortfalls by 'top-up' or refresher training. When creating training programmes, it is necessary to consider the needs of trainees of varying abilities.

In addition, when designing training programmes, there is a need to understand the frequency of delivery for certain course materials to individuals. Any 'refresher' training may not necessarily be as intensive as the initial training on the subject matter but needs to be delivered in a way that ensures that levels of understanding and knowledge are maintained. This applies equally for workers who may only use certain skills on an intermittent basis.

The expected outcome at the end of this phase is to have a training programme defined for each job or skill category providing:

— Eligibility criteria to select the suitable profiles in compliance with needs;
— A graded training programme for each relevant competency related to the particular job category;
— Opportunity for personnel to evolve in accordance with their own capacities while complying with the employer's needs.

Figure 9 illustrates some of the main stages in the design of a training programme for a waste technician. In order to perform the activity efficiently, a waste technician needs at least three key competencies, with a certain level of proficiency for each:

— A reasonable understanding of decommissioning methods and challenges, to the extent that it helps them understand the challenges or issues related to waste;
— A complete understanding of waste acceptance criteria (WAC) so that they will be able to decide whether a given package is in conformity with the specifications;
— A good understanding of waste package characterization techniques so that they can verify whether a package radiological activity is measured/calculated in a way that it conforms to WACs.

Depending on the initial background and experience of the person being trained, they may need to go through all of the stages, or only some of them, or even to a different level of detail of training on any of the stages. For example, an operator will need more in depth training on all aspects when compared to a maintenance technician who will already be partly familiar with some notions of decommissioning principles and waste package characterization.

### 6.2.3. SAT development phase

As an analogy with what was described for the design phase, the range of potentially available materials for the development phase depends on both existing tools as well as the investment the owner/operator is ready to consider. Complying with the outcomes of the analysis and design phases,

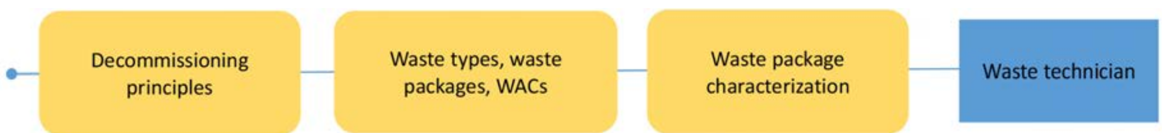


*FIG. 9. The main stages in the design of a training programme for a waste technician.*

the objective of the development phase is to prepare all the training materials. Therefore, the following sequence of steps are to be taken:

— Collect any existing materials identified as suitable with the new needs[11];
— Identify the gaps and the resulting efforts and associated costs;
— Decide on the appropriate approach ('in-house' or 'outsourced') for performing the development phase[12], in accordance with the global owner/operator's strategy.

The main outputs from the development phase are developed, reviewed, piloted, improved and approved training material, as well as instructional and trainee material and selected trained and qualified instructors. For the example given above, this would include, for three areas:

— Teaching materials;
— Digital solutions such as VR simulations and serious games[13];
— Training facilities or collaborative centres and representative mock-ups.

Figure 10 illustrates a training portfolio for each of the competence areas identified for a waste technician. In this example, three levels of proficiency have been identified for a given competence, each of them related to the content of a training module. The training packages developed for each may also be useful for other roles. The 'DECOM Principles' module could be used for the majority of other roles in decommissioning.

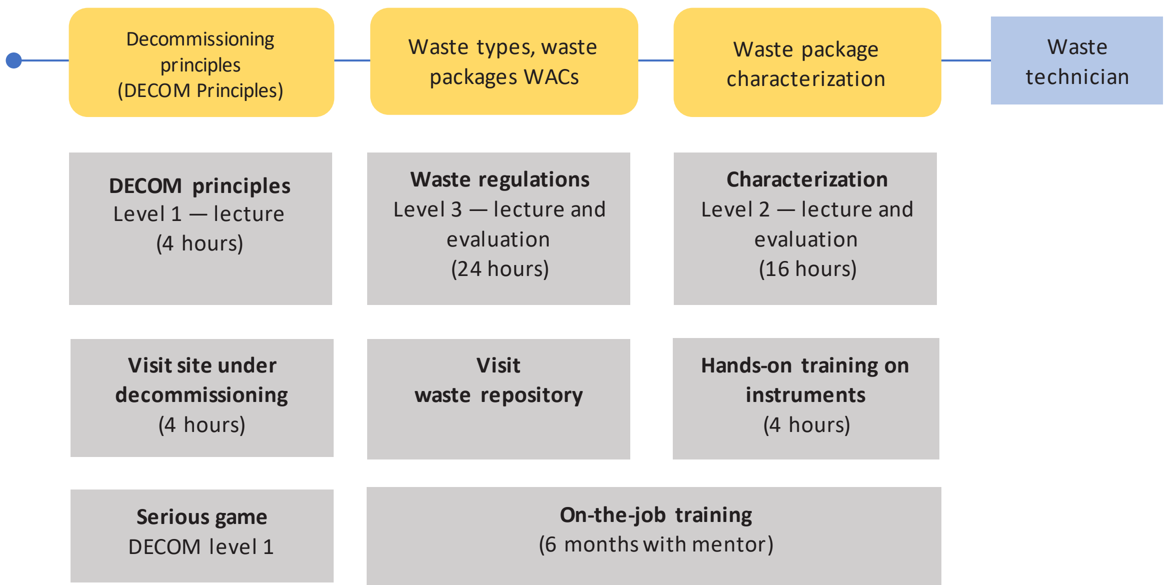


*FIG. 10. Example of a training portfolio for each of the competence areas identified for a waste technician.*

[11] Appendix VI includes a table showing how the emphasis in training is typically influenced for a selection of activities relating to operation and decommissioning.
[12] Detailed comparisons between the several options are described in Section 7.1.
[13] Serious games use simulation technologies developed in video gaming to test scenarios in non-entertainment fields.

### 6.2.4. SAT implementation phase

The objective of this phase is to conduct the training using the relevant materials. By definition, such a process is continuous, addressing several needs, including:

- First time training for newcomers;
- Refresher training for continuing roles;
- Retraining to convert personnel from one role to their new role;
- Adapting and adjusting the training to take into account the feedback resulting from operational experience.

The expected outcome from the implementation phase is a suitably qualified and experienced pool of competent staff.

In the waste technician example, if return on operating experience shows that new characterization techniques have been qualified and used on certain projects, they will need to be integrated into the course material. Appendix VII provides a case study illustrating a methodology for the identification of training needs for a decommissioning programme through to the deployment of training programmes.

### 6.2.5. SAT evaluation phase

The objective of this evaluation phase is to assess the effectiveness of the training programme as well as the relevance of the associated tools and methods. This phase is critical for the operator in terms of having to satisfy and demonstrate its own organizational requirements but also to comply with regulatory and any national legislative requirements, e.g. health and safety.

To evaluate each training programme, the typical methods used include:

- Performance indicators, to assess either the level of implementation or the efficiency of the delivered training;
- Internal or external audits to be conducted for each training process to demonstrate that the processes satisfy qualification and certification requirements;
- Evaluation by the trainees of the quality and relevance of the training programme.

The expected outcome of this phase is:

- Degree of conformity with the KPIs established in the analysis phase;
- Evaluation programmes for internal and external audit purposes;
- Definition of the associated process to analyse the above outputs and to develop and implement continuous improvement of the training programme.

The resulting analysis could be used in a number of ways, ranging from incremental improvements (e.g. update and modify some roles) to a radical revision of the training strategy.

In the waste technician example, it may appear after a few training sessions that the module on DECOM principles is redundant, with more focus required on decommissioning application, so that the module can be excluded. On the other hand, trainees may declare after a while that they need more training on characterization than was proposed initially, in which case the course will be extended.

Appendix VIII provides examples of international initiatives and programmes to develop skills in nuclear training and decommissioning. Appendix IX provides an example of training course content for ‘leading change from operation to decommissioning’.

TABLE 4. ADVANTAGES AND DISADVANTAGES OF DECOMMISSIONING TRAINING OPTIONS

| Training options | Advantages | Disadvantages |
|---|---|---|
| In-house | • Globally less expensive (internal staff, mutualized equipment, local investments).<br>• Reusable at minimal marginal cost.<br>• More flexible and adaptable content.<br>• Easier to incorporate in the personnel agenda.<br>• Secure key internal knowledge.<br>• Gives credibility and projects a positive image to external stakeholders.<br>• Supports enhanced personnel motivation and fosters greater commitment to decommissioning. | • Difficulties to mutualize associated former investments with other parties.<br>• Requires time to be set up and incorporated in the decommissioning schedule.<br>• Requires adequate internal competence, the ability to train and teach and the ability to design and develop courses.<br>• Requires volume of return for investment taking into account number of employees, number and frequency of training courses.<br>• Certification of proficiency is not necessarily externally accredited. |
| Outsourced | • Readily available (no extra time required to be set up).<br>• No need for internal skills such as internal competence, the ability to train and teach and the ability to design and develop courses.<br>• Less importance for amortization considerations.<br>• No need to consider number of employees, number and frequency of training courses.<br>• Certification of proficiency more likely to be externally accredited, and may therefore be more easily transferable between projects. | • Training support is restricted to the contract (intellectual property considerations).<br>• Globally expensive (no possible mutualization or investments amortization (particularly in the case of fleet effect)).<br>• Less flexible and adaptable content.<br>• More difficult to be incorporated in the personnel agenda.<br>• Does not secure key internal knowledge.<br>• Weakens the owner/operator's credibility and external image.<br>• No gain on public acceptance.<br>• May not foster commitment of personnel to decommissioning. |

# 7. PRACTICAL ASPECTS AND TOOLS FOR TRAINING

## 7.1. DIFFERENT APPROACHES TO TRAINING

A decision on the most appropriate option for the decommissioning training approach is influenced by the following:

— The national policy on the future use of nuclear energy;
— State or private ownership of nuclear facilities;
— One or multiple operators within a country;
— Scale of the nuclear industry within a country (number of facilities).

Based on these considerations, there are several options for training, namely:

— In-house;
— Outsourced to a training provider;
— A mix of both in-house and an outsourced provider.

Table 4 outlines the advantages and disadvantages of the in-house and outsourced options.

Once the decision has been made on the option to be used, a number of associated resources need to be available, for example:

— Instructors and trainers;
— Digitalized training (computer or web based);
— Training facilities with digital simulators and mock-ups.

While instructors and trainers are generally available, training facilities with digital simulators and mock-ups are less common, and therefore organizations are starting to collaborate and share costs for their use. Additional processes can be used to supplement these resources, such as audits and application of lessons learned, including international feedback from experience.

Refining the selection of the appropriate training option requires consideration of the resource implications in relation to the following:

— Trainee's profile and background;
— Purpose of the training;
— The level of competence required;
— Available funding.

These resources are described in more detail in the following sections.

## 7.2. INSTRUCTORS AND TRAINERS

The quality and effectiveness of training relies on the experience and competence of the instructors and trainers, as well as on the quality of the training materials and processes [33]. Quality needs to be ensured across all of these dimensions. Moreover, the importance given to training and its recognition by the organization, will have an impact on the overall training quality and effectiveness.

A decision to outsource training will normally provide suitable instructors and trainers but may require additional support to address the specific needs of the decommissioning programme. If the decision is to provide in-house training, this may require more attention and effort to ensure that suitable instructors and trainers are available.

The following requirements will ideally be taken into account when selecting instructors and trainers:

— Minimum professional competence for the job classification;
— Managerial skills;
— Teaching and educational skills;
— Knowledge of adult learning;
— Positive and enthusiastic nature.

Qualification requirements for instructors and trainers could include the following:

— Qualification or certification relevant to the skills being taught;
— Professional training and/or experience in teaching;
— Periodic training to maintain professional competence;
— Familiarity with the SAT approach.

An understanding of developments in nuclear decommissioning and an ability to take into account lessons learned from international experience are an advantage.

The availability of experienced people may allow an organization to conduct effective mentoring programmes. The development and use of such programmes can support and complement the following different training methodologies:

— Theoretical training (classroom tuition);
— On the job training (OJT);
— Fellowship, internship, secondment.

The use of OJT enables a trainer to demonstrate the technology of the operation in actual situations, providing an enhanced learning experience that may be suitable for certain roles in decommissioning. It also records the progress and performance of the employee using evaluations and documentation of the work undertaken.

In summary, instructors and trainers are fundamental to the deployment of successful training programmes. Organizations need to put in place appropriate mechanisms to ensure that instructors and trainers possess all the required competences to support the effective delivery of training.

### 7.3. DIGITALIZED TRAINING

The experience gained over the last two decades has demonstrated that the most effective type of training in decommissioning is that which is undertaken either in a live working environment or with mock-ups (particularly for certain roles). Nevertheless, the operational experience has also emphasized a need for classroom tuition and self-study types of training.

There is a specific need for personnel to learn about safety requirements relevant to decommissioning, and to keep up to date with them. There is also a requirement for personnel, including contractors, to maintain training records as evidence that necessary levels of competence have been attained.

Increasingly, such safety training is undertaken using digital tools, e.g. using training packages uploaded on computers and/or made accessible on-line on the web. As interactive technology develops, and with the increasing use of multimedia and VR, the term technology based training (TBT) is now being used.

There are many organizations providing such services, including educational entities. In some Member States, there are specialized training facilities allowing VR and AR training for decommissioning.[14]

TBT is usually presented as a modular series of individual topics that can be called from a menu, with extra information which may be accessed if required. Pre-set questions are used throughout to assess the level of understanding gained by trainees; these may be used to monitor the direction taken through the course material and to manage the rate of progress. There is often a concluding assessment or test module with questions designed to assess the overall levels of understanding of the material.

Where digitalized training is used, it often includes direct access to an instructor or mentor who can provide advice on the training material and analyse the results of tests. These are used to determine the level and pace of delivery of the training material to suit the individual trainee’s competence level.

TBT is a useful tool for decommissioning because it is suitable for the delivery of:

— Standard repetitive safety training modules that form the basis of worker training requirements, i.e. it can lead to more efficient use of instructor time.
— Refresher type courses.
— Training for personnel with differing levels of competence.
— Training for personnel who do not feel confident or comfortable with a classroom type situation, i.e. they can work at their own pace.

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[14] For example, CEA Marcoule, and the EdF Industrial Decommissioning Demonstrator testing and training facility to be operational in Chinon by 2022, France; the VR laboratories at the Institute for Energy Technology in Halden, Norway; and at Hochschule Mannheim, Germany.

— Assessments providing evidence of completion and competence.
— A means of direct application by the trainee of the principles addressed in the course that is not possible in a classroom environment (this can make it a more interesting and fulfilling experience).

