TRANSITION TO DECOMMISSIONING ROADMAP

Roadmap to guide operators through the transition to decommissioning

A product of the

Transition to Decommissioning Industry Working Group

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CONTENTS

Acronyms

ALARP/ALARA	As Low As Reasonable Practicable / As Low As Reasonable Available
BAT	Best Available Technologies
CNO	Chief Nuclear Officer
DF	Decontamination Factor
ELS	Executive Leadership Team
EP	Emergency Plan
EPRI	United States Electric Power Research Institute
FSAR	Final Safety Analysis Report
FSD	Full System Decontamination
HSA	Historic Site Assessment
HR	Human Resources
KPI	Key Performance Indicator
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
I-WG	Industry Working Group
LLW	Low Level Waste
LILW	Low and Intermediate Level Waste
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols Manual
NEA	Nuclear Energy Agency
NEI	United States Nuclear Energy Institute
NPP	Nuclear Power Plant
OPEX	Operating experience
PCB	Polychlorinated biphenyls
POCO	Post Operational Clean Out
SAR	Safety Analysis Report
SF	Spent Fuel
SFP	Spent Fuel Pool
SFPI	Spent Fuel Pool Island
SSCs	Systems/Structures/Components
TTD I-WG	Transition to Decommissioning Industry Working Group
TP	Transition Phase
TS	Technical Specification
USNRC	United States Nuclear Regulatory Commission
VLLW	Very Low-Level Waste
WANO	World Association of Nuclear Operators
WNA	World Nuclear Association

1. Introduction

The Transition to Decommissioning Industry Working Group (TTD I-WG) launched in March 2019 and comprised of representatives from utility personnel dedicated to sharing experiences to help deal with pre-decommissioning challenges. Primary objectives of the group were to:

1. Provide a forum in which industry representatives meet to identify opportunities, needs, issues and solutions related to:
   - Preparing the plant for decommissioning.
   - Process optimisation through activities such as benchmarking.
   - Transition of staffing from operation to post-operation and start of dismantling activities.
   - Development of common industry products and guidelines with concurrence from WANO.
   - Issues driven by WANO Executive Leadership Team (ELT) and the CNO Forum.
2. Provide industry communication and leadership.
   - Provide methods for effectively communicating I-WG information, activities, and products through an appropriate online platform.
   - Provide coordination with other industry groups engaged in or whose efforts may affect TTD activities to ensure that efforts are complementary and non-duplicative.

The objective of this roadmap is to summarise results of the TTD I-WG. The document provides guidance for the preparation of decommissioning nuclear power plants that can contribute to a safe and cost-effective transition phase; from operation to decommissioning. The scope of this roadmap excludes the dismantling and restoration phase.

The document can be structured in four different areas:

Area 1: Strategic Considerations	Chapter 3: Global Strategy
Area 2: Legal, Regulatory and Licensing Considerations	Chapter 4: National Policy and Regulations for Decommissioning Chapter 5: Decommissioning Plan Chapter 6: Safety Case Strategy during the Post-Operational Phase
Area 3: Technical Considerations	Chapter 7: Spent Fuel Management Chapter 8: Asset Management Optimisation Chapter 9: Plant Characterisation Chapter 10: Material and Waste Management Optimisation
Area 4: Managerial Issues and Leadership	Chapter 11: Change Management for the Transition Chapter 12: Human Resources Strategy Chapter 13: Retaining Knowledge and Information

	Chapter 14: Estimating Costs and Funding

When a licensee decides to permanently cease operations at a nuclear power plant or nuclear power reactor, the facility must be decommissioned by safely removing it from service and reducing residual radioactivity in order to leave the site in a state that is suitable for its next intended use authorised by the regulators. According to the IAEA Safety Glossary [4] the term 'decommissioning' refers to the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. Dismantling refers to the taking apart, disassembling and tearing down of the structures, systems and components of a facility for the purposes of decommissioning.

The figure below shows the phases in a lifecycle of a nuclear power plant and the main activities to be executed and planned for a successful transition phase. The transition phase starts when the decision to permanently shutdown the plant is taken and goes until the beginning of the decommissioning strategy implementation; case "a" reflects deferred dismantling and case "b" reflects immediate dismantling. Historical Site Assessment (HSA) is a critical part of transition phase planning that will have to include detailed information with several aspects to be re-evaluated as maintenance and investment policy review, human resources review, decommissioning planning, safety analysis, risk assessment, environmental monitoring, emergency planning, physical security and safeguards, waste management, fire protection plan and training programme.