An example of the use of digitalized training and e-Learning is provided in Appendix X.

In summary, TBT can complement other training methods, taking into account the following:

— The use of the latest technologies may foster motivation to participate in training;
— The need to regularly update the training material to integrate the latest operational experience;
— TBT may be used in conjunction with other training approaches as part of a balanced training programme.

## 7.4. TRAINING FACILITIES AND COLLABORATING CENTRES

The development of training facilities and collaborating centres[15] has become increasingly important due to the scope, extent and duration of training requirements for decommissioning. Typically, the facilities have included:

— Classroom facilities and equipment for lectures and training;
— 3-D models and digital platforms enabling VR;
— Realistic mock-ups to train people and test equipment.

Although training facilities and collaborating centres require significant investment, they represent good value for money, since they can be used before and during decommissioning activities throughout the decommissioning programme. Moreover, they enable organizations to mitigate specific risks through the testing and updating of scenarios and equipment.

### 7.4.1. Digital simulations

The use of 3-D models and physical mock-ups has increased worldwide. These offer:

— Relative ease of use;
— Usefulness in assessing the feasibility and relevance of the foreseen solutions;
— Relatively high return on investment in terms of budget and schedule;
— Attractiveness to younger generations;
— Relevance as a communication tool to various stakeholders.

More complex arrangements have been developed, such as simulators and mock-ups composed of a simulation platform combined with a nearby experimental hall. These arrangements enable organizations to do the following:

— Implement 3-D simulation to define and check the feasibility of the decommissioning scenarios;
— Train operators using VR on representative 3-D models in order to improve their ability, and to minimize the duration of operation and reduce dose;
— Train operators in more realistic conditions;
— Demonstrate to external stakeholders the relevance of techniques and skills deployed by the operators.

[15] Collaborating centres are used to promote the practical use of nuclear techniques worldwide and help the IAEA implement its own programme activities.

Simulation techniques used in support of decommissioning and training include the use of 3-D models generated using computer aided design (CAD) systems or 3-D modelling using gamma cameras, gamma spectrometers and laser scanners (on-site 3-D scanning) and associated software; interactive graphics robotic software; or other software. These models are used to simulate the relative spatial positions of all components in the location where an activity will be undertaken — those to be dismantled and also other components newly introduced for decommissioning purposes like cables, cranes and access ways.

In the training of personnel involved in decommissioning, the prime considerations are those associated with radiological and industrial safety. These are particularly important in terms of the requirement to minimize the potential exposure of workers to ionizing radiation and to minimize the spread of radioactive contamination. Generally, the ideal situation is for a typical dismantling or waste packaging operation to be completed according to the pre-planned course of action such that the work is completed successfully and the radiation doses minimized to the extent reasonably practicable, i.e. the ‘time at risk’ is controlled. Hence, it is extremely important that the working procedures are well understood and are practised by workers, wherever possible, before the work is undertaken.

One of the most powerful tools to develop working procedures and to train personnel is the use of a mock-up, especially for the training of personnel when dismantling highly radioactive equipment. Mock-ups are also used extensively in training centres to simulate the typical working environments found in the industry. An example of this is the simulation of standard dismantling/cutting operations in confined areas to permit training in the use of full plastic suits and the associated breathing apparatus arrangements. Further realism can be introduced through the use of invisible agents to simulate contamination. Training effectiveness is increased when the training can be matched to the simulation of actual facility conditions and by rehearsing operations in an inactive facility.

Examples of where the use of mock-ups can assist the training process include:

— Developing tooling and equipment such that potential problems with the use of tooling can be foreseen and its limitations are fully understood. This is particularly true where the use of remote disassembly equipment is being considered.
— Training in the use of personal protective equipment.
— Identifying any element of risk, and to test potential methods of mitigation.
— Developing disassembly techniques, and to train workers in the execution of such procedures.
— Establishing the duration of individual activities and, hence, to acquire an aid to controlling any dose considerations.
— Minimizing the spread of both radiological and chemical (e.g. asbestos) contamination, thereby reducing the risk to both workers and the environment.
— Establishing team working arrangements.
— Simulate faults or emergency situations and train in the associated recovery procedures (e.g. sudden collapse of worker, building evacuation).
— Defining, safely and securely, alternative decommissioning scenarios encountered in an unexpected situation at the real work site.
— Preparing and improving operator efficiency in maintenance and control procedures for remote handling equipment being used on-site and potentially contaminated (minimization of dose rate exposure, change of spare parts, practice of specific maintenance tools).
— Assisting in the planning of waste minimization (optimizing waste packaging, conditioning, control, lifting, handling and evacuation).

### 7.4.2. Use of 3-D models

Workplace reproduction can be provided by 3-D models at an affordable cost, making them a useful tool to assess and increase the compliance of scenarios, taking into account national regulations, local constraints and safety considerations. They can be used to help define and assess the feasibility of scenarios, not only from a technical perspective, but also taking into account the operator’s human ability.

Their flexibility facilitates testing of multiple scenarios, in order to identify optimal configurations. The level of detail and engineering capacity involved depends on the required or desired application. Point cloud models combined with photographs can be acquired very quickly and at low cost. The effort to convert the point cloud model into a full CAD model is significant and increases with the accuracy of the model required. For one-off decommissioning purposes and to understand the surroundings without entering the controlled areas, more simple models are sufficient. When physical modelling (radiation, movement of parts, structural calculations) are necessary, a CAD model with good accuracy is necessary. Forward planning will help to define the best approach and the level of detail for each part of the facility.

The widespread use of 3-D models has made them a common tool to optimize scenarios, to share issues and find solutions, with a resulting increase in worldwide experience. Hence, it is a great asset to demonstrate the relevance and efficiency of decommissioning scenarios with safety rules and requirements, in the process helping to improve them by taking into account international feedback. Their increasing accuracy also helps to save time during the licensing process and to obtain the required authorizations prior to operational work.

In addition, during decommissioning, the use of 3-D models is often coupled with an automatic recording of operations. While performing actual decommissioning, tasks can instantly be modelled and saved. In the case of an accident in the workplace, 3-D modelling allows for the investigation and analysis of causes that led to a failure or an injury. The outcomes can be used to identify unexpected risks, to safely find and test solutions, and improve scenarios and safety in the workplace. If necessary, the results of such 3-D investigations may lead to the optimization of existing scenarios or the need for complementary training for operators. As a result, 3-D modelling can help to develop new case studies, exercises and practice training, where personnel need to pay particular attention to certain operations.

Coupled with realistic mock-ups, 3-D modelling is particularly important when there are areas that were inaccessible during operation due to dose considerations and/or because they were sealed behind many layers of shielding. In such cases the only way to develop methods of disassembly is by the use of mock-ups constructed from original as-built drawings and data and taking into account the way they have been updated. Work in such areas also creates challenges regarding the prediction of radiation dose uptake for workers. In situations where it is not always possible to obtain radiation survey data, mock-ups are invaluable as they allow personnel to train and develop techniques and tooling such that the 'time at risk' for the workers is kept to an absolute minimum.

Appendix XI contains examples of two recent case studies illustrating real operational tasks resulting from the combination of 3-D modelling and simulators using representative mock-ups, both dedicated to decommissioning.

Software tools have an advantage over physical mock-ups, as they can be reused multiple times. They can also be easily and quickly updated, corresponding with the evolution of the decommissioning programme as work progresses.

### 7.4.3. Physical mock-ups

Mock-ups have proven to be cost effective in mitigating risks and improving safety in all industrial sectors. However, even if the traditional requirements of some industrial domains (chemistry, electronics, etc.) fit easily for small size mock-ups, this may not be true for decommissioning activities and their associated risks. Realistic, full scale physical mock-ups which comply with the dimensions and characteristics of the materials to be dismantled and the characteristics of the tools to be used are essential to demonstrate safety and facilitate global assessments.

The corresponding costs need to be considered as part of the overall budget for the decommissioning programme. However, experience gained through decommissioning programmes over the last decade has proven to be useful and it is likely to be relevant in the future.

The engineering phase related to the design of the planned mock-ups has to address two main considerations: representativeness and return on investment. For representativeness of mock-ups, the size and scale drive the relevance of the tests to be performed and training. Full scale models are often essential to demonstrate not only the feasibility of scenarios but also the suitability and performance of the tools being used.

The benefits of a well designed mock-up need to be assessed, taking into account the following:

— The potential for multiple uses of mock-ups in the case of a fleet;
— The sharing of expenses through collaborative initiatives;
— The use of the mock-ups not only as a training tool but also as a means of task mitigation throughout the delivery of the decommissioning programme;
— The possible use for other training purposes, such as operation and maintenance in nuclear power plants and fuel cycle where tasks are similar to those within decommissioning.

# 8. CONCLUSIONS

Decommissioning of nuclear facilities is a process involving a wide range of activities such as radiological characterization, decontamination, dismantling of facility systems and equipment, and the management of waste and other materials. Many organizational and management needs arise during the course of decommissioning projects. A significant amount of attention has been focused on the technical aspects of decommissioning and many IAEA publications have been issued to address the technical aspect. However, human resource considerations, particularly the training and qualification of decommissioning personnel, are becoming more important with the growing number of nuclear facilities of all types that are reaching or approaching the decommissioning phase.

A sufficient number of competent and motivated personnel have to be available during every phase of a nuclear facility’s life cycle, including decommissioning. One of the prerequisites for successfully carrying out a decommissioning project is the management vision and long term strategic plan for the use of human resources and for the assurance of the full competence of all personnel (the employees and contractors) involved at all stages in the decommissioning project.

The requisite resources and appropriate responsibilities at the executive level need to be allocated by the operating organization, decommissioning project managers and contracting organization to ensure the competence of all personnel (the employees and contractors) involved at all stages of the decommissioning project, and to preserve knowledge for future generations. It is necessary to define the management vision for the integrated management of human resources, including personnel training, at an early stage of a decommissioning project. An integrated process involving human resources strategic planning, recruitment, selection, training, qualification, motivation, performance evaluation, development and knowledge preservation needs to be established for the safe and efficient implementation of decommissioning activities.

Attention needs to be paid to the training of all categories of personnel, including management, professional staff and workers. Training of personnel, although an important means to achieve the required level of organizational and human performance, cannot alone ensure competence. Change management policies and practices also need to be implemented to achieve the requisite level of performance of the personnel involved in decommissioning. Training of personnel for a decommissioning project needs to be viewed as an integral part of the human resource management process. In order to perform the decommissioning project in a safe and efficient manner, the operating organization and decommissioning project managers have to develop and communicate to the staff the vision for the integrated management of human resources, including training of personnel.

# Appendix I

# TRANSITION FROM OPERATION TO DECOMMISSIONING FOR RINGHALS 1 AND 2 IN SWEDEN

## I.1. INTRODUCTION AND CONTEXT

Ringhals is the largest nuclear power station in Sweden. There are four reactors on-site, one boiling water reactor (BWR) and three pressurized water reactors (PWRs) with a total installed power of 3951 MW(e). The combined production capacity is approximately 30 TWh per year providing about 20% of total electricity demand in Sweden.

The Ringhals AB company is the operator and licence holder for the site. The owners of Ringhals AB are Vattenfall (70.4 %) and Sydkraft Nuclear Power (29.6 %), part of the Uniper group. Ringhals AB currently has about 1300 employees.

While Vattenfall is the majority owner of Ringhals, it has exclusive responsibility for decommissioning. In 2015, as majority owner, Vattenfall decided to close Ringhals Units 1 and 2 some five years ahead of schedule. Ringhals 2 closed at the end of 2019 and Ringhals 1 ceased operation towards the end of 2020. Ringhals 3 and 4 are planned to continue operation into the 2040s under current assumptions.

Ringhals 1 is a BWR built by Asea-Atom and has an installed electrical capacity of 881 MW(e). It began operating commercially in January 1976. Ringhals 2 is a PWR manufactured by Westinghouse with an installed electrical capacity of 865 MW(e) and began commercial operation in May 1975.

Vattenfall has made a strategic decision to separate continued operation of Ringhals 3 and 4 from the decommissioning of Units 1 and 2. Accordingly,

— Ringhals AB is the licensee and has responsibility for continued operation at the Ringhals site;
— Decommissioning of Ringhals Units 1 and 2 is to be managed by Vattenfall's nuclear decommissioning division (Business Unit Nuclear Decommissioning (BUND));
— Vattenfall will be responsible for decommissioning Ringhals Units 1 and 2 when both units are 'fuel free' in 2022.

## I.2. DIVISION OF RESPONSIBILITIES DURING THE POST-OPERATIONAL PERIOD (TRANSITION PHASE)

During the post-operational period (or transition phase) the following division of responsibilities will occur:

— Ringhals AB retains full responsibility for Ringhals Units 1 and 2 during the transition period;
— Vattenfall will continue to build up its decommissioning organization so that it is ready to take over responsibility for the decommissioning of Ringhals Units 1 and 2 at the assigned date, i.e. when both units are in a fuel free state.

Thus, Ringhals AB is responsible for undertaking all operations at the facilities during the transition period, including shut down, fuel removal, transfer, etc. Ringhals AB will execute these activities primarily with Ringhals personnel. There will also be a number of post-shutdown site management activities relating to the separation of Units 1 and 2 from the still operating Units 3 and 4. The division of responsibilities between Ringhals AB and Vattenfall is illustrated in Fig. 11.

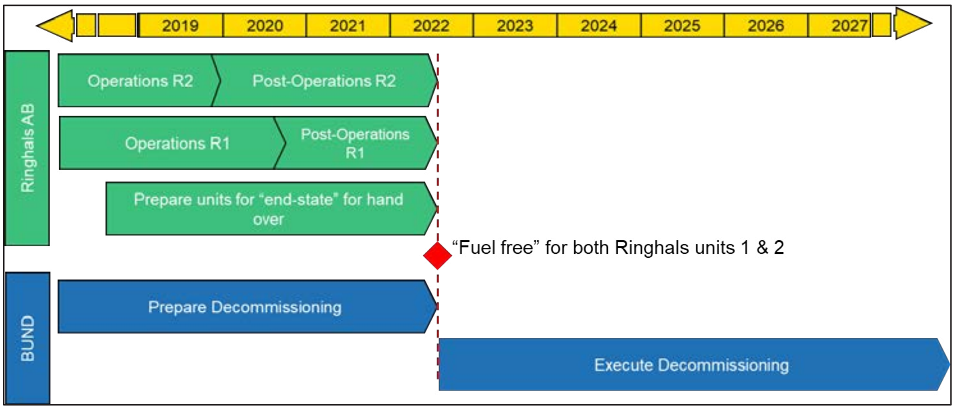


*FIG. 11. Division of responsibilities between Ringhals AB and Vattenfall (courtesy of Vattenfall).*

In addition, there will be a number of post-operational activities at Ringhals Units 1 and 2 aimed at preparing the units for decommissioning and delivering them at the agreed 'state at licence transfer'. These activities will be undertaken under the responsibility of Ringhals AB. The exact nature of what is to be done and by whom will be subject to a system of specific agreements between Vattenfall and Ringhals AB. This will include such diverse activities as the formal submission of certain documents to the regulatory authorities, primary system decontamination, and maintenance or shutdown of a range of ancillary systems. These agreements will also address the allocation of costs and personnel resources to these tasks, including from Ringhals AB, Vattenfall and from the supply chain.