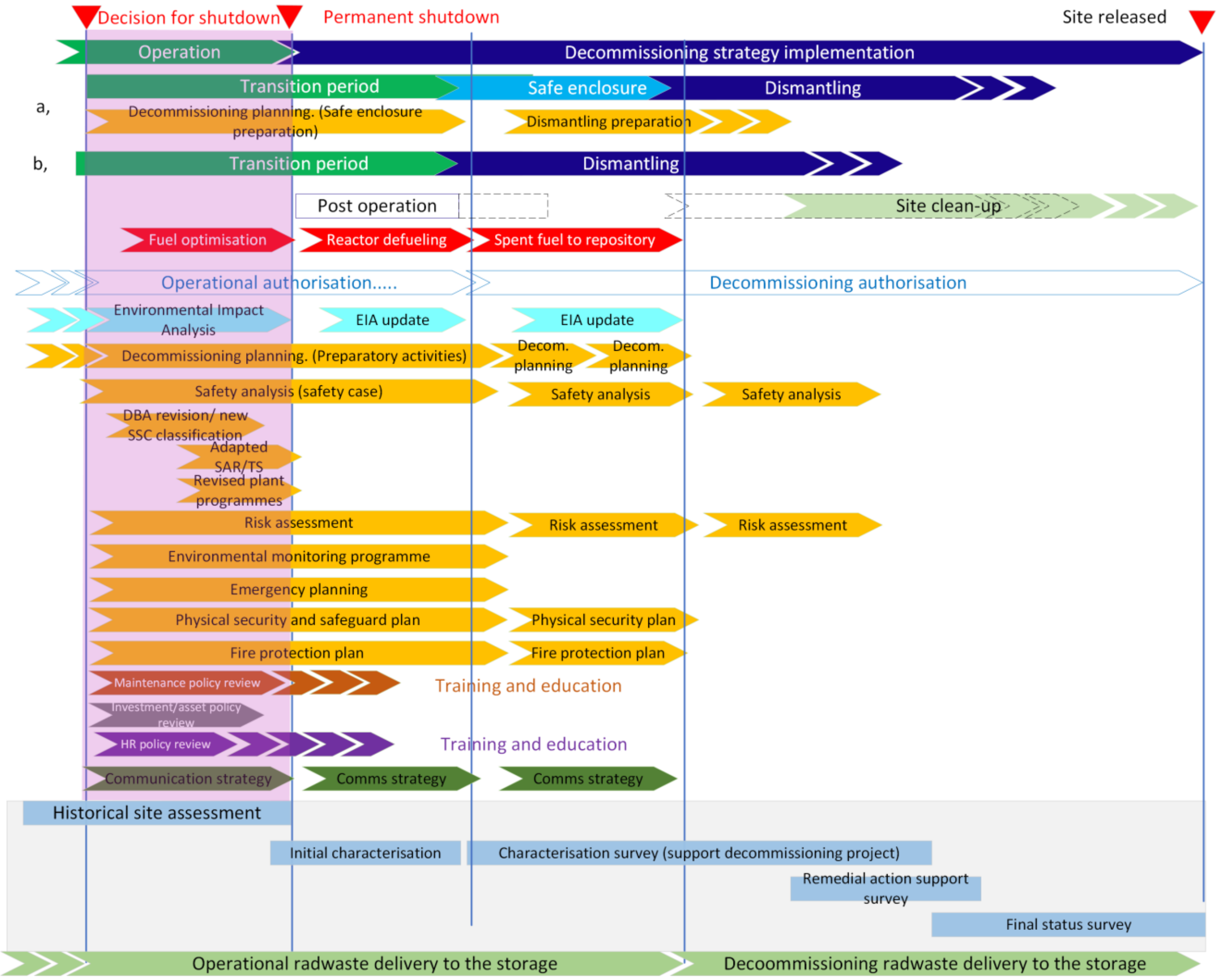


Figure 1-1: NPP lifecycle activities and transition phase main planning activities

Two decommissioning strategies are considered applicable for nuclear power plants [11]:

- Immediate dismantling: In this case, decommissioning actions begin shortly after the permanent shutdown. Equipment and structures, systems and components of a facility containing radioactive material are removed and/or decontaminated to a level that permits the facility to be released from regulatory control for unrestricted use or released with restrictions on its future use.
- Deferred dismantling: In this case, after removal of the nuclear fuel from the facility (for nuclear installations), all or part of a facility containing radioactive material is either processed or placed in such a condition that it can be put in safe storage and the facility maintained until it is subsequently decontaminated and/or dismantled. Deferred dismantling may involve early dismantling of some parts of the facility and early processing of some radioactive material and its removal from the facility, as preparatory steps for the safe storage of the remaining parts of the facility

A combination of these two strategies may be considered recommended on the basis of safety requirements or environmental requirements, technical considerations and local conditions, such as the intended future use of the site, or financial considerations.

International organisations agree that the transition from an operating nuclear facility to the implementation of the dismantling phase is critical in every decommissioning project, and more clearly when immediate dismantling is the selected strategy. Preparation for transition to decommissioning is a key issue for the success of the global decommissioning project to minimise delays and undue costs; to optimise personnel and other resources; and to initiate preparatory activities for decommissioning in a planned, timely and cost-effective manner, with the overall objective of ensuring safe and efficient decommissioning [31].

This roadmap provides valuable recommendations and suggestions for aspects that would be more relevant to a transition phase for a full nuclear power plant lifecycle. The roadmap also helps prepare change management through identifying topics to be addressed. Although there is a required sequence to follow, it should be adapted to each situation.

2. Description of the Transition Phase

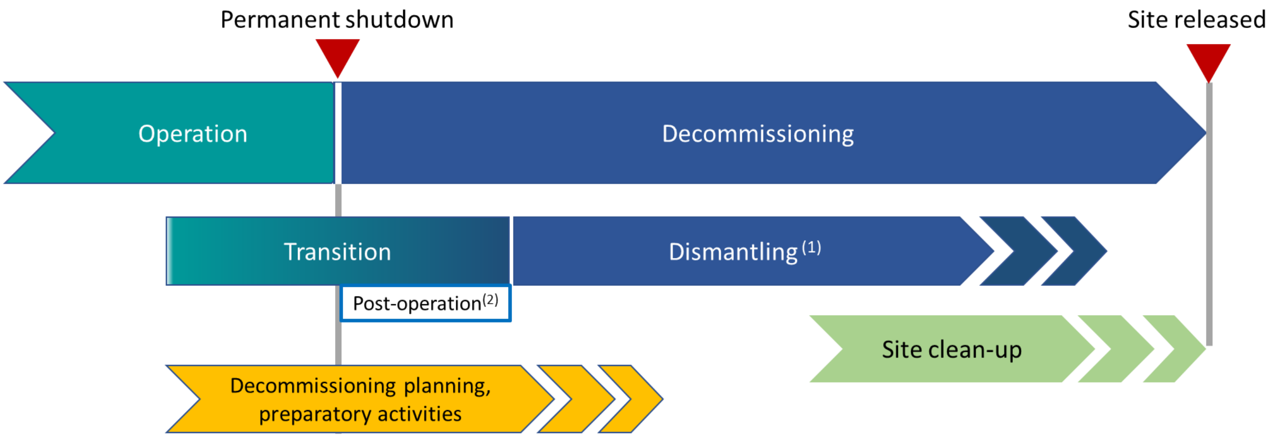
The term Transition Phase (TP), also referred to as the “transition period”, “preparation for decommissioning” or “transition”, varies from country to country and sometimes from plant to plant. The term “transition phase” can be found in many national and international documents and is lately used to describe the phase starting with the decision of permanent shutdown or the last years of planned operation onwards and ending with granting the authorisation for decommissioning (when required), or by approval date of the final decommissioning plan. For the deferred dismantling strategy, the transition phase may also include a stabilisation phase to modify/prepare the site for its safe storage period.

The transition from an operating nuclear facility to the implementation of the dismantling phase is critical in every decommissioning project. The smoothness of this transition process depends on its preparation and therefore an unplanned shutdown decision or poorly prepared transition can have a negative impact on its execution. As several changes need to be initiated to prepare the facility for dismantling, preparation for transition from operations through to decommissioning should be started as soon as possible once a permanent shutdown is decided. It is considered good practice for the preparation of this phase to start well before permanent shutdown [31].

The main two goals during transition phase are to:

1. Bring the facility to a safe and stable post-operational status and transition from facility’s operational situation to one in which operations, surveillance and maintenance are reduced in accordance with the lower safety risk and the systematic reduction of hazard.