The primary system decontamination, which is the first supplier agreement for preparatory activities related to the decommissioning of Ringhals Units 1 and 2, shows how these arrangements between Ringhals AB and Vattenfall work in practice. A contract for primary system decontamination of both units was signed with Westinghouse in 2019. Vattenfall's decommissioning programme has specified which work needs to be done, and Ringhals AB has handled the procurement and was the official signatory to the contract. Finally, there will be cooperation between Vattenfall and Ringhals AB concerning the retention of key competences and possible transfer of personnel from Ringhals to the Vattenfall decommissioning organization or projects.

## I.3. BUILDING COMPETENCE FOR THE DECOMMISSIONING ORGANIZATION

Vattenfall is building up its decommissioning organization for Ringhals Units 1 and 2, as part of the overall development of the BUND nuclear decommissioning division. Figure 12 provides a high level overview of the competences that will be required, and also offers a prognosis of the number of personnel required as full time equivalents, including for supplier roles. Note that in this figure, bars on the left side of the figure are competences required earlier in time, while those on the right are somewhat later.

## I.4. EVOLUTION OF THE ORGANIZATION

As suggested in the preceding section, the decommissioning organization will be built up over time. The aim is to have an organization that is ready and available at all times, which means that it needs to evolve and be adjusted in accordance with the programme's needs and schedule. Figure 13 provides a generic example of the evolution from a relatively simple organization, suitable for the planning and development phase, to a more complex, larger organization more suitable for executing decommissioning work (the organizational chart is intended as an example only.)

Table 5 lists some of the major characteristics associated with the organization and how they differ during the development and execution phases.

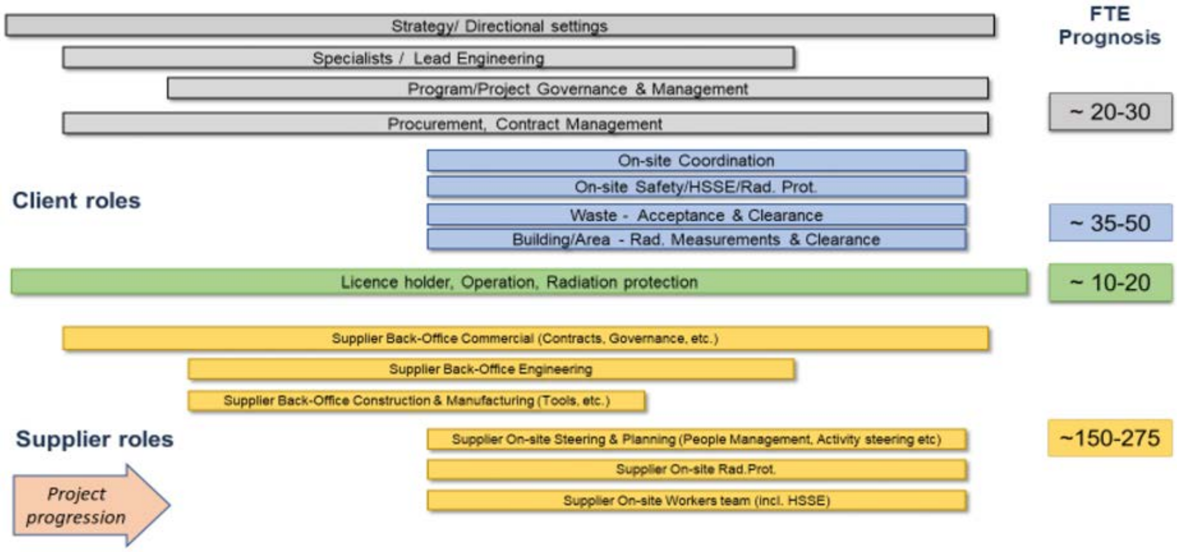


*FIG. 12. Overview of the competences that will be required. This Figure also includes a prognosis of the number of personnel required as full-time equivalents (FTEs), including for supplier roles (courtesy of Vattenfall).*

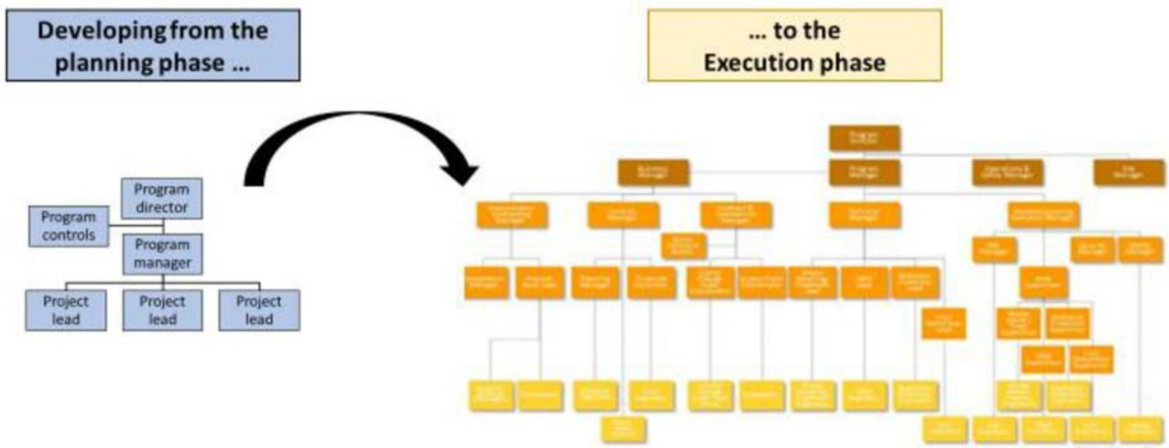


*FIG. 13. Generic example of the evolution from a relatively simple organization (suitable for the planning and development phase) to a more complex, larger organization (more suitable for executing decommissioning work) (courtesy of Vattenfall).*

TABLE 5. MAJOR CHARACTERISTICS ASSOCIATED WITH THE DECOMMISSIONING ORGANIZATION AT DIFFERENT LIFE CYCLE STAGES

| Characteristic | Development phase | Execution phase |
|---|---|---|
| Strategy | Formulation | Execution |
| Focus | Internal | External (commercial/supply chain) |
| Stakeholders | Few | Many |
| Interfaces | Few | Multiple |
| Minor cost | Minor | Major |
| Organization | Small, simple | Large, complex |
| Use of resources | Limited | Extensive |
| Risk mitigation | Simple | Complex, integrated |

# Appendix II

# HUMAN RESOURCE CHALLENGES AT THE IGNALINA NUCLEAR POWER PLANT IN LITHUANIA

## II.1. INTRODUCTION

The Ignalina Nuclear Power Plant (INPP) is situated in the rural northeast corner of Lithuania, bordering Latvia and Belarus. The authorities of the former USSR chose the site and initiated construction of the plant. Since INPP was intended to service the north-west region of the former USSR, one unit of the plant was able to produce 80% of Lithuania's electricity demand after the country's independence in 1990.

In the 1980s, up to 10 000 people worked on the construction site. The nearby town of Visaginas was purposely built to service INPP. During operation, Visaginas had over 30 000 inhabitants and, following plant closure, it still has some 20 000 inhabitants.

INPP operated two RBMK (high-power channel-type reactor)-1500 water cooled, graphite moderated, nuclear power reactors. Operation began in 1983 for the first unit and 1987 for the second unit. At that time, they were the most powerful nuclear energy reactors in the world.

Lithuania joined the European Union (EU) in 2004, agreeing to the irreversible shutdown of INPP as it was similar, although not identical to the Chernobyl type reactor. Thus, the first unit was shut down on 31 December 2004 and the second unit on 31 December 2009. This meant that INPP went from being an electricity producer to a decommissioning project while still maintaining the status of an organization operating a nuclear facility with the purpose of gradual and safe decommissioning of the plant.

In 2002, the Lithuanian Government decided to decommission the first unit through immediate dismantling. A number of factors were taken into consideration when opting for this decommissioning method, including social, economic, financial and environmental consequences, as well as the available knowledge base at the plant.

Immediate dismantling was also supported by INPP employees since this option promised a higher level and continued employment. This method has many advantages as the complicated work requiring special knowledge and skill would be performed by INPP staff members who already have extensive experience in operating the equipment. In fact, some of the employees were present during the construction and installation of the facility, which would ensure safe decommissioning.

This was a unique project since it is the first ever dismantling of an RBMK type reactor anywhere in the world. Taking into account the exceptional circumstances of INPP's closure, the EU is providing substantial financial assistance. It is expected that by 2038, the site will achieve 'brownfield' status.

## II.2. ORGANIZATIONAL CHANGE CHALLENGES

Preparatory activities for INPP's decommissioning started well before the closure of the first unit, although the staff only really perceived the change from operation to decommissioning the plant when the second (last) unit ceased operation. The transition from operation to decommissioning is better considered as a 'process', rather than a 'period' leading to substantial organizational changes with significant challenges in change management and employee engagement.

Experience with INPP has shown that immediately after the decision to decommission a nuclear power plant is taken, a determined, results driven senior management team needs to be established, and this team will ideally give its full commitment to ensuring the success of the transition from operation to decommissioning.

A Decommissioning Project Management Unit (DPMU), comprising both former operators and foreign experts from leading international nuclear industry companies, was set up in 2002 in preparation for decommissioning. These preparatory activities covered the elaboration of the final decommissioning plan, engineered waste inventory and radiological characterization, and also defined the radioactive waste processing facilities and transport routes.

The DPMU acquired an appropriate level of competence in project management and planning, but lacked adequate reactor technical expertise for decommissioning RBMK type reactors. During the five years of operation of the second unit, after the first unit closed, INPP managers as well as most plant operating staff were still focused on operation, and their commitment to supporting decommissioning had reservations.

The phased plant shutdown avoided a ‘clean break’ start to the transition period. However, after the second unit’s closure, as decommissioning became the key activity for the organization, there was friction between the DPMU and the rest of the plant operating staff (in particular, the former senior operators) as they worked under completely different corporate cultures. In such a situation, senior management was faced with the challenge of integrating the activities of two separate divisions (DPMU and the former Technical Department) for efficient decommissioning planning and implementation.

The DPMU was successfully relocated and merged into the renamed decommissioning department (the former Technical Department). Highly committed younger INPP managers were appointed to senior positions for operational activities and key decommissioning projects. The role, input and ‘ownership’ of the former operators in decommissioning was increased and the number of consultants reduced. Selective training, high employee engagement and improved internal communication and cooperation promoted initiative which is essential in pioneering decommissioning. The challenge of how to preserve the accumulated project management and planning competences that former operators lacked was solved by consolidating and optimizing teams.

As decommissioning is project and task based rather than the continuous process based activity of operation, and as actual decommissioning dismantling activities had now started, further transformation of the decommissioning organization including flattening of the organizational structure was appropriate. A division specifically for decommissioning project implementation was established in 2014 aiming to strengthen the plant’s project management functions. Subsequently, planning was separated from execution services in order to ensure stricter adherence to the decommissioning plan, dismantling activities were restructured in order to ensure more rational use of human and material resources, maintenance services were centralized and post-operation activities were restructured and finally management of radioactive waste activities is being restructured.

## II.3. LONG TERM STAFF PLANNING

As RBMK type reactors are designed for fully autonomous operation, more than 5 000 employees worked at INPP during its operation. After the closure of the first unit staffing levels were reduced to 3 900 employees with the constant gradual dismissal of a total of 1 100 employees in further years up to closure of the second unit, when another substantial downsizing of more than 1 000 staff took place. In 2010, when the operation of both units ended, about 2 000 employees worked at INPP. In 2020 slightly fewer than 2 000 employees are still working at INPP, although since 2010 about 700 employees have been replaced with a similar number of new people with different competences and skills.

The critical staffing challenges have been to: accommodate the major reductions in staff; employ the required number of qualified personnel at the right decommissioning phase; retain sufficient experienced staff; preserve and properly transfer knowledge; and agree on a basis for, and decide which, decommissioning activities are to be in-house or outsourced.

The solution INPP would highly recommend is: first, once the decision on decommissioning has been made and before decommissioning starts, carry out a thorough analysis to develop a long term strategy and plan for the employment of decommissioning staff, to which senior management are committed, to identify staffing needs for the entire decommissioning period, taking into account the different decommissioning phases and the variable number of staff and competences required as well as the level of outsourcing. Second, put in place a redundancy plan to avoid losing many of the older, qualified and experienced staff eligible for voluntary retirement.

Specific actions that can be taken include: listing key staff positions and backup for safety related positions; preparing a long term staffing programme for safety related positions; ten year plans for human resource provision activity and for ensuring competences for safety related positions; and an annual analysis of demand for young specialists coupled with a ‘Young Specialists Engagement Programme.’

## II.4. STAFF RETENTION STRATEGY

The government decision of immediate dismantling using operational staff was essential for social and technical reasons, primarily for nuclear safety. This caused two ongoing staff retention challenges: first, difficulties in retaining and redeploying skilled and experienced staff knowledgeable in the decommissioning activities that require physical strength and stamina. Second, the challenge of workforce ageing and retention due to retirements.

Since a number of new specific competences for decommissioning are needed once the plant enters into the decommissioning phase, the solution has been the development of an employee recruitment and retention strategy, and the required training and retraining for new decommissioning activities. Specific actions taken included: a results oriented remuneration system; knowledge accumulation and preservation system; employee performance evaluations; employment engagement surveys; retraining for decommissioning activities; recruitment of mostly young residents and training on-site; and outsourcing of complex assignments.

From 2010, the plant has retrained former operators for new duties related to decommissioning activities, and newly employed staff in decommissioning activities. Since 2015, INPP has assessed annually the demand for human resources according to the decommissioning plan and employee retirement age.

## II.5. DECOMMISSIONING COMPETENCE TRAINING

Decommissioning competence training forms a central part of ensuring that staff are adequately trained and skilled for their work. A central focus is on internal personal training at INPP since the plant and the specific skills required are unique: on-site/on the job training is the obvious solution.