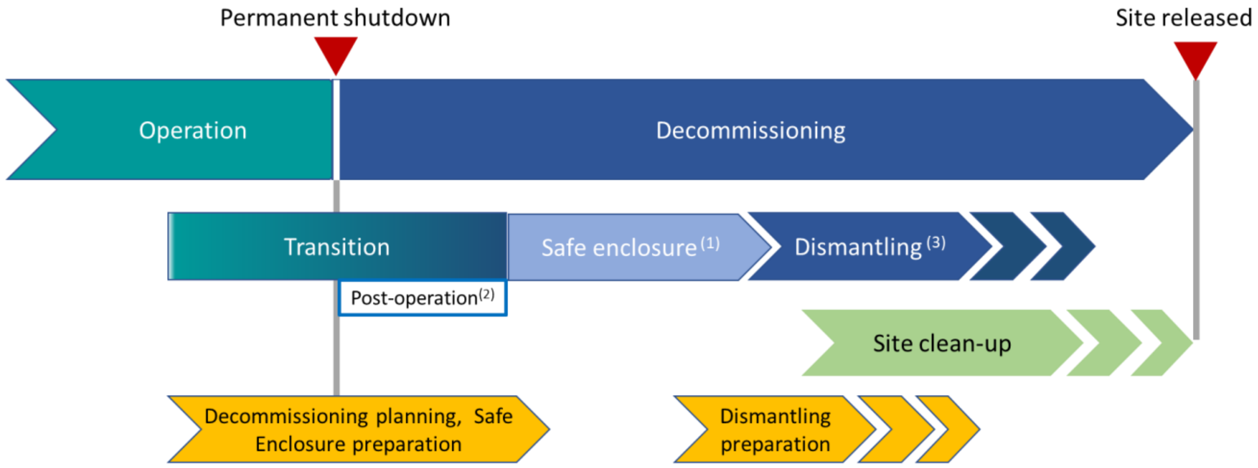
2. Prepare the facility for decommissioning.



(1) In some countries the commencement of dismantling activities requires a Decommissioning Authorisation

(2) The duration of the post-operation phase differs between countries and even between plants with terms ranging from few days to several years. Defueling from the spent fuel pools activities are normally included in this phase

Figure 2-1: Transition in relation to operation and decommissioning for a planned shutdown and immediate dismantling strategy - Adaptation of figure in [31].



1) *In some countries the commencement of Safe Enclosure period requires a Decommissioning Authorisation*

2) *Stabilization phase to modify/prepare the site for its safe storage period*

3) *In some countries the commencement of dismantling period after Safe Enclosure requires a new Decommissioning Authorisation*

Figure 2-2: Transition in relation to operation and decommissioning for a planned shutdown and deferred dismantling strategy - Adaptation of figure in [31].

The transition phase could therefore be divided in two phases:

1. First phase or pre-shutdown phase: transition[1] to decommissioning starts with the decision of permanent shutdown or from the last years of operation until the final shutdown, with the main objectives of staying at a high level of nuclear safety to optimise what has to be done during the last cycles and to prepare the final shutdown and decommissioning (organisational, licensing and technical issues).

2. Second phase, also known as the post-operational phase, from the final shutdown until active dismantling. During this phase, the main objective will be to remove spent fuel from pools[2], and associated regulatory consent being key milestone. Post Operational Clean Out (POCO), management of operational waste that remain on the site (if any), modify systems and facilities required for dismantling, safe storage, etc. In some cases, this second phase is carried out under decommissioning authorisation[3].

The transition phase includes planning and activities involved with the changes caused by the end of operations until the decommissioning strategy implementation. There is a lot of literature compiling information on what is required to be done in the transition phase before active dismantlement of the plant can begin. References [22], [31] and [44] include a detailed description of the potential scope for this phase.

[1] IAEA defines transition phase more narrowly as the time period between the permanent shutdown of the facility and the granting of authorisation to begin decommissioning actions. This has the disadvantage of not including the necessary preparations for transition ahead of permanent shutdown.

[2] The removal of the fuel from the reactor is one of the activities that are normally carried out in the transition period, nevertheless there are past and recent experiences in which the dismantling begins with spent fuel still in pools.

[3] For example, in Germany all the plants that have been or will be shutdown after 2018, have obtained the first decommissioning authorisation before the final shutdown (Brokdorf, Emsland, Grohnde, Gundremmingen-C, Isar-2, Neckarwestheim-2, Philippsburg-2), therefore the post-operational activities are carried out under decommissioning license.

3. Global Strategy

3.1 Strategic Issues during the Transition Phase

Senior-level management of an organisation responsible for plant decommissioning need to take a set of strategic decisions to prepare the decommissioning project. All of these strategic decisions are influenced by several factors and constraints; they can be classified as strategic corporate issues and strategic technical issues.

The objective of this roadmap is not to go into detail about these issues but to provide guidance on those that are considered most relevant and strategic for utilities due to their effect on company safety, cost and human resources. These strategic decisions must be reviewed regularly from different angles (readiness review) and adjusted if necessary.

Any decision must be framed within the national policy and regulatory context. Chapter 4 describes relevant considerations on this issue that need to be understood to define the strategy during transition and decommissioning phases.

3.1.1 Strategic Corporate Issues

In relation to corporate issues, before facing the transition phase, some critical questions need to be answered to define the project strategy. Table 3-1 includes examples of these questions, the list is not exhaustive and should be reviewed as examples. The final decision has to be adopted by each operator, according to their national policy and regulatory framework, company policy, and the specificity of each site.

Policy and Regulatory Framework • What is the national policy for decommissioning (e.g. who is responsible for decommissioning?, what decommissioning strategies are allowed according to the legal and regulatory framework?) • What are the overarching regulatory requirements? (e.g. is a decommissioning authorisation required?, is a post-operational period between the final shutdown and the dismantling execution required?, is a defined “end-state” of the site?) • What is the model of licensing in the country during the different phases? (operational, post operational, etc.)
Site Owner Company/Operator/Licensee • What is the selected decommissioning strategy (deferred or immediate dismantling)? • What is the company business model, and how is it to be applied in the context of a decommissioning project? • What is the company experience on decommissioning? • What is the company structure, and how will this relate to decisions on decommissioning projects? • How large is the nuclear fleet of the company, and what is the relationship between facilities in operation and those in decommissioning? • What is the decommissioning business model (Self-Perform, General Contractor, License transfer, Asset Acquisition/Transfer, etc.)? • Who are the different stakeholders?