The focus on internal personal training includes initial personnel training/retraining for job position and certification, continuous personnel training and certification to maintain and enhance skills, training by contractors when implementing decommissioning projects, mandatory regulated training for all employees, and specific training for potentially hazardous equipment or tasks. In addition, training to improve management skills (in particular, on project management, change management, risk management, process optimization) was arranged for management and leading specialists of the plant.

## II.6. CONCLUDING REMARKS

Early and thorough planning to address transition and change management challenges is likely to bring significant benefit. Decommissioning needs to be considered as the primary mission of the organization once permanent shutdown as occurred. To avoid the emergence of several separate fragmented divisions within the organization, the integration of operation and decommissioning knowledge needs to take place as soon as possible after shutdown.

An integrated structural transformation strategy is required well in advance, although its gradual implementation is advised at the appropriate time according to ongoing decommissioning needs. The continuous improvement of the organizational structure is recommended to establish a flattened structure for quicker decision making, lower costs and efficient communication. In addition, to ensure staff support and retention, given the constant changes and high employee engagement, proper internal communication is of paramount importance.

Initiative and training, adaptability and flexibility, living with change, a flat structural organization, constant senior management involvement, good governance and working with stakeholders characterize the essential qualities required of management and employees for a successful transition from plant operation to plant decommissioning.

## Appendix III

## WORKFORCE TRANSITION AT THE ROCKY FLATS PLANT, USA

### III.1. DRIVERS BEHIND THE DECOMMISSIONING DECISION

The Rocky Flats Plant was a nuclear production facility near Denver, Colorado. Operated from 1952 to 1992, the plant was under the control of the US Atomic Energy Commission, succeeded by the Department of Energy (DOE) in 1977. Weapons production was temporarily halted in 1989. In 1995, cleanup was estimated to take until 2060 at a cost of $36 billion. Kaiser-Hill was appointed to take charge of integrated site management in 1995 and subsequently negotiated a sole source cleanup contract in 2000.

There were over 800 structures to be decommissioned and demolished, over 21 t of weapons grade material to be dispositioned, over 1.3 million $m^3$ of waste, and 6 million gallons (22 712 470 L) of water to be treated. Cleanup was completed in October 2005 for $6.7 billion, resulting in savings of almost $30 billion and 55 years.

When closure began in 1995 there were just over 5 500 employees and subcontractor personnel on-site. The workforce was made up of 1 500 steel workers, 200 building trades workers and 250 security officers. The balance were subcontractor, management, professional and support staff. When closure was achieved in October 2005, there were only a handful of environmental restoration subcontractor personnel at the site, as shown in Fig. 14.

### III.2. THE PLAN

After performing a project risk assessment update in 2002, the project leadership determined that the greatest risk to closure was the workforce, which felt that it was working itself out of a job. Ambiguity and uncertainty are stressful and increases safety infractions, workplace violence, productivity lags, sabotage, and other risks. Additionally, retaining critical skills until no longer needed was an overall workforce risk.

To keep them focused on safe work, a path for the workforce after closure with a positive human outcome was critical. Under the direction of the Chief Financial Officer and Vice President of Administration, a team was formed to design a proactive Workforce Transition (WFT) programme. This programme was comprehensive, including a career transition centre, benefits plan revisions and

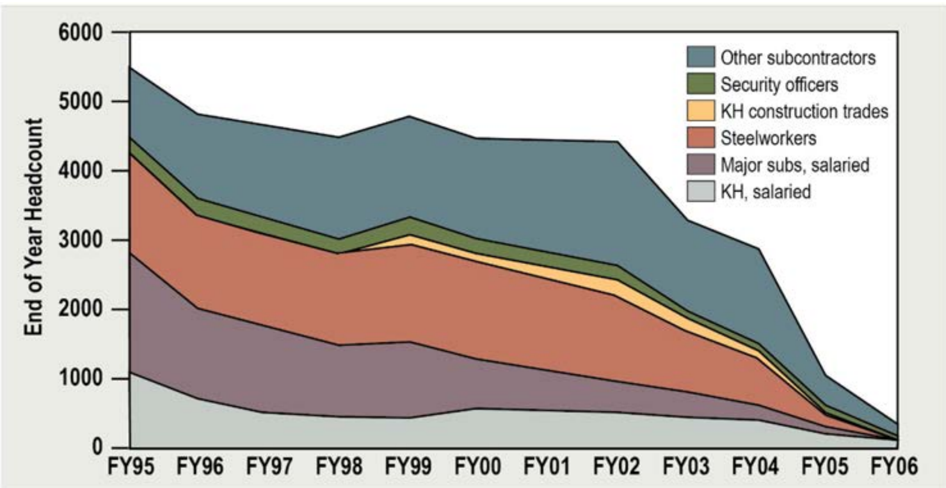


*FIG. 14. Rocky Flats annual head count trends (courtesy of LENS).*

assistance, and monetary retention incentives. The aim was to prepare the workforce for the future, employment in the nuclear industry or other industries, starting their own business, or retirement. WFT was run like a project with a budget, schedule and set of deliverables.

## III.3. CAREER TRANSITION CENTRE

The Career Transition Centre (CTC) was designed to provide employees with services to transition to a new professional career. Its proactive approach empowered employees to take control of their future and become confident that they were prepared for the job market. At least one visit to the CTC was required of all employees. The services offered included:

— Exclusive job fairs for Rocky Flats workers;
— DOE approval of modified benefit plans;
— Financial planning seminars for workers;
— A search engine that accessed job placement sites and open position postings locally, domestically and internationally in nuclear and other industries;
— Job skills analysis;
— Classes on resumé preparation, interviewing and salary negotiation;
— An entrepreneurial resource programme with up to $5 000 assistance for new business start-ups.

Additionally, the vacation accrual cap was removed which provided employees with more paid time to find employment after their assignment was completed. The project leadership offered on-line, classroom, and personal assistance to develop actions tailored to optimize outcomes for every site worker.

## III.4. SITE WIDE PROACTIVE APPROACH

A key element in the proactive approach to workforce transition was ensuring that every employee attended at least one session at the CTC. Many employees were reluctant to visualize what their professional future would be like. Some employees chose to not make their first (mandatory) appointment at the CTC. Their supervisor followed up to ensure that their next appointment was made and that they attended that appointment. The results were very positive; employees who were reluctant to go to the CTC discovered a place where they could acknowledge their skills and capabilities and receive training in multiple areas to prepare them for the future. Their future was in their control. This significantly reduced employee stress over closing the site and gave them confidence in their ability to find employment after Rocky Flats.

The WFT programme held job fairs exclusively for Rocky Flats employees. The Chief Financial Officer and Vice President of Administration arranged meetings with companies interested in relocation to the Denver area in which the highly skilled workforce was described and the companies were invited to participate in job fairs at Rocky Flats. Companies ranged from Fortune 500 to medium/small companies from all industries, both domestic and global. The job fairs were successful — many employees got interviews and received job offers during the job fairs.

To incentivize the retiring workforce, the DOE gave approval to modify benefit plans by reducing early retirement reductions, eliminating social security offset, adding a lump sum option for salaried employees, and allowing early reduced retirement for qualified employees. Financial planning seminars were provided by professionals for interested employees.

Monetary retention incentives included a: compensation plan for salaried and hourly employees to encourage them to safely work towards early site closure; completion/retention rewards to reduce turnover risks; contributory retirement plan improvements; spot cash incentive awards; and tuition reimbursement qualification relaxation. To help employees find jobs following project completion, the DOE arranged for their employees to take advantage of the services of the CTC.

## III.5. EMPLOYEE COMMUNICATIONS

Very early in the closure programme, the decision was made to radically increase the communications to the workforce and to personalize transition information down to the individual employee level. Each employee was empowered and aided in the development of a ‘personal transition plan’.

One crucial decision was to offer early notification of the duration of expected positions and target termination dates for each employee. Rather than wait to give a few weeks or a few months of notice of job termination, the project leadership chose to give every employee as much time as possible to ensure the success of their personal transition plan. In many cases, this notice was several years in advance. Early notification substantially reduced worker anxiety and increased the retention of critical skills.

Early in the closure programme, all supervisors and managers were given specialized training in the benefits available to employees and in how to interact with employees to reduce job related stress and to identify the transition needs of employees. Training and participation in transition activities was mandatory since the successful transition of the workforce was of the highest priority. Effective and purposeful interactions with all employees was key to a safe work environment and the early closure of the site.

## III.6. ECONOMIC DEVELOPMENT

An estimate suggested that closing Rocky Flats would have a negative impact of almost $2 billion on the local and state economies. Historically, workforce spending generated ~7 000 regional jobs (determined by the Governor’s Office of Economic Development). Therefore, an important element of the WFT was to assist workers in finding jobs in the local community. A proactive approach working with city, county and state economic development organizations attracted new companies to the state and surrounding communities, leading to new job opportunities for the workforce, stabilization of the tax base for the communities and state, and maintenance of jobs. To achieve this outcome, the organization carried out the following:

— Informed economic development organizations of the capabilities of the Rocky Flats workforce.
— Met with over 120 local and global businesses, informing them about the capabilities of the Rocky Flats employees.
— Met with companies considering opening their business in the area and described the capabilities of the workforce.
— Conducted job fairs specifically for the Rocky Flats workforce; invited a broad base of employers (nuclear, non-nuclear, large, medium, and small) to participate and learn at first hand the capabilities of the workforce.
— Met with State and Federal Congressional delegations to describe Rocky’s WFT. They chose to support implementation of the aggressive placement programme.

## III.7. RESULTS

Rocky Flats closed 15 months earlier than the closure contract stipulated with a safety record that set the standard for the DOE closure sites, as shown in Fig. 15, along with results for the closure workforce.

Through this proactive programme, employees were able to take control of their future with training, tools, techniques, and — above all — confidence in their ability to find employment. This approach is applicable for companies that are downsizing, moving, or closing irrespective of the type of industry.

Techniques used by Kaiser-Hill to perform the cleanup have been adopted throughout the industry and their WFT approach and plan have been used as the standard in DOE-managed programmes. Treating employees with respect and dignity translated into a safe and successful accelerated closure.

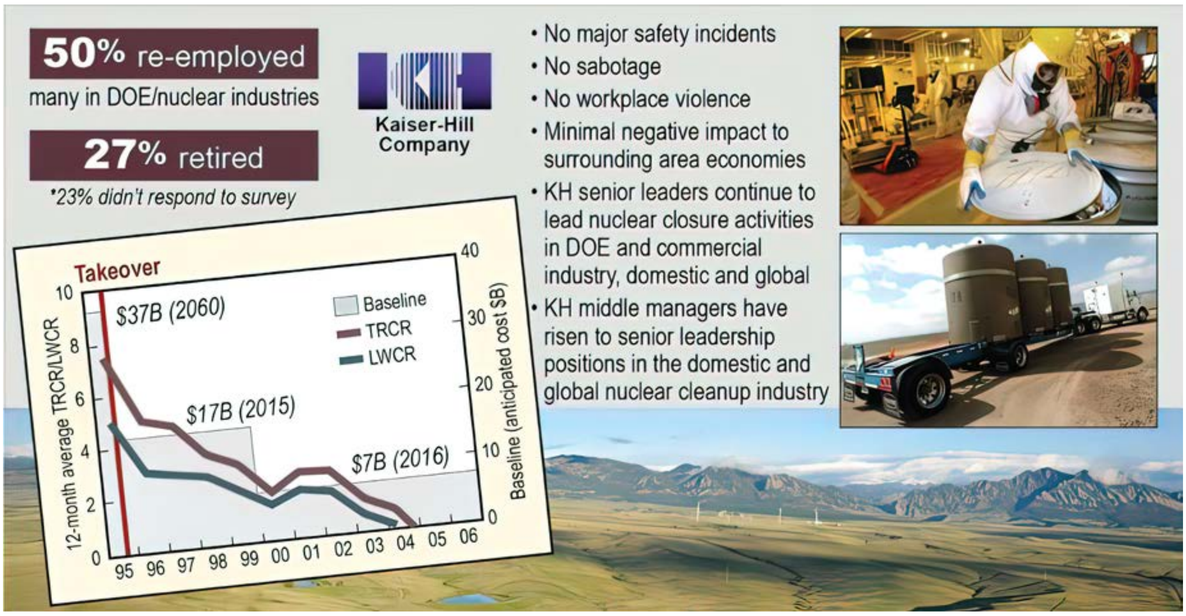


FIG. 15. Safety statistics and workforce metrics (courtesy of LENS).

# Appendix IV

# KNOWLEDGE AND EXPERIENCE TRANSFER FOR NUCLEAR POWER PLANT DECOMMISSIONING IN ARMENIA

## IV.1. INTRODUCTION

The Armenian Nuclear Power Plant (ANPP) consists of two water cooled, water moderated power reactor (WWER)-440/270 units, a Soviet type reactor that is a modified version of the WWER-440/230 for special seismic conditions. Unit 1 began commercial operation in 1976 and Unit 2 in 1980. Both units were shut down shortly after the 1988 Spitak earthquake. Unit 1 is in long term shutdown mode. Recommissioning work on Unit 2 was performed from 1993 to 1995, and Unit 2 restarted operation in November 1995.

One key aspect of the decommissioning planning is the transfer of know-how and experience as developed in European Union Member States regarding decommissioning of nuclear facilities to ANPP for further detailing, licensing and decommissioning work at the plant.

## IV.2. DECOMMISSIONING PLANNING FOR ANPP

### IV.2.1. Developing the decommissioning strategy and plan

The strategy for ANPP decommissioning was developed in the framework of the European Union's Technical Assistance to the Commonwealth of Independent States (TACIS) programme in 2006 and adopted by the Government of Armenia in November 2007. The selection process was based on IAEA recommendations on selection of a decommissioning strategy [34, 35], taking into account local conditions.

In view of Unit 2's life extension, the strategy document will be revised accordingly. The revised strategy document will include the following:

— Final shutdown is expected in 2026 due to Unit 2's life extension;
— The post-operation period needs to be prolonged as fuel of higher enrichment is now used (the estimated cooling time before transfer from pools to a dry storage facility is 10–12 years) if no other solution is found.

Most of these activities are implemented or are in progress within the European Union's On-site Assistance Programme and the Instrument for Nuclear Safety Cooperation Action Programme 2009.

### IV.2.2. European Union cooperation in developing decommissioning planning

Extensive support was provided to Armenia on general decommissioning activities at ANPP through the EU's TACIS programme on the basis of national regulations, best practices in EU Member States and compliance with internationally agreed guidelines, standards and regulation. Assistance was also provided to implement pilot decommissioning activities for selected ANPP systems. The specific aims of the project were:

— Knowledge transfer in document development (design, safety related and administrative planning documents);

— Transfer of experience (training in decommissioning technologies, procedures based on SAT, lessons learned, etc.)

One of the key aspects of this project is the transfer to ANPP of know-how and experience in the decommissioning of nuclear facilities acquired in EU Member States. The aim is to ensure the efficient and safe decommissioning of the ANPP site. The project results will create the basis for the implementation of all further activities at ANPP, developing its decommissioning concept and selected licensing documents, and starting pilot implementation of the concept and approach for selected systems in Unit 1.

To develop local Armenian capabilities and to ensure sustainability in the area of decommissioning, local company/experts and ANPP personnel were involved in the implementation of project activities. Involvement in the project will help to develop local expertise for future decommissioning activities at ANPP.

### IV.2.3. Specific objectives

— Use a systematic approach to develop the complex decommissioning concept for the ANPP. This will facilitate planning, organizing and executing all decommissioning activities in a logical and systematic manner, including preparation of the detailed technical baseline documents for the decommissioning of all SSCs at the ANPP based on the approved Decommissioning Strategy and Initial Decommissioning Plan.
— The concept includes a high and intermediate level description of the major processes to be implemented repeatedly for implementation for decommissioning, along with related activities: the process map, i.e. a description of the general approach and the conceptual ideas/logic behind these processes; the process model, i.e. further development of detailed planning documents.
— Develop specific licensing documents for decommissioning activities at ANPP, such as the: safety analysis report and environmental impact assessment report (for post-operation, safe enclosure preparation and safe enclosure stages of ANPP decommissioning).
— Develop a decommissioning waste management programme and define tools for the planned decommissioning operations, including estimates of waste types, categories and physical/ radiological characteristics based on nuclear power plant decommissioning experience. Review Armenian criteria for release from regulatory control against similar (EU) criteria. Develop technical specifications for decommissioning equipment, packaging and free release/clearance monitoring equipment.
— Develop a decommissioning information management system (DISDB), which includes a comprehensive database for decommissioning.

## IV.3. DECOMMISSIONING INFORMATION MANAGEMENT SYSTEM

DISDB is a modular system (Fig. 16) designed to collect and use all plant data/documentation relevant to decommissioning work (e.g. planning, preparation, radiological characterization, plant inventory, radiological condition, history, fragmentation, packages, free release, etc.). The scope of work includes the following:

— Designing an appropriate information system/model for decommissioning purposes. The design includes entity relationship, data flow and functional hierarchy diagrams, as well as other design models, methods or tools necessary for ANPP's decommissioning.
— Developing a database for ANPP decommissioning.
— Providing training in the use of the installed software and database population.
— Providing detailed user manuals for individual modules.

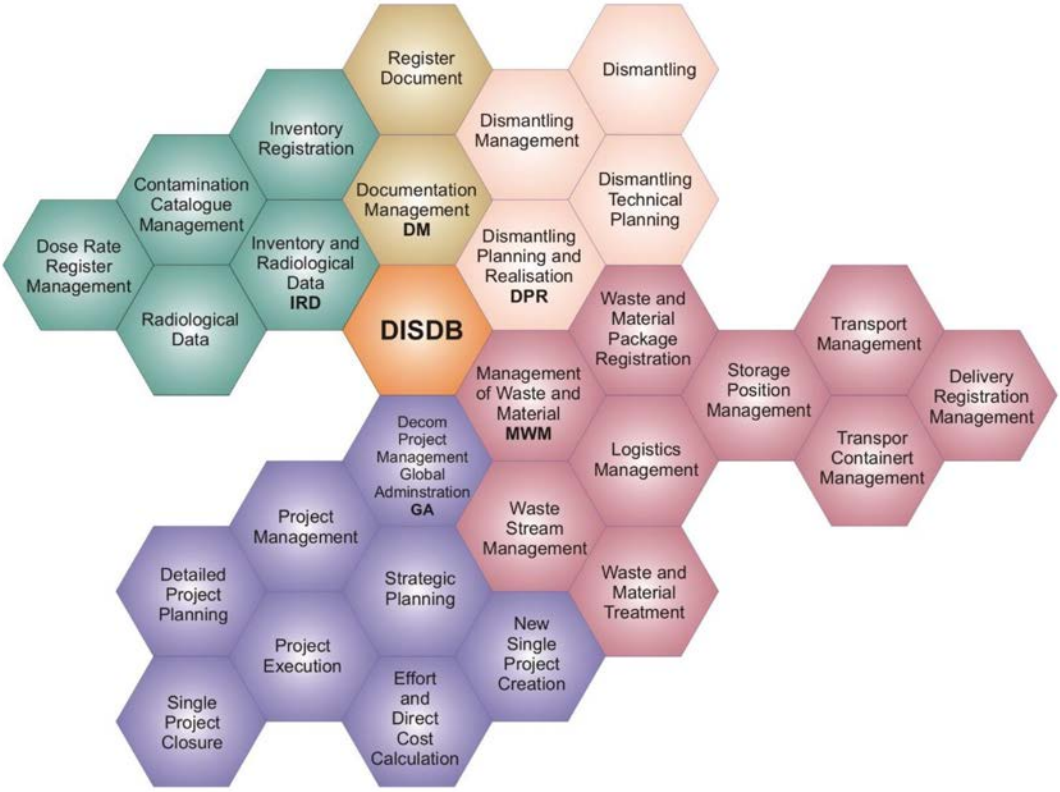


*FIG. 16. DISDB structure (courtesy of Armenian Nuclear Power Plant).*

## IV.4. CONCLUSION

This initiative provided valuable input into the development of the ANPP organizational structure and helped ANPP specify needs in training and retraining of personnel taking into account existing level of knowledge and skills applicable to different stages of future decommissioning activities.

## Appendix V

## CASE STUDY ON RETAINING KNOWLEDGE FROM THE IMPLEMENTATION OF DECOMMISSIONING PROJECTS IN FRANCE

Électricité de France (EdF) is responsible for the decommissioning of nine permanently shutdown reactors whose design is used a range nuclear technologies (graphite moderated, heavy water moderated, fast breeder and PWRs). The associated decommissioning programme is being implemented as quickly as practicable.

Taking into account international benchmarks, its own operating experience and lessons learned, EdF identified criteria which had the potential to help it ‘face the unexpected’ while decommissioning, including:

- Uncertainty regarding the quality of physical and radiological inventory (technical difficulties linked to the lack of inventory, lack of knowledge of the history, no access, sampling, etc.).
- Uncertainty regarding the availability of the waste route (strategy implementation needed to be revised due to the unavailability of a disposal route, for instance, with a resulting large impact on programme costs).
- Occurrence of unexpected events, including remaining contaminated areas or spots of contamination.

To reduce the risk of facing the unexpected, EdF developed a programme called DOCADEC to secure all useful data needed to perform the decommissioning. DOCADEC has been implemented for the first generation programme but was developed mainly to prepare for the decommissioning of reactors which are still under operation. Its objective is to enable the following:

- Use of the technical knowledge of first generation power plant operators.
- Use of international practices from other licensees having a similar strategy (e.g. Germany, Japan, Spain, Sweden and USA).
- Application of lessons learned from previous experience.
- Build in nuclear power plant operation, new designs and future decommissioning operations.
- Improve discussions with the regulator by mastering past experience through a sound process of knowledge management.
- Provide answers to the regulator’s safety requirements.
- Ensure the financial responsibility and liability of nuclear site decommissioning.
- Improve knowledge of the specific characteristics and history of the plants in operation in the nuclear fleet, taking account of the homogeneity of their design, to better prepare for their decommissioning.
- Manage, secure and share knowledge and define the best way to preserve it.
- Ensure the efficiency of future decommissioning projects and continuous improvement of their technical and financial aspects.

The objective of DOCADEC is to acquire information for decommissioning and to preserve all design and operating data on:

- Dismantling;
- Decommissioning techniques, scenarios and tools;
- Cost base;
- Requirements of the safety authority.

DOCADEC is therefore a series of actions to:

- Establish the initial required (regulatory and operating) documentation for decommissioning with regard to local safety rules and adopted strategy;
- Gather all updates and changes to the documentation;
- Establish the accurate current state of the plants (initial design, modifications, evolution, physical inventory, sampling, characterization and radiochemical inventories) which will facilitate the assessment of the amount, nature and type of waste generated by decommissioning.

This programme is structured according to categories and items, each designed to store documents that facilitate accurate definition of the current state of the nuclear power plant, as described in Table 6.

Figure 17 provides an example of DOCADEC's main knowledge goals with regard to characterization and inventory items.

DOCADEC is not considered a one-off project but as a continuous activity, in the case of any future nuclear power plants, to:

- Ensure the holistic collection and conservation of essential data during the design, construction and operating phases of the plant;
- Preserve all the design construction and operating data of interest for future/new nuclear power plant decommissioning and dismantling (40–60 years later).

In the case of already operating or shutdown nuclear power plants, before decommissioning:

- Establish accurate radioactive inventories of the overall structures;
- Obtain geometrical and state (corrosion, distortion) data before performing the preparatory work of dismantling, check the waste route availabilities and get on time, waste disposal agreement.

Two complementary methods are used in DOCADEC. First is data analysis, including historical data such as interviews with former operators, and data correlation through samples analysis. Second, there is in situ inspection, including the sampling of radioactive structures, e.g. nuclear circuits, buildings, materials, land and within the reactor vessel (graphite, concrete, steel, etc.). A visual examination is also possible, including the use of robots or personnel to directly view the main components, take pictures, and conduct radiological cartography and dimensional measurements. Once the knowledge is acquired with a good level of confidence, it is recorded and preserved in a sustainable way through DOCADEC through different means depending on various parameters (context, future use of the site, etc.).

TABLE 6. ITEMS AND CATEGORIES IN DOCADEC

| Category | No. of items | Examples |
|---|---|---|
| Frame of reference | 7 | General operating rules<br>Safety case<br>Legal authorization, regulatory documents<br>Reports |
| History | 22 | Annual reports<br>Safety quality<br>Waste zoning<br>Technical reports |
| Description | 31 | Design documents<br>Ground plan<br>Drawings<br>Equipment<br>Materials |


*FIG. 17. Example of DOCADEC's main knowledge goals with regard to characterization and inventory items (courtesy of EdF).*

## Appendix VI

## EVOLUTION OF TRAINING EMPHASIS FROM FACILITY OPERATION TO DECOMMISSIONING

The operation of nuclear facilities and their subsequent decommissioning place significantly different challenges on the managers and workforce present at those facilities [18]. As well as addressing the requirement to ensure that personnel are technically competent to undertake the tasks assigned to them, training activities also need to address requirements relating to safety culture, which are significantly different between facilities in operation and those under decommissioning. Table 7 provides an analysis of the differences in training emphasis for these two situations.

TABLE 7. ANALYSIS OF DIFFERENCES IN TRAINING EMPHASIS BETWEEN NUCLEAR FACILITIES IN OPERATION AND UNDER DECOMMISSIONING[a]

| Operation | Decommissioning | Change in training emphasis | Example |
|---|---|---|---|
| Reliance on permanent structures for operational life of the facility. | Use of temporary structures to assist dismantling. | More focus on individual tasks and achieving ‘fitness for purpose’. | (1) Requirement to work in custom made containment structures.<br><br>(2) Permanent fire protection systems, containment and confinement systems during operation; temporary fire protection measures (i.e. fire watches, hoses); breached confinement/containment systems during decommissioning requiring pre-planning for individual tasks. |
| Safety management based on operational nuclear facility requirements. | Safety management systems based on specific nuclear work site requirements and associated risk analysis to be adjusted as work progresses. | More focus on adapting/ adjusting timely workshop task requirements and their interrelationships as work progresses. | (1) Hazard assessments based on several tasks being completed simultaneously by different groups of workers.<br><br>(2) Established system of validated normal and emergency operating procedures during operation; one-of-a-kind dismantling activities during decommissioning, with minimal possibility to fully validate procedures unless a representative mock-up/training facility is available as scheduled in the global decommissioning programme. |
| Production oriented management objectives. | Project completion oriented management objectives. | More focus on project management skills and ‘completion culture’. | Working to an agreed project completion cost and programme. |

TABLE 7. ANALYSIS OF DIFFERENCES IN TRAINING EMPHASIS BETWEEN NUCLEAR FACILITIES IN OPERATION AND UNDER DECOMMISSIONING[a] (cont.)

| Operation | Decommissioning | Change in training emphasis | Example |
|---|---|---|---|
| Permanent employment with routine objectives. | Visible end of employment, with uncertainty of retention. | More focus on human factor and safety management issues. | (1) Requirement to retain motivation and enthusiasm without sacrificing safety culture.<br><br>(2) Long term employment (i.e. 40 years during operation); short term employment leads to large turnover of personnel during decommissioning. |
| Stable resource pool of known ability to match relatively stable/predictable requirements. | Much smaller stable resource pool topped up as/when required using highly mobile contractors. | More focus on ensuring and maintaining a reliable supply of fully competent workers, and contractor management. | (1) Permanent useful skills to be identified and kept prior to decommissioning.<br><br>(2) Potential use of contractors; development of common transferable standards of competence. |
| Established and developed operating regulations. | Change of regulatory focus. | More focus on change management issues and multiple simultaneous tasks. | Long history of regulations and specificity for operations. |
| Predominant radiological risk. | Changed nature of radiological risk, industrial risk more significant. | More focus on the correct blend of training to cater for both industrial and radiological risk issues. | (1) Training of technicians in radiological/disassembly skills to create a multi-skilled decommissioning operative.<br><br>(2) Stable design and stable maintenance activities during operation; cutting, rigging, scaffolding, fire safety risks during decommissioning. |
| Focus on functioning of systems. | Focus on safety functioning systems in a permanent evolving configuration. Management of materials and radiological inventory in a moving context. | More focus on waste categorization and minimization issues. | (1) Training in waste segregation, waste management and environmental assessments.<br><br>(2) Routine preventive and corrective maintenance, and waste generation during operations; large amounts of liquid and solid waste to remove and handle during decommissioning. |
| Repetitive activities. | Likely one-off activities (except in the case of serial effects in a fleet decommissioning programme). | More focus on short term activities. | Use of custom built mock-ups. Routine operations controlled by procedures during operating phase; unique one of a kind tasks with new procedures each time during decommissioning (except in the case of serial effects in a fleet). |

TABLE 7. ANALYSIS OF DIFFERENCES IN TRAINING EMPHASIS BETWEEN NUCLEAR FACILITIES IN OPERATION AND UNDER DECOMMISSIONING[a] (cont.)