• Is an entire site closing or only a part of it? (the number of units will be closely related to the company structure and should be considered) • What is the closing schedule of the nuclear the fleet in the company?
Funds/Investment • Are there sufficient funds available for decommissioning at the time of shutdown? • What is the link between financial strategy and time scale for decommissioning? • What has to be financed with the funds collected and dedicated to decommissioning, and what has to be financed through other means? • How are the funds allocated? How are they used? What are the funds disbursement mechanisms? What are the reporting requirements for use of decommissioning funds?
Human Resources (HR) Strategy • Will the company shut down only one reactor or the entire site? • What is the plant organisational approach? (specialised in-house resources or external contractors) • What is the company HR model for the different phases and organisation transition from operation to decommissioning? • What is the staff age profile? • Is it possible to relocate the staff to another nuclear plant? • What are the profiles of the available staff? How can they be aligned to decommissioning activities to ensure retraining valuable staff, promoting skills transfer, and "experience feedback"? • What are the expectations of the plant personnel? • How will the company motivate personnel to keep focus on nuclear safety during the last operational years? (communication of staffing transition strategy is closely linked to this issue) • How will the company manage the redundancy process? Are their formal requirements (e.g. staff agreements, unions) that must be followed, or opportunities that can be utilised (e.g. support for retraining or redeployment of personnel)? • How will the plant personnel be integrated in the decommissioning business model? • What is the knowledge management policy of the company?

Table 3-1: Example of questions to be answered for corporate issues

The following paragraphs summarise the most relevant corporate decisions that needs to be taken to complete a successful decommissioning project.

As indicated in Chapter 1, two possible decommissioning strategies are applicable (immediate or deferred). In general, immediate dismantling is the preferred option but there are situations in which it is not practical. Although the selected strategy is generally decided during operation as it is the base for cost estimation and fund provision, once the decision of final shutdown is taken the licensee should check if the selected strategy is still appropriate. According to reference [7], the selection is influenced by several factors:

- The national policy and the regulatory framework.

- The type of facility and interdependences with other facilities or infrastructure located at the same site.
- Proposed reuse of the facility or site and the desired end-state.
- The physical status (e.g. ageing components and structures) and the radiological status of the facility.
- Safety and nuclear security aspects.
- The availability of expertise (knowledge, skills and experience), technologies and infrastructure (tools, equipment, supporting facilities and services).
- The environmental impact of the facility and of its decommissioning.
- Societal and economic factors and the socioeconomic impact of decommissioning.
- The availability of infrastructure for radioactive, hazardous and conventional waste management, including facilities for pretreatment, treatment, conditioning and storage of waste, as well as existing or anticipated waste disposal options.
- The availability of financial resources for decommissioning.

These considerations also apply in the case of unforeseen permanent shutdown for financial, technical or political reasons. In this case a review of the preferred decommissioning strategy might be necessary based on the situation that initiated the unforeseen shutdown, in order to evaluate whether a revision of the decommissioning strategy is necessary.

Reference [7] also indicates that *a licensee in charge of several decommissioning projects for different facilities at different sites in the same State could develop an overall decommissioning strategy (a corporate strategy) in order to optimise the decommissioning projects of individual facilities and related solutions for the management of radioactive waste*.

The selection of the decommissioning model as described in 3.2 is a key decision that will condition the needed decommissioning organisation. When the operator is also in charge of decommissioning, the change from an operational to a decommissioning organisation is not easy and requires a smooth transformation of both corporate structures and culture. While the operational organisation is designed for safe and reliable processes, dismantling companies need to convert fundamentally to agile, project-oriented organisations. If decommissioning responsibility is transferred to an external organisation, smooth handover of responsibilities is needed during the transition phase.

The provision of adequate funds for decommissioning and a funding mechanism forms part of decommissioning planning and is usually a legal obligation. The funds for financing decommissioning are based on a set of reference scenarios, boundary conditions and assumptions to come up with an overall plant-specific estimate for the decommissioning cost. Although well documented, these assumptions will always remain a best estimate at a certain point in time, and as such, uncertainties, risks and progressive insights have to be taken into account to ensure adequate funding. Adequate financing based on a detailed and reliable decommissioning cost estimate is needed for the decision on the decommissioning strategy. If no or insufficient funds are available, deferred dismantling will be an option. It is important to be aware if there are restrictions on the use of decommissioning funds to cover costs or activities during the post-operational period. Where such restrictions exist, additional financial resources will be required to cover these costs. The estimation of costs and funding of transition activities is explained in Chapter 14.

Decommissioning requires specialised knowledge that is not always available or necessary while the plant is operating. During the transition phase, a contracting or management approach of self-performance, outsourcing or insourcing policy should be decided taking into account different aspects (technical, organisational, HR, financial).

The overall project requires an integrated approach, with a master planning from shutdown to final disposal of the waste, integrating all important site activities and projects. The overall optimisation of the decommissioning schedule should take into account its impact on finance and human resources.

Good relation and communication with the public during planning of the decommissioning process is vital due to the public sensitivity on nuclear operations. During the preparation of the decommissioning project the concerns, issues and views of the different stakeholders should be taken into consideration. Environmental and social impacts on local community play an essential role and to be successful the project needs to be open, transparent and clear to all (engaged) stakeholders to avoid wrong perceptions about the decommissioning activities and the future or reuse of the plant. Strategy of communication is briefly explained in Chapter 11, including internal communications within the organisation.

After getting a clear decision for shutdown (end of operating license, political decision, industrial or economical choice, decision from the regulator or a combination of reasons), the reason for decommissioning must also be thoroughly communicated to all stakeholders and for this a communication strategy (internal/external) and plan should be prepared.

Decommissioning of a nuclear power plant implies important changes in the organisation compared to the many years of a stable operation. Based on those new activities in decommissioning there will be a need for a project based methodology and more flexibility in the organisation during the transition phase. A human resources strategy should be defined in an early stage in order to manage and support the transformation process in an early phase of the decommissioning including the post-operational phase: retention plan for critical staff, training for new competences, knowledge retention and transfer.

3.1.2 Strategic Technical Issues

The legislative and regulatory framework and authorisation for decommissioning is an important factor in the selection of a decommissioning strategy and different approaches may exist in countries. A clear licensing structure with realistic regulatory requirements is essential. It is necessary to get your government and authorities involved in an early stage in order to understand the deliverables, commitments and necessary authorisations. Considering the decommissioning plan, it will be reviewed and endorsed by the regulatory authorities, including hearings to be held to the public if required by regulations. In some countries a very precise and detailed decommissioning plan is a precondition before starting decommissioning and the activities that can be developed during transition phase are clearly regulated. In other countries a more flexible framework is in place, that allows plans to be refined successively as the transition and decommissioning progresses. National policy and regulations for decommissioning are explained in more detail in Chapter 4.

Chapter 9 includes a description of the Plant Characterisation during the transition phase. Characterisation is one of the key activities not only in decommissioning preparation but also throughout the entire decommissioning project. It plays a key role in providing the necessary confidence and understanding about the initial/current state of the facility. It is important to decide when the plant characterisation should start. Last outages could be used to get radiological information in those systems and components that are not physically accessible during normal operation.