| Operation | Decommissioning | Change in training emphasis | Example |
|---|---|---|---|
| Familiar with working environment. | Need to take into account a regularly evolving environment as work progresses. | More focus on pre-job preparations, job hazard analysis and risk assessment. | (1) Interactive approach to safety management, with emphasis on coping with 'worst case' scenarios.<br><br>(2) Stable design and confinement/ containment systems during operations; system integrity breached during decommissioning requiring hazard analysis for each activity. |
| Exposure to high radiation and contamination levels unlikely, or for a short time. | Exposure to high radiation and contamination levels unlikely, or for a short time. | More focus on dose management issues. More frequent use of remote handling tools imposing special training and abilities. | (1) Routine long term use of PVC airline suits. Requirement for radiological monitoring/assessment skills.<br><br>(2) Operations during decommissioning are similar to maintenance (change of steam generator, cutting of big components or parts of circuits). To be replaced during operation phase but not replaced during decommissioning. Risks induced by space constraints and dose exposure may be higher during the operation phase than decommissioning. Nevertheless, more emphasis is on dose assessment to optimize costs and minimize delays. |
| Routine levels of materials shipped off-site. | Much larger amounts of materials shipped off-site, but following routine procedures. | Focus on hazardous material handling, and materials management skills, as well as induced waste (ashes, gas releases) due to more frequent thermal cutting operations, for instance | (1) Environmental assessment training. Transfer systems for radioactive material.<br><br>(2) Low level waste shipped during operation; bigger volume of low level waste and conventional materials shipped off-site during decommissioning. Contaminated residues (i.e. Pu in glove boxes and ventilation systems), large quantities of liquid waste from system flushing, etc., will ideally be taken away regularly during operation phase to lower the dose exposure and ease decommissioning when decided. At the end, no more high level waste to be processed, handled and shipped during the two phases. |

TABLE 7. ANALYSIS OF DIFFERENCES IN TRAINING EMPHASIS BETWEEN NUCLEAR FACILITIES IN OPERATION AND UNDER DECOMMISSIONING[a] (cont.)

| Operation | Decommissioning | Change in training emphasis | Example |
|---|---|---|---|
| Relatively stable isotopic composition. | Relatively stable isotopic composition as the source term remains the same. As soon as defueling is under way, 99% of the radioactivity disappears from the site. Operation becomes easier to manage as natural decay allows the lowering of dose rate and more space becomes available as decommissioning work progresses and waste is removed. | More focus on non-routine radiological issues, waste management, control, packaging and shipment. | Increased scope, content and intensity of waste management, handling, control operations, radiological safety training and environmental impact, i.e. encouraging recycling and reuse of materials, preservation of disposal capacities as rare resources. |
| Training programmes designed for 30–40 years of use. | Training programmes designed for a few years of use.<br>Training programmes using a realistic mock-up to define alternatives to the planned scenario in the event of an incident or occurrence of an unexpected situation. | Emphasis changed to radiological and industrial safety training.<br>Ability to use remote handling tools, 3-D modelling. | Tailored and personalized training programmes during decommissioning. Need to encourage the implementation of nearby realistic/representative experimental training facilities to: check decommissioning scenarios; assess induced waste volumes; and train operators to solve unexpected situations. |
| Initial training programmes that are months to years long with extensive continuing training. | Initial training programmes that are a few days to weeks long with continuing training, as needed. | Emphasis on one-time, unique tasks versus routine operations (except in the case of serial fleet effect). | Development of refresher training tailored to suit individual tasks/ durations during decommissioning. Need to take advantage of nearby modular design training facilities to implement adjustable representative configurations as the work progresses and evolves. |

[a] This table is derived in part from Ref. [4].

# Appendix VII

# CASE STUDY ON MOVING FROM OPERATIONAL TO DECOMMISSIONING TRAINING IN FRANCE

## VII.1. INTRODUCTION

The Orano Group, comprising six business units (Fig. 18) and 16 000, employees, has been operating nuclear fuel cycle facilities for over 40 years.

The group’s main sites of La Hague in western France and Melox in the south-east are part of the recycling business unit. They provide fuel reprocessing and mixed oxide (MOX) fuel fabrication services to nuclear utilities. Combined, they represent nearly 4 000 employees and employ more than 2 500 contractors on a permanent basis.

## VII.2. TRAINING IN ORANO

The nature of fuel cycle activities, which combine a high degree of technicality, the manipulation of spent nuclear material, and the imperative of maintaining the highest safety standards, requires constant development of the skills of both staff and contractors. The group as a whole provides a training catalogue of 3 200 courses and has a number of training centres in its main plants to provide hands-on training, as well as its own training institute. As an illustration, the La Hague site only has 600 courses and a training centre with scale 1 mock-up facilities. In 2018, there were 12 000 training sessions for a total of 150 000 hours of training delivered to 2 500 people.

## VII.3. DECOMMISSIONING IN ORANO

Dismantling, decommissioning and site remediation have been part of the group’s activities from the earliest stages due to the limited lifespan of mines and facilities. Mines were remediated from the 1970s on while dismantling operations began at the same time as the first reprocessing plants in both La Hague and Marcoule were being modified to receive and treat new types of spent nuclear fuel.

From 2000 on, the first reprocessing facilities had reached the end of their operational life, which led to the deployment of broad front decommissioning operations by the group. At the same time, a number of power reactors, mainly in the USA and Germany, also entered decommissioning.

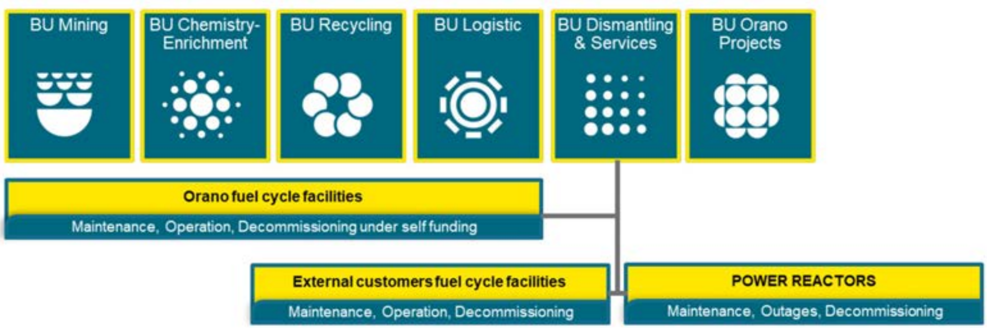


*FIG. 18. The Orano Group in 2019 (courtesy of Orano).*

As a consequence, the Orano Group decided to create a business unit dedicated solely to decommissioning and waste management. This led to the professionalization of decommissioning activities, which in turn led to the deployment of a decommissioning specific training initiative.

## VII.4. OPERATIONS TRAINING USED FOR DECOMMISSIONING

The operation of nuclear facilities requires a number of skills which in fact are directly applicable to decommissioning; indeed, for many years small dismantling operations were conducted by operations staff. Often, they were considered an extension of maintenance operations. This is true both for reactors and fuel cycle facilities.

In fuel cycle activities, where modifications or equipment replacement are significant, the comparison between operation and decommissioning is particularly relevant. As an illustration, the following operations activities and skills can be applied to decommissioning:

— Characterization;
— Inspection;
— Equipment decontamination;
— Equipment repair or replacement;
— Equipment replacement;
— Remote handling;
— Waste conditioning;
— Operational health physics;
— Nuclear safety analysis.

The associated skills which were part of the regular training of operations staff were thus readily available for early dismantling operations. This approach remained valid as long as dismantling remained a minor activity within operations, and its economic significance remained small compared with operational costs.

The available resources and skills permitted safe and efficient dismantling operations, but overall dismantling, waste arisings and economics were suboptimal. Consequently, as several Orano sites entered broad front decommissioning, it became necessary to deploy a systematic, professional approach to decommissioning and develop the associated skills.

## VII.5. DEVELOPMENT OF SAT FOR DECOMMISSIONING

In order to address the challenges of successfully managing the dismantling of large nuclear sites over decades of decommissioning, Orano deployed an approach which can be summarized below:

— Elaboration of a decommissioning plan;
— Definition of resource and skills needs;
— Analysis of existing resource base and skills;
— Definition of training requirements;
— Deployment of training programmes.

## VII.6. DEVELOPMENT OF A DECOMMISSIONING PLAN

The definition of a long term decommissioning plan and the associated time schedule is a necessary first step. It can be used to:

- Underpin the definition of skills needed over time;
- Communicate to stakeholders and employees in order to facilitate transition, training and re-skilling.

A corollary of the elaboration of the decommissioning plan is the necessary definition of a make/buy policy on the part of the owner/operator. On Orano sites, the elaboration of decommissioning plans was a regulatory requirement needed to substantiate the DECOM licence application. With respect to the make/buy approach, the Orano policy was to maximize the proportion of internal resources in high added value areas.

## VII.7. DEFINITION OF RESOURCE AND SKILLS NEEDS

Upon completion of the decommissioning plan, an organization was defined to implement the decommissioning programme, which in turn led to the identification of the resources and skills needed. The definition of resource needs involved both a job description (types of jobs and associated competences) and quantity (number of people needed in each job description).

Figure 19 illustrates the list of DECOM specific job descriptions that were specified by Orano based on the positions for which specific training is needed when engaging in decommissioning activities. Once the job descriptions or positions were defined, it was necessary to define for each of them the actual skills needed and degree of proficiency for each skill. To this end, Orano defined five main areas of skills corresponding to the key pillars of the activity:

- Quality, health and safety;
- Operation;
- Dismantling and decontamination;
- Project;
- Transverse skills.

For each area, a series of typical skills was identified which could potentially be relevant for any or all of the job descriptions listed. A total of 50 skills were thus defined (Fig. 19). The list below provides an example of skills under each of the main categories/areas:

- Quality, health and safety, including nuclear safety evaluation;
- Operation, including plant process knowledge;
- Dismantling and decontamination, including characterization;
- Project, including project cost management;
- Transverse skills, including communication.

Orano then defined three potential levels of proficiency for each skill. As an illustration, for the ‘project cost management’ skill, the three levels of proficiency were:

- *Basic:* Cost management; knowledge of the elements of the project cost breakdown structure.
- *Intermediate:* Ability to estimate costs using norms or evaluation methods; ability to evaluate the financial impact of risks.

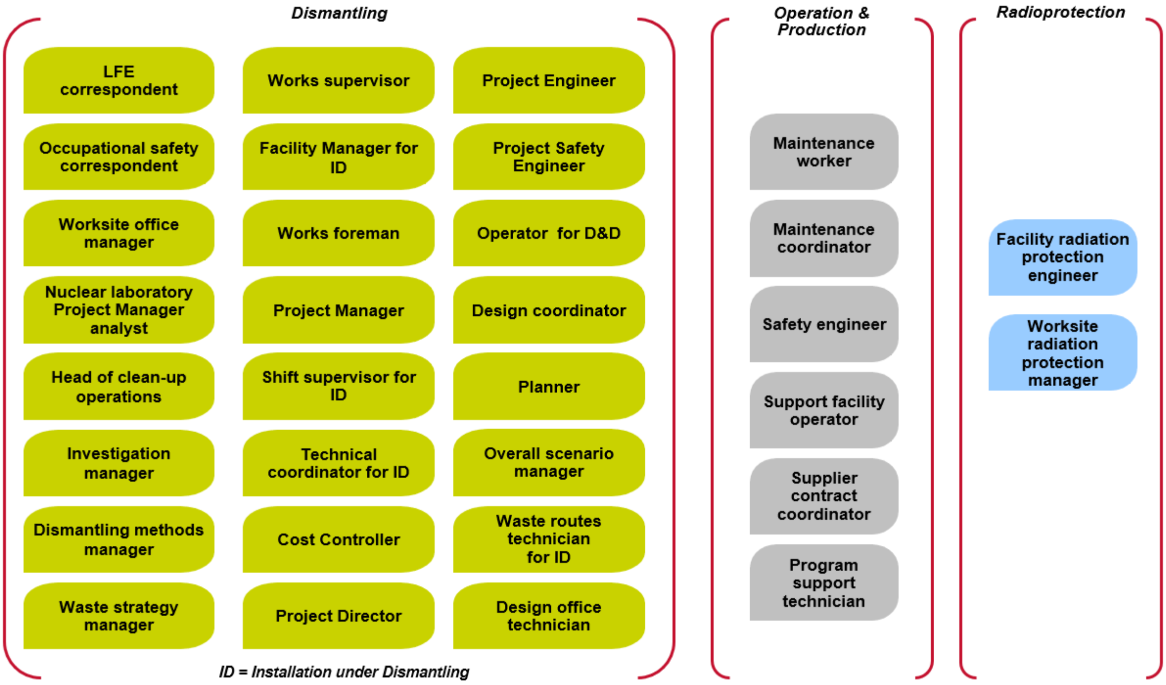


*FIG. 19. Orano list of DECOM specific job descriptions (courtesy of Orano).*

— *Senior:* Ability to use cost estimate tools; explain the different approaches and their applications; propose improvements to the methodologies; evaluate the potential financial impact of changes and propose mitigation measures.

Finally, for each job description, Orano selected the required skills in each major area, as well as the required level of proficiency for each skill. As an illustration:

— A project manager is required to have at least an intermediate level in cost management under the project area, but only a basic level in nuclear safety evaluation under quality health and safety.
— A maintenance operator needs only a basic level in cost management under the project area, but at least an intermediate level in nuclear safety evaluation under quality health and safety.

## VII.8. ANALYSIS OF RESOURCE BASE AND SKILLS

Upon starting broad front decommissioning operations, the different Orano sites had a population of skilled workers, technicians and engineers in the jobs associated with operations. It became necessary to evaluate this population and jobs portfolio against the population and job needs for the delivery of the decommissioning programme. This appraisal had to be conducted at three levels: quantitative, qualitative and over the duration of the programme.

In addition to the above exercise, an additional check was made to evaluate the difficulty associated with retraining from one job to another in technical terms, the idea being that there may be limitations in the possibility to retrain people of certain job categories into other job categories. Figure 20 provides an excerpt from the result of the evaluation, with an increasing level of challenge being indicated by the colour sequence green, yellow, orange and red. For example, it appeared not very challenging to retrain a health physicist to become a waste technician, while it would prove much more challenging to retrain a plant operator to become a waste technician.

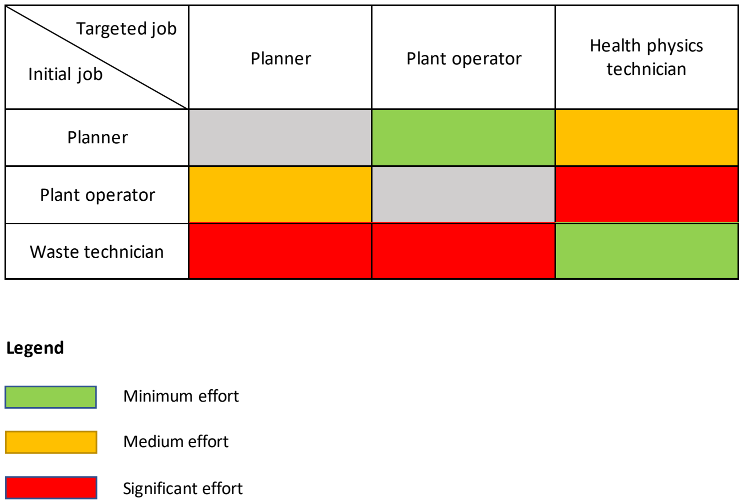


*FIG. 20. Job change difficulty matrix (courtesy of Orano).*

## VII.9. DEFINITION OF TRAINING REQUIREMENTS

The elements discussed so far include:

- Population and skills base;
- Population and skill requirements;
- DECOM specific job and skill description;
- Job change difficulty matrix.

The next steps were to: communicate the transition needs; conduct individual interviews with all concerned staff; collect aspirations; compare them with the needs; and subsequently define the training requirements for the different sites, when relevant. These stages, although simple to describe, were the most time and resource consuming of the entire exercise.

## VII.10. ROLL OUT OF THE TRAINING PROGRAMMES

Once the definition of training requirements was established, the last stage consisted of defining and rolling out the training programmes. In many areas, the programmes could be based on training courses already available for operations staff. In other areas it was necessary to adapt existing courses, or complement them with DECOM specific modules. Finally, in some areas it became necessary to develop specific training modules.

As an illustration of each situation:

- For the skill ‘plant process knowledge’, existing training programmes were available from operations;
- For the skill ‘nuclear safety evaluation’, some DECOM specific modules had to be added;
- For the skill ‘DECOM project management’, a specific training programme was developed.

Within the definition of training programmes, the notion of ‘mode of training’ was also defined. The training mode could be of several types: lectures, mentoring, practical cases, hands-on, or a combination of these elements.

# Appendix VIII

# EXAMPLES OF INTERNATIONAL INITIATIVES AND PROGRAMMES TO DEVELOP SKILLS IN NUCLEAR TRAINING AND DECOMMISSIONING

The Rosatom Technical Academy, in cooperation with the IAEA, has hosted a number of regional workshops and specialized trainings sessions in the field of decommissioning and remediation of territories. At present, Rosatom Tech has the status of an IAEA Collaborating Centre in the field of knowledge management and human resource development for nuclear energy and nuclear security.

In September 2011, a series of events devoted to decommissioning were held at the Rosatom Tech regional workshop on Developing and Delivering Training Programmes to Support Implementation of Complex Decommissioning Projects. Participants came from Azerbaijan, Hungary, Lithuania, Republic of Moldova, Romania, Slovakia, Tajikistan, Ukraine and Uzbekistan), and included those who were in charge of developing and delivering learning activities for personnel involved in the decommissioning projects. At the workshop, all participants attended a comprehensive course of lectures and presented their national training programmes. Experts from the Russian Federation and the United Kingdom were invited to conduct lectures.

The workshop trained participants in the fundamentals and the best practices relating to:

— Identifying the training and educational needs of ‘implementers’ for the different project life cycle stages, taking account of the main activities involved in decommissioning projects;
— Approaches to the development and delivery of training and educational services.

Since 2014, the IAEA and the Rosatom State Atomic Energy Corporation State Atomic Energy Corporation “Rosatom” have conducted regional training courses, at the Rosatom Technical Academy, for decision makers in the planning and implementation of environmental remediation at uranium legacy sites. The events were carried out as part of the implementation of the Commonwealth of Independent States Interstate Target Programme Reclamation of Territories of States Affected by Uranium Mining.

The objectives of the courses were as follows:

— Development of managerial and technical competences of target country staff in the planning, implementation and management of remediation programmes and projects;
— Create a platform for sharing experiences and best practices among the stakeholders.

From 2014 to 2019, 11 two week regional training courses on environmental remediation were held at the Rosatom Technical Academy for 150 specialists from Kazakhstan, Kyrgyzstan, Russian Federation, Tajikistan, Turkmenistan and Uzbekistan. The course topics covered the basics of the environmental remediation of uranium legacy sites, stakeholder engagement, project planning and management, regulatory aspects, and technologies of remediation. The result of these activities was the building of a pool of specialists capable of solving practical problems.

In 2017, representatives from ten IAEA Member States — Armenia, Bulgaria, Hungary, Kazakhstan, Republic of Moldova, Romania, Russian Federation, Serbia, Slovakia and Tajikistan — took part in a regional workshop entitled Transition and Management of Decommissioning on a Multi-Facility Site. The participants were representatives of national authorities, regulatory authorities and operators of nuclear installations, as well as representatives of State enterprises. It was organized by the IAEA and Rosatom Technical Academy in cooperation with the Government of the Russian Federation as part of an IAEA Technical Cooperation project entitled Enhancing Capacities in Member States for Management of Decommissioning Projects (RER9138).

The workshop was intended to provide a platform for discussion of aspects related to the transition of nuclear facilities from operation to decommissioning, and to the management of decommissioning when implemented at sites that have several nuclear facilities. The workshop included presentations on the following:

- International recommendations and national approaches;
- Experience and challenges related to the transition of facilities from operation to decommissioning and to aspects of decommissioning within multi-facility sites;
- Practical exercises on drafting transition plans;
- Identifying specific opportunities and challenges for the decommissioning of selected multi-facility nuclear sites.

Case studies were analysed to understand the experience and lessons learned from completed and ongoing decommissioning projects in different countries. Experts from the Moscow Federal State Unitary Enterprise “Radon”, Joint Stock Company (JSC) TENEX, JSC VNIINM *im*. A.A. Bochvara, JSC PDC UGR, NRC Kurchatov Institute and JSC SRC IPPE presented Russian experience in the decommissioning of research facilities.

Holding such events at the Rosatom Technical Academy helped to identify expert speakers and form the necessary basis for the preparation and conduct of specialized training in the field of decommissioning. It is also noted that the accumulated experience in the implementation of personnel training projects in the field of remediation of territories, an integral part of the decommissioning of nuclear facilities, supports the training of personnel involved in the decommissioning of various nuclear fuel cycle facilities.

## Appendix IX

## TRAINING COURSE ON MANAGING CHANGE FROM OPERATION TO DECOMMISSIONING

The French Alternative Energies and Atomic Energy Commission (CEA) is one of Europe's largest research bodies and is active in the fields of low carbon energies, information and health care technologies, defence and security. As a nuclear operator, it is responsible for dismantling its nuclear facilities at several sites in France and for managing the waste resulting from such activities. It is also a key player in research on techniques and technologies used in such dismantling operations.

Table 8 presents an overview of training courses delivered to personnel expected to participate in the decommissioning of the Eole and Minerve research reactors located at CEA's Cadarache site.

TABLE 8. EXAMPLE OF TRAINING COURSE CONTENT FOR LEADING CHANGE FROM OPERATION TO DECOMMISSIONING

| Session title | Pedagogical objectives per session (competences targeted) |
|---|---|
| 1. Introduction | • Knowledge of the facility, the players and reminder of the objectives.<br>• Evaluation of the individual constraints. |
| 2. Regulatory aspects | • Explain dismantling regulations.<br>• Explain waste management regulations.<br>• Explain cleanup regulations. |
| 3. Dismantling project management | • Describe the phases.<br>• Describe the players.<br>• Describe the distribution of tasks and the different possibilities.<br>• Describe the risks/opportunity analyses. |
| 4. Scenarios | • Explain the importance of input data.<br>• Describe the construction of a scenario.<br>• Explain the choice of the reference scenario. |
| 5. Feedback/lessons learned | • Define feedback/lessons learned.<br>• Explain their use in the different phases.<br>• Explain how they are to be enhanced. |
| 6. Inventories | • Describe the physical inventory.<br>• Describe the radiological inventory. |
| 7. Nuclear waste | • Describe the disposal organization acceptance criteria to approve files. |
| 8. Safety/security | • List the main risks encountered.<br>• Illustrate each of the possible risks with examples.<br>• Describe the risk factors. |
| 9. Work site monitoring and follow-up | • Describe the reasons for and the content of work site visits and meetings.<br>• Describe the transfer of information.<br>• Describe any project delays and how these are being addressed.<br>• Describe the nature of a work site interruption.<br>• Describe the schedule updating.<br>• Describe budget updating. |

# APPENDIX X

# CASE STUDY ON DIGITALIZED TRAINING AND E-LEARNING IN CANADA

## X.1. E-LEARNING

Many owners have developed significant training resources that support e-learning, or self-paced learning. Specifically, Ontario Power Generation (OPG) has developed significant e-based learning programmes in conjunction with its industry partners in North America and focused efforts to satisfy two objectives. First, to streamline and simplify the training delivery model to reduce the burden and improve the quality of learning. Second, to adapt to the new learning styles of the younger generation who are increasingly familiar with the technology and learning methods associated with digital platforms. This generation is more receptive to video and interactive training programmes, where instructor presence is less important to the learning objectives. The interaction of the training devices has been advancing further with technology and currently there is a growing movement to include VR technology to enhance training. OPG has implemented the use of VR for training in the handling of radioactive screening devices, and is currently expanding the application of this technology to maintenance training programmes. In this area, components are modelled in 3-D and VR can be used in the mock-up process without exposing workers to radioactive fields.

OPG's e-learning development team has designed and implemented an effective and innovative on-line learning environment that, since 1998, has delivered over three million course credits using state of the art technology (e-learning management system and infrastructure) and high quality training content (courseware, multimedia, instructional design). E-learning is on-line, trackable training delivered over a web based platform to a wide group of users. This requires the integration of training content with high quality graphics, interactive trainee exercises, and on-line testing to ensure knowledge transfer.

Approximately 500 courses are currently offered on-line at OPG covering topics such as conventional safety, general employee training, radiation protection, operation, maintenance, chemistry, engineering, leadership, among others These courses are available from a single intranet portal, and an external internet site serves external trainees requiring access from OPG's contracting partners and agencies. OPG's e-Learning Management System (e-LMS) not only serves as the portal, but also tracks trainee course requirements and progress, administers and scores examinations, and helps close the continuous improvement loop by managing trainee comments from initial input through to resolution and closure.

There has been a very favourable response to the use of e-learning in OPG, with high user ratings for the courses offered on-line. This is a core strength of OPG's in-house e-learning team, which uses advanced authoring tools to develop custom video, sound, graphics, and text tailored specifically to the OPG learner population and work environment. In particular, OPG has developed on-line, interactive, multimedia objects (exercises, animations, demos, simulations) that help reinforce and verify the knowledge transfer of trainees.

The OPG e-learning environment offers 24/7 accessibility and a learn at your own pace capability to employees, and also provides for automated tracking, electronic testing, on-line invigilation, and a reduced need for employee travel to support training. In addition, it supports other forms of instruction, such as OJT or traditional classroom delivery. It can serve as pre-training for OJT or a classroom course, provide structure and content for a facilitated classroom delivery, or be a convenient method for continuing training or requalification. Many such learning activities involving on-line deliveries of training content are being used at OPG to maximize overall training programme value.

E-learning courses required for critical nuclear qualifications closely follow the SAT process to ensure that industry standards are met or exceeded. Traditional SAT process steps are implemented using an e-learning-specific project model that includes storyboarding, graphic design, interactivity development, and web based deployment. Team members working on e-learning projects using this model require a wide variety skills and talents in areas such as multimedia, instructional design, programming and development.

The increasing demand for training has elevated e-learning to the extent that it now accounts for approximately 30% of all training delivered within OPG (or approximately 250 000 course deliveries annually in recent years). It has proven to be a cost effective method for delivering high volume training within the company. As a result, e-learning is recognized as an important strategic lever for improving the human performance of OPG’s highly technical workforce of approximately 10 000 employees and contractors. Employing e-learning on a company wide scale to help meet increased demand for training has seen widespread use in the global electrical utility industry.

## X.2. VIRTUAL REALITY

Recently, OPG has looked at the wider use of VR. With a recent decision to upgrade the turbine control system at one of its facilities — the Darlington Nuclear Generating Station — OPG has been working to develop interactive immersive tools that are being used to support design reviews for the new equipment that will be supplied, and ultimately how the training for the maintenance organization, including the new equipment, will be managed. Approaches under investigation include the use of 3-D displays for realistic, detailed and accurately rendered real time visualization.

OPG has further developed the use of 3-D and VR technology as it applies to training and work simulations. The following examples illustrate possibilities for creative new tools and techniques to be used in the training environment. Currently, new employees at Pickering Nuclear are trained and tested by an individual giving instruction in a one on one setting, or by the use of structured e-learning modules. By implementing VR into the training process, training efficiency can be improved, and the dynamic learning has enhanced employee satisfaction with the training effort. VR kiosks where new employees can put on a ‘Vive’ headset and are immersed in a fully 3-D simulation of the plant’s reactor vault environment, are currently in the testing phase. Devices using augmented reality could eventually replace physical manuals, diagrams and written procedures by overlaying information and instructions directly onto head-up displays.

# Appendix XI

# CASE STUDIES ON 3-D MODELLING, SIMULATORS, MOCK-UPS AND DEMONSTRATORS

## XI.1. INTRODUCTION

During the past ten years, a number of nuclear plants around the world have reached the end of their lifetime. Despite the consideration of lifetime extension, demonstrating the capacity of successfully performing the decommissioning phase has become a requirement for operators. Demonstrating their technical and financial mastery of this compulsory step in a nuclear facility's life cycle enables operators to increase their credibility, gain public acceptance and enhance stakeholder confidence beyond economic considerations.

To achieve this aim, in the context of an increasing number of nuclear decommissioning work sites worldwide, operators have to:

— Secure the required skills and to ensure their availability, on time;
— Train operators and increase their ability/efficiency;
— Derive the benefit of technical innovation by testing new tools or adapting the existing ones to a specific context or for unexpected situations.

These criteria led to the need to develop dedicated 3-D simulators and demonstrators to define decommissioning scenarios, check their feasibility on representative mock-ups, or adapt them by safely testing alternative solutions with minor impact on time and costs.

Two case studies illustrate the tools and means currently used by EdF in its decommissioning activities, but also used by other partners worldwide to prepare their own nuclear dismantling programme.