An important strategic issue is the determination of the long-term management of the spent fuel. After reactor final shutdown residual heat will decrease exponentially but the spent fuel has to stay within the fuel pool during several years to meet the license requirements for dry cask storage (if dry storage of the spent fuel is decided). The defueling is on the critical path for decommissioning and this wet storage still requires, during this period, the necessary cooling, purification, makeup and power. Spent fuel strategy issues are explained in more detail in Chapter 7.

Besides the spent fuel management, the material and waste management systems and facilities, including final repositories for all types of waste, should be defined and available at the time of decommissioning. If this is not the case, firm planning for these types of facilities is a priority. Meanwhile, appropriate solutions for waste processing and interim storage are required to allow for conditioned waste to be safely stored. A strong interaction and open dialogue with all stakeholders are needed. The design of an optimised material and waste management strategy is explained in Chapter 10.

The decision to perform a system decontamination (full or partial system decontamination, primary system decontamination in a PWR) and its scope during transition phase should be based on a cost-benefit analysis. This is major activity which requires a lot of preparation and should be anticipated in time.

When successful, a full system decontamination (FSD) serves to reduce radiation exposure to decommissioning workers, to reduce the contamination of components to such levels that may be disposed of in a lower category or recycled/reused in the conventional industry, and also to minimise the potential of spreading contamination during dismantling.

A typical parameter to be considered is the Decontamination Factor (DF) defined as the projected or actual radiation field reduction obtained on the component which will be or has been decontaminated. A choice has to be made between aiming for a lower DF (with a smaller amount of radioactivity being removed from the system) or a higher DF (with more radioactivity being removed from the system through the use of more aggressive processes but with a higher volume of secondary waste). The analysis should have the following end-points [48]:

- Provide recommendations on whether a primary/secondary system (or sub-system) decontamination is cost beneficial and feasible (taking into account the potential for an unsuccessful or only partially successful FSD).
- Determine the scope of decontamination required.
- Identify decontamination methods available.
- Determine the effects of decontamination on other decommissioning activities.

The cost-benefit analysis must consider the reduction in exposure for decommissioning activities, and balance them against decontamination costs, occupational exposure received during the decontamination process, and handling of secondary waste. This document does not analyse in more detail the decontamination of system as part of the activities in the transition phase. There is an extensive bibliography summarising real experiences that could be used as guidance.

To enable a controlled transition into the decommissioning phase, the end-point[4] of the facility after the transition phase should be clearly defined and documented. The end-point of a facility is related to: the source-term reduction and draining/cleaning of systems, the required equipment status or the interconnection with other utilities. The end-point is also strongly related to the following decommissioning considerations and strategic decisions:

- Cold and Dark strategy which refers to de-energising, depressurising, and draining all plant systems that are no longer needed for decommissioning and sometimes replacing them with mobile or temporary solutions.

[4] 'Transition end points' are the detailed specifications for the physical condition and configuration to be achieved at the end of the post-operational phase

- Preliminary dismantling works during the transition phase (e.g. removal of insulation, electrical motors, reactor vessel internals segmentation (in some countries), etc.). Depending on the regulations most of these activities may be permissible without needing a specific authorisation process.
- Reuse of locations or buildings as buffer storage areas or material and waste management units.

Key aspects to contain within the transition end-point documentation are:

- Fuel and radioactive waste inventory.
- System and infrastructure status.
- Spare-parts or tools inventory.
- Common functions and interconnections with other units.

In Chapter 8, Asset Management Optimisation, some principles are explained in more detail.

Plants should also consider dismantling and/or releasing non-radioactive systems and buildings during the transition phase. These activities are relatively low-cost and are typically beneficial to conduct early in the decommissioning process to free up space at the site for later dismantling activities, to reduce the potential for contamination of these non-radioactive areas, and to minimize monitoring requirements in these areas throughout the decommissioning.

There are other strategic decisions that need to be taken when facing transition phase, the following bullets include all technical aspects that should be considered:

- Spent fuel management strategy.
- Material and waste management strategy (including operational wastes).
- Licensing strategy.
- Dismantling, technological and remediation strategy.
- Maintenance, investment strategy including risk management.
- Securing the facility “Lifetime Records” covering design, commissioning, and operational phases.
- Preparation/submittal of regulatory documents.
- Shutdown of (redundant) systems and draining of circuits and systems.
- Systems/Structures/Components (SSCs) re-categorisation.
- Removal of Asbestos (when existing in the site) and other hazardous materials.
- Perform Historical Site Assessment and Initial Site Characterisation.
- System decontamination.
- Modification of auxiliary systems (electrical supply, ventilation, fire protection, treatment of liquid effluents, conditioning/processing of radioactive waste, etc., can be either modified and adapted or be replaced by new supporting systems). These modifications could include the cooling and cleaning systems for spent fuel pools (SFP).
- Modification of auxiliary installations (mainly for material management).
- Dismantling of non-nuclear facilities (if necessary and allowed by the license or authorities).

- Development of new technologies and equipment for dismantling, decontamination, disposing waste and materials generated during dismantling.
- Adaptation of the licensing basis: Immediately after the final shutdown of the plant, the licensing basis of the plant is the same as when it was in operation. This means that operating procedures, technical specifications, surveillance of systems and equipment operability must be maintained until the engineering/licensing process, that changes the licensing basis is completed and the associated procedures are revised. Following the procedures above reduces the risk, and hence results in a progressive reduction in hazard/risk levels.

It is not the objective of this roadmap to go into detail about all these activities but to provide a guide for those that are considered most relevant or strategic for the utilities due to their effect on safety, costs and human resources of the companies. These strategic decisions must be reviewed regularly from different angles (readiness review) and adjusted if necessary.

3.2 Decommissioning Models

The selection of the decommissioning model is a key decision that is taken by the top-level management of the companies and condition all the managerial issues both during transition and decommissioning phases. The decision is mainly affected by the following issues:

1. What is the selected decommissioning strategy?
2. Who is responsible for decommissioning in the country? Who has to assume the extra cost that could arise in the decommissioning project?
3. How large is the nuclear fleet of the company? Is there a shutdown schedule for the nuclear fleet?
4. Does the regulatory framework allow the transfer of licensee?

There is experience of projects with different decommissioning models, ranging from the traditional model where the plant owner/operator engages a contractor or makes a joint venture with a contractor specialised in decommissioning to full transfer of ownership and license. All variants in between are possible.

Table 3-2 shows a summary of the decommissioning models used in the US. The US have evolved in recent years to new models in which third-party specialist decommissioning contractors have been able to take the lead at shutdown nuclear power plants and drive efficiencies in decommissioning and site restoration. One of the key points in this evolution is the flexible NRC license transfer process that may be impossible, or not desirable, to achieve in all places.

Decommissioning Model			Examples	Owner Risk Transfer
Utility-led model	Self-perform	Managed and Performed by the Owner/operator that uses specialty subcontractors for some tasks. Owner/operator remains licensee and retains all the responsibilities on the site.	Maine Yankee Trojan Yankee Rowe Humboldt Bay 3	Very Low
Utility-led model	General contractor	Owner/operator engages specialized decommissioning contractor in charge of majority of dismantling tasks under a lump-sum contract. Owner/operator remains licensee and retains all the responsibilities on the site.	San Onofre 2&3 Fort St. Vrain	Moderate
Third-party transfer model	License Transfer	A contractor acquires plant assets and leases site from owner, and takes responsibility for shutdown plant as licensed decommissioning operator. NRC licensee is transferred to the contractor that also assumes: • Nuclear decommissioning trust funds with risk that funds are not enough • Nuclear liability Plant employees generally participates with the contractor (contractual relationship is negotiated with owner/operator) Owner keeps ownership and responsibility of spent fuel. The site is returned to owner upon completion.	Crystal River 3 Lacrosse BWR Zion 1&2	High
Third-party transfer model	Asset Transfer	This model provides for the complete divestment of the nuclear asset. A contractor acquires the facility and site and assumes the NRC license. The contractor acquires all assets and liability owner: • NRC license • Nuclear decommissioning trust funds with risk that funds are not enough • Nuclear liability • Ownership and responsibility of spent fuel • Plant employees (number and profiles negotiated with plant owner/operator)	TMI-2 Indian Point 1, 2 and 3 Oyster Creek Pilgrim Vermont Yankee Ft. Calhoun Palisades	Total

Table 3-2: USA Business Decommissioning Models

In most countries the operator is also responsible for decommissioning by law, but there are some exceptions (Spain, Italy, Slovakia, Lithuania, Bulgaria, UK for Magnox reactors, etc.). In these last countries, the transition phase is more complex and needs to define well in advance the relationship between both organisations to avoid inefficiencies in the global project without compromising safety.

In Germany, Sweden, France, Belgium and Switzerland the decommissioning of NPPs is developed under a self-perform model, although with some differences among owners and countries.

The decommissioning model that a company adopts will probably differ if this company has a nuclear fleet and needs to face the decommissioning of several nuclear power plants at the same time. In this case Utility Holding Company could be in charge of decommisioning of the plants using a fleet approach. German and Sweden utilities are clear examples that should be analysed.

- Reference [75], includes a description of the strategy foreseen by **[Redacted Company Name 1]** in Germany for decommissioning of its nuclear power plant fleet. In 2016 **[Redacted Company Name 1]** defined a global decommissioning strategy, which was based on the integral consideration of all project management dimensions, in particular took into account "fleet approaches" to maximise synergies. The aim was by 2040 to provide predictability and stability for the decommissioning organisation and complete the decommissioning projects. The implementation of the strategy takes place organisationally via a clear definition of responsibilities. **[Redacted Company Name 1]** is managed as an independent GmbH within the E.ON Group. The operational implementation responsibility for the decommissioning lies with the heads of the plant (LdA). At the same time, there is a joint responsibility between headquarters and locations to achieve the agreed strategy in order to ensure the implementation of the ambitious optimization levers.

- The operator of **[Redacted Company Name 2]**’s NPPs is **[Redacted Plant Name 3]** that is also responsible for overall planning of decommissioning. Reference [76] includes a description of the **[Redacted Company Name 2]**’s decommissioning model for all its nuclear fleet.

According to [13], in Sweden, owners and operators decide how they wish to undertake and organise decommissioning. **[Redacted Company Name 5]** and Uniper follow a self-perform model but with different approaches.

- **[Redacted Company Name 5]** has created a “Business Unit Nuclear Decommissioning” (BU.ND), to manage the decommissioning of **[Redacted Company Name 5]**’s nuclear facilities in Sweden and Germany. Recognising that the projects need to be undertaken pursuant to the applicable regulatory frameworks and conditions prevailing in both countries, BU.ND nonetheless aims to benefit from learnings and synergies between the decommissioning projects. In the particular case of **[Redacted Plant Name 6]** NPP in Sweden, **[Redacted Company Name 5]** made a strategic decision to separate continued operation of **[Redacted Plant Name 6]**Units 3 and 4 from the decommissioning of Units 1 and 2. **[Redacted Plant Name 6]** AB is the licensee for all the **[Redacted Plant Name 6]** units and will retain this responsibility even during the decommissioning of Units 1 and 2. **[Redacted Plant Name 6]** AB is responsible for continued operation at the **[Redacted Plant Name 6]** site and the post-operational period until Units 1 and 2 are fuel free. BU.ND manages the decommissioning projects, with its operational responsibilities increasing once fuel has been removed from the units. Recognising the shared and differentiated responsibilities of the licensee (**[Redacted Plant Name 6]** AB) and the decommissioning manager (BU.ND), an integrated programme management model is being implemented, incorporating both organisations.
- **Uniper** has decided to follow a fleet approach with common decommissioning strategies and joint tenders, where appropriate, as well as coordination of the schedules between the decommissioning projects. Decommissioning projects are managed by departments within the licensee’s organisation.

In France, **[Redacted Company Name 9]** takes in charge all lifetime phases of a nuclear power station. Therefore, Nuclear Generation Division is in charge of operational and defueling phases and will hand over to the Decommissioning Division for decommissioning. During the transition phase, both divisions work together to organise an efficient and smooth transition.

The decision of a deferred decommissioning strategy (for unavailability of funds or for a technical decision) is another important issue that could condition the model during transition phase. In this case, the post-operational phase is mainly focused on stabilising the plant for a latency phase instead of preparing for decommissioning.

3.3 Programme Governance

Effective programme governance is a key success factor for a decommissioning programme where Transition to Decommissioning is part of. Several internal and external stakeholders are involved in a decommissioning project and the cost associated with the programme is huge. So there is a need for an effective governance process in decommissioning, involving the right decision-makers to ensure efficient and timely decisions. The decommissioning programme should make a set of governance principles and define different types of governance bodies and their respective roles and responsibilities.

Programme governance definition according to Project Management Institute (PMI): *"Programme governance is the performance domain that enables and performs programme decision making, establishes practices to support the programme and maintains programme oversight. Programme Governance comprises the framework, functions, and processes by which a programme is monitored, managed, and supported in order to meet organisational strategic and operational goals."*

A decommissioning programme governance plan can be set up, which means:

- Definition of roles and responsibilities of the key stakeholders and decision making
- Planned governance meetings
- Dependencies, assumptions and constraints
- Benefits, performance metrics (KPI's) and measurements

The programme activities that support programme management and governance should include:

- Change Management
- Communications Management
- Financial Management
- Information Management
- Procurement Management (including contract and claim management)
- Quality Management (including return of experience)
- Performance Management
- Resource Management (or HR Management)
- Risk Management
- Schedule Management (including Planning and interfaces)
- Scope Management
- Integration Management
- Stakeholder Management (including management of commitments)
- Health, Safety, Security, Environment Plan

The programme governance model has to be developed taking into account that the prime responsibility for safety shall remain with the licensee. The integrated management system for each phase shall provide a single framework for the arrangements and processes necessary to address all the goals of the operating organisation. These goals shall include safety, health, security, environmental, quality and economic elements [11].