## XI.2. CASE STUDY OF 3-D MODELLING: DEMPLUS (OREKA, EDF GROUP)

DEMplus comprises 3-D simulation software dedicated to nuclear projects, providing a decision support tool based on real-time 3-D technologies. Its purpose is to prepare and follow up a project in the nuclear field through a global approach.

The software enables users to:

— Check the technical feasibility of an intervention (in terms of accessibility, performance of tools and the radiological environment);
— Evaluate costs in real-time, calculate intervention durations, allow planning for the establishment of radiological and waste assessments.

Use of this software helps reduce safety risks in decommissioning and improve the performance of activities, e.g. through greater use of sensitivity studies to evaluate dismantling.

### XI.2.1. Major operating principles

The user can add physical, radiological and kinematic values to the 3-D model imported into DEMplus, providing a virtual representation of the project environment. An 'avatar' (human or robotic system) can be moved into the virtual environment with an equivalent dose rate received indicator displayed in real time. The user can move to a series of operations (cut, decontamination, transfer/entry/exit of material, etc.) to construct a scenario and have access in real time to results concerning duration/costs/wastes/dosimetry.

From the reporting module, global project results can be retrieved. Users can then enter in project review mode, depending on their specific requirements, and perform sensitivity studies allowing the optimum scenario choice.

Once imported, the model becomes more than a graphical representation of the environment, i.e. the 3-D model embeds all physical, radiological and kinematic inventory data. It allows collaborators involved in the same project to easily plan, visualize, simulate and share data throughout the project's life cycle.

Figures 21–24 provide illustrations of:

— Physical inventory in DEMplus;
— Dosimeter displaying the instantaneous dose during an operation in DEMplus;
— 3-D dose mapping representation of dosimetry into an area;
— Definition of a container and of a waste stream.


*FIG. 21. Physical inventory in DEMplus (courtesy of EdF).*


*FIG. 22. Dosimeter displaying the instantaneous dose during an operation in DEMplus (courtesy of EdF).*

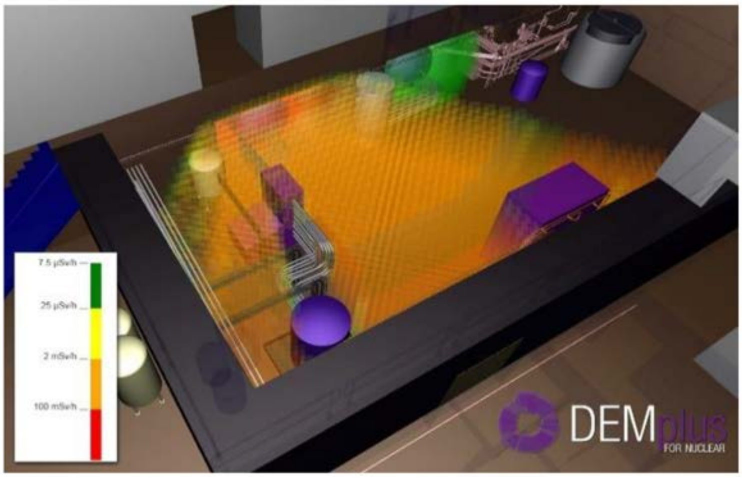


*FIG. 23. 3-D dose mapping representation of dosimetry into an area (courtesy of EdF).*

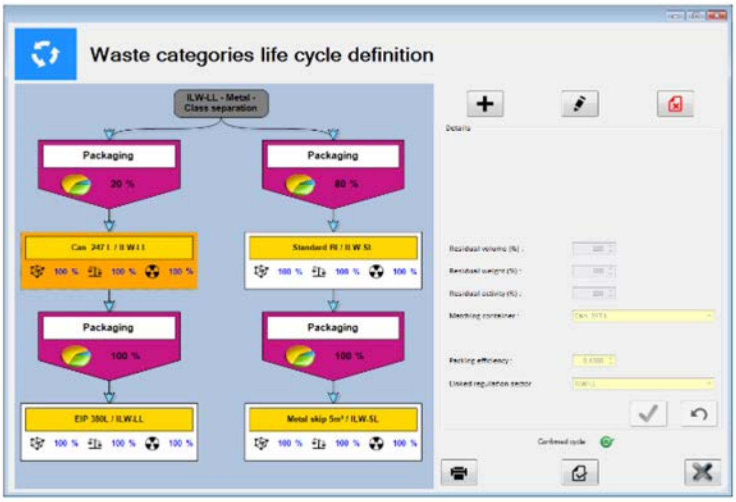


*FIG. 24. Definition of a container and a waste stream (courtesy of EdF). PCM: plutonium contaminated material, HHISO: half height International Organization for Standardization.*

## XI.2.2. Case study of the use of a mock-up and simulator in decommissioning — International Decommissioning Demonstrator (EdF group)

### *XI.2.2.1. A modular concept to build international synergies around the dismantling of graphite reactors*

The complexity of the decommissioning process for graphite reactors is mainly due to their dimensions, geometry, access and presence of graphite. The difference in the scale and quantity of waste generated from decommissioning follows a ratio moving from 10 to 20 compared with the dismantling of other nuclear technologies (PWR, etc.). Limited operational experience is available worldwide on this topic. Technological developments on remote tools are essential to complete these operations, which led EdF to decide to build an Industrial Demonstrator which will allow the optimization of the design and performance of the main tools integrated on the platform used to dismantle the first French graphite reactor (Chinon A2), as shown in Fig. 25.

The facility is planned to be constructed in a central location in Europe, near the Chinon nuclear power plant in France. The building (20 m high × 70 m long × 35 m wide) will consist of a large experimental hall with physical simulators and full scale mock-ups of parts of the reactor for metal and graphite structure dismantling risk mitigation operations. The facility will also feature 3-D modelling and a digital platform. In due course it will be used for other EdF graphite reactors, but it is also designed to be modular: additional simulators can be set up through extensions of the building to address complementary needs for other reactors and designs.

Over time, the intention is that the Industrial Demonstrator will become an international decommissioning platform to enable operators from various backgrounds to train themselves, improve their abilities and techniques, and test or adapt their tools.

The main milestones are:

— *2019–2021:* Building, engineering for the definition of the first tests, mock-ups and digital tools (3-D modelling, etc.).
— *2022–2026:* Technological development of remote tools.
— *2026–2029:* Dismantling scenario optimization and platform design.

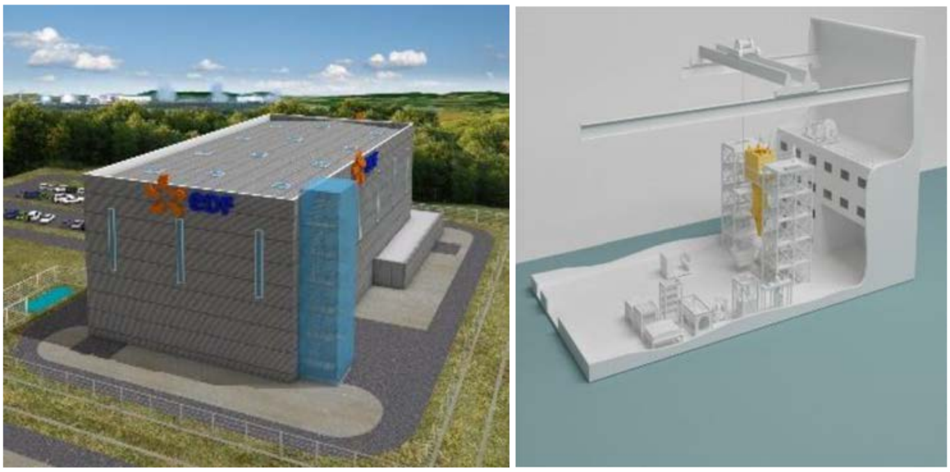

*FIG. 25. External and internal views of the Industrial Demonstrator for the dismantling of EdF's first generation graphite reactors (courtesy of EdF).*

*FIG. 26. Planned mock-up of plant in the EdF Industrial Demonstrator (courtesy of EdF).*

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# ANNEX: SUPPLEMENTARY FILES

The supplementary files for this publication can be found on the publication's individual web page at www.iaea.org/publications.

1. PERSONNEL REQUIREMENTS DURING DECOMMISSIONING OF NUCLEAR POWER PLANTS

# ABBREVIATIONS

| | |
|---|---|
| ANPP | Armenian Nuclear Power Plant |
| AR | augmented reality |
| BWR | boiling water reactor |
| CAD | computer aided design |
| CEA | French Alternative Energies and Atomic Energy Commission |
| CTC | Career Transition Centre |
| DOE | US Department of Energy |
| DPMU | Decommissioning Project Management Unit |
| EU | European Union |
| EDF | Électricité de France |
| INPP | Ignalina Nuclear Power Plant |
| OJT | on the job training |
| KPI | key performance indicator |
| OPG | Ontario Power Generation |
| PWR | pressurized water reactor |
| RBMK | high-power channel-type reactor |
| SAT | systematic approach to training |
| SSC | structures, systems and components |
| TBT | technology based training |
| VR | virtual reality |
| WAC | waste acceptance criteria |
| WFT | workforce transition |
| WWER | water cooled, water moderated power reactor |

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| Nystad, E. | Institute for Energy Technology, Norway |
| O’Sullivan, P.J. | International Atomic Energy Agency |
| Ovanes, M. | International Atomic Energy Agency |
| Palmer, D. | Consultant, United Kingdom |
| Pieraccini, M. | Électricité de France, France |
| Reid, R. | Electric Power Research Institute, United States of America |
| Rob, A. | Ontario Power Generation, Canada |
| Serbanescu, D. | Consultant, Romania |
| Szabó, V. | Nuclear Regulatory Authority, Slovakia |

**Consultants Meetings**

Vienna, Austria: 14–18 May 2018, 25–29 September 2018,

25–29 March 2019, 9–13 December 2019

**Technical Meeting**

Vienna, Austria: 1–5 July 2019

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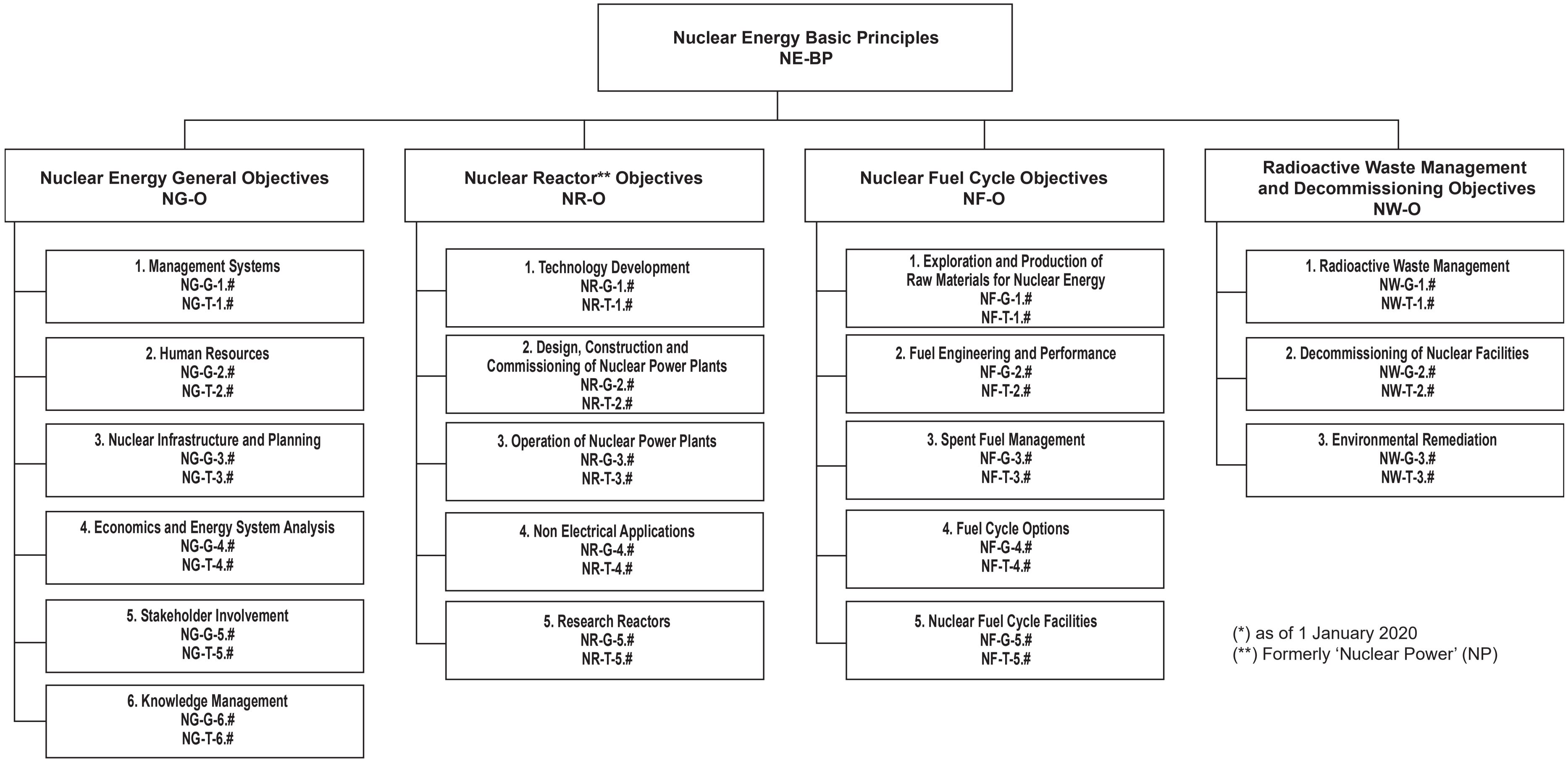


(*) as of 1 January 2020
(**) Formerly 'Nuclear Power' (NP)

*Key*

| | |
|---|---|
| **BP:** | Basic Principles |
| **O:** | Objectives |
| **G:** | Guides and Methodologies |
| **T:** | Technical Reports |
| **Nos 1–6:** | Topic designations |
| **#:** | Guide or Report number |

*Examples*

| | |
|---|---|
| **NG-G-3.1:** | Nuclear Energy General (**NG**), Guides and Methodologies (**G**), Nuclear Infrastructure and Planning (topic **3**), **#1** |
| **NR-T-5.4:** | Nuclear Reactors (**NR**), Technical Report (**T**), Research Reactors (topic **5**), **#4** |
| **NF-T-3.6:** | Nuclear Fuel (**NF**), Technical Report (**T**), Spent Fuel Management (topic **3**), **#6** |
| **NW-G-1.1:** | Radioactive Waste Management and Decommissioning (**NW**), Guides and Methodologies (**G**), Radioactive Waste Management (topic **1**) **#1** |

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