4. National Policy and Regulations for Decommissioning

The development of a safe, effective, and cost-efficient strategy for the decommissioning of a nuclear facility in each country must be done within the national overall framework including the nuclear policy and the safety and regulatory requirements.

The government has the responsibility to establish the national policy for decommissioning, spent fuel and radioactive waste management by means of different instruments, statutes, and laws.

This policy can be understood as the highest level of boundary condition that has to be considered in each decommissioning project. For example, some governments establish in the national policy that immediate dismantling is the only strategy allowed, or that the site has to be released for unrestricted use after decommissioning.

The regulatory framework is one of the key factors in a decommissioning project. The overall objective is to perform the decommissioning project as efficiently as possible while maintaining a high level of safety.

Since decommissioning nuclear reactors is a relatively recent or new activity in many countries, the associated regulatory framework and processes may not have the corresponding maturity. The number and types of facilities to be decommissioned in a state, together with the types of decommissioning activities planned for the future, will influence the content of the legislation, as well as the extent of the regulatory infrastructure that is needed to ensure safety [18].

4.1 National Policy

According to [2], a national policy should reflect national priorities, circumstances, structures, and human and financial resources. Implementation of the policy requires that there is an adequate and appropriate institutional framework for decommissioning in the country, when it does not exist, the first step should be to establish it.

The same reference states that the policy should enable a graded approach to be taken to decommissioning, reflecting the level of the hazard posed by the facility to be decommissioned and its complexity.

The national policy should ensure the safety of decommissioning a nuclear facility. In particular, the decommissioning of a nuclear facility should:

- Provide protection of people and the environment both now and in the future.
- Include a long-term commitment to ensuring that sites and waste from them are properly managed.
- Provide efficiency in the use of resources.
- Provide open and transparent interactions with stakeholders.
- Include public participation in consultations.
- Meet the needs of the present without compromising those of future generations.

In addition to these general principles, the national policy could define other elements that have to be considered in the design of the decommissioning project and conforms relevant boundary conditions:

Decommissioning approaches	• Decommissioning strategy (immediate or deferred) • Maximum time for defueling • Maximum time for decommissioning completion • Starting point of decommissioning

Radioactive Waste management	• Integrated Waste management strategy:
	  • Radwaste processing facilities
	  • Radwaste storage and disposal options

Spent Fuel management	• Spent fuel management options (on-site or centralised storage facilities, reprocessing, final disposal)
Waste minimisation	• Need to minimise the generation of radioactive waste during decommissioning of facilities through clearance, recycling and/or reuse • Application of the waste hierarchy and Best Available Technologies (BAT) throughout the decommissioning lifecycle
End-state for the site	• The specific end-state for the site (unrestricted or restricted use of the site)[5]

4.2 Regulatory Requirements and Criteria

A regulatory framework generally includes the criteria to be followed by the licensee to design, plan and execute the decommissioning of a nuclear facility. In particular, the following criteria should be clear when preparing the decommissioning project:

- Clearance levels for the main streams of material produced in decommissioning.
- Methodology and limits for release from regulatory control of materials, buildings and grounds.
- Dose limits (ALARP/ALARA).
- Radwaste management criteria (e.g. waste acceptance criteria, transport requirements, consideration of BAT, ALARP exposures, etc.).
- Personnel qualification criteria needed from final shutdown to site release.

A relevant issue that should be considered is that the overall risk level (types and nature of the associated hazards to the public, workers, and environment) is significantly and progressively reduced as spent fuel is removed and the decommissioning progresses. According to [11], a graded approach should be applied in all aspects of decommissioning in determining the scope and level of detail for any particular facility, consistent with the magnitude of the possible radiological risks arising from the decommissioning. The type

[5] According to [4], Restricted use is defined as the use of an area or of materials subject to restrictions imposed for reasons of radiation protection and safety. Unrestricted use is defined as the use of an area or of material without any radiologically based restrictions

of information and the level of detail in the decommissioning plans and supporting documents, including the safety assessments, should be commensurate with the type, scale, complexity, status, and stage in the lifetime of the facility and with the hazards associated with the decommissioning of the facility.

Most countries also request to obtain an Environmental Impact Statement prior to any active decommissioning activities. The environmental impact assessment should be conducted with the preparation of the final decommissioning plan to demonstrate that the decommissioning project will not cause unacceptable adverse effects on the environment. As indicated in 4.3, if decommissioning is carried out under a phased approach, a final decommissioning plan and an environmental impact assessment for each phase is generally needed.

The environmental impact assessment is highly dependent upon the selected site end-state strategy since the level and condition of residual radioactivity maintained on site after decommissioning will have an impact for decades to come. In addition, the site end-state definition is a highly "stakeholder sensitive" subject.

The conduct and regulatory oversight of decommissioning actions should be applied in a manner that is commensurate with the hazards and risks associated with the decommissioning of the facility.

A graded approach consists of adapting the level of detail of the safety analysis to the area/equipment, or stage being considered, based on an initial assessment of the potential risk associated with a given zone or stage. A graded approach should not only be applied to the safety assessment but also to oversight, e.g. surveillance, inspection and control, organisational structure, emergency plans, work and process control, documentation, and training.

Depending on national regulations, an operating licence may remain in effect during all or part of the transition phase but the graded approach should be adapted to the new situation consistent with the magnitude of the possible radiological risks.

It is good practice to review and adapt facility instructions and the facility surveillance programme to ensure that it is appropriate initially for the transition phase and then for decommissioning, as content specific to the operational phase can probably be removed. It is also important to carry out this review in a systematic manner and in accordance with the appropriate approval route for changes to safety case documentation [10].

4.3 Authorisation Process for Decommissioning

As previously mentioned, a regulatory framework to undertake decommissioning activities exists in all countries. This framework defines the authorisation process. Usually, different authorities are involved in the authorisation process, as different disciplines are involved.

In general, no specific license is required for the plant shutdown itself (with some exceptions). However, in most cases, the licensees must inform (and sometimes an approval is needed) the relevant authorities of the intention to permanently shut down a unit, and there could be a requirement to submit reports for approval of proposed management and structural changes before decommissioning activities start.

Depending on the country, decommissioning may be subject to the granting of a license specifically for decommissioning or an authorisation to perform decommissioning actions in the framework of a license granted for the whole lifetime of the facility until the facility is released from regulatory control. When no specific license is required for decommissioning, other authorisations are usually applied (e.g. environmental impact statement).

In addition, two approaches have proved to be relevant to decommissioning:

- For small facilities such as research reactors, establishing a single decommissioning authorisation process can be rather straightforward.
- The situation can be quite different for large and complex projects like a power reactor or a fuel cycle facility. Decommissioning of large facilities may be conducted in a number of phases in accordance with the decommissioning plan. It is generally good practice to produce separate safety assessments for different phases, so that they are focused on current and near-term activities and to avoid overly complex documentation that unnecessarily addresses tasks that may not be executed until years later. The level of detail of the safety assessments for later stages is typically less than for the earlier ones The decommissioning strategy and work methods may evolve through a decommissioning project, so it is important that supporting safety assessments be kept in line with such project developments [10].

For the above reasons, a phased or staged approach to safety assessment should be considered for having considerable advantages in terms of programming, cost and quality [10].

In the case of utilities owning several nuclear plants, a fleet approach for specific activities of decommissioning is considered to allow optimisation of decommissioning time and costs. The regulatory body and the licensee could agree that the major application documents in support of the final decommissioning plan be developed at the corporate level and submitted to the regulatory body as common for all fleet facilities. In this case, optimisation of the authorisation process could be considered [31].

The following figure includes the evolution of authorisations. Depending on the country and/or the site, transition phases could have different durations. The post-operational phase could practically not exist in a case where the dismantling phase starts immediately after unloading (empty core).

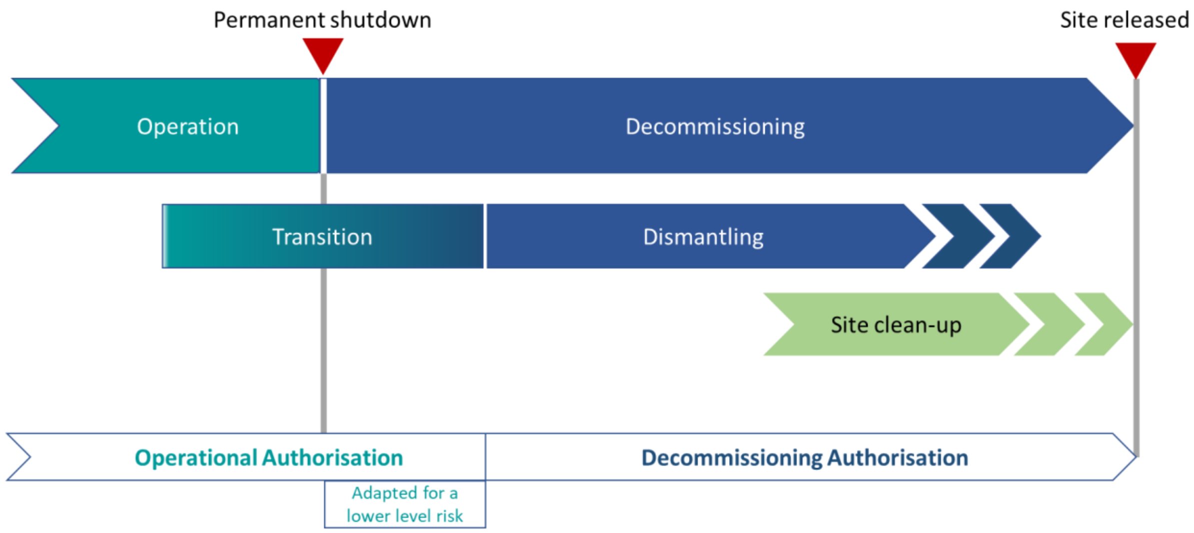


Figure 4-1: Evolution of the authorisations for a Nuclear Power Plant in those countries where a decommissioning license is needed (immediate dismantling strategy) - Adaptation of figure in [31].

Therefore, it is very important to engage all concerned parties at an early stage (safety regulator, environmental agency, local and regional communities), in the definition of a commonly agreed end-state for the site.

4.4 Regulatory Authorities' Roles and Responsibilities

The regulatory and legal requirements needed to be fulfilled to undertake decommissioning activities are not only defined by the nuclear regulator, but also by other competent authorities (environmental protection agency, health authority, building authority, local authorities, fire safety authority, etc.).

All relevant competent authorities involved in the authorisation process for decommissioning of the nuclear plant should be identified at an early stage during preparation for decommissioning. The roles, limitations of each authority, interactions and timescales of the approval process need to be clear in order to establish the schedule and provide adequate resources for the decommissioning project.

Besides regulatory authorities, it is also convenient to identify other stakeholders in advance as comprehensive and early stakeholder engagement is essential to build confidence in the decommissioning project and have a smooth transition process.

Finally, it is also recognised that regulatory authorities should adjust their approaches to the changing risk profile during decommissioning and remain flexible to adequately address this change in order to ensure a successful transition to decommissioning [31].

4.5 Regulator and Operator Dialogue

Throughout the entire life of the facility, a fluent dialogue between regulatory authorities and licensees is targeted to ensure that regulatory requirements are duly implemented. Moreover, a continuous and constructive dialogue could help in understanding authorities' expectations as well as concerns on the decommissioning authorisation application. Consequently, the review by the authorities should be carried out in a smooth and timely manner, saving time and costs.

Agreements and commitments between regulatory authorities and the licensee could be useful for addressing specific cases of overlapping jurisdictions between different authorities. It could also be an advantage for all of them in a case where several nuclear power plants are expected to apply for decommissioning at the same time.

Suggested approaches for establishing a fluent dialogue are as follows:

1. Arrange joint training with the regulator.
2. Define a clear process for communication and interactions. Establish a good working relationship with the regulator in an adequate manner to build confidence between the parties.
3. Ensure discussions are carried out with a common language to avoid misunderstandings; decommissioning is a multidisciplinary project and "different languages" are used.
4. Hold formal and informal discussions on generic and specific issues about decommissioning, in which relevant topics could be identified and addressed for formal discussions.
    - Permits required according to the activities to be carried out.
    - Documents (structure and content) supporting the authorisation application.
    - Safety requirements/criteria to be fulfilled.
    - Define the way to implement a graded approach according to the needs of the facility which vary along the decommissioning project.
    - Process and time schedule.

- In case of possible amendments in regulation, information could be obtained in advance, and implementation of new requirements discussed with the regulator.

5. Organise plant walkdowns to gain a more realistic view of the future decommissioning project, involving multidisciplinary teams from both sides.

5. Decommissioning Plan

This chapter describes fundamental considerations for the decommissioning plan. The plan is to be submitted to the regulatory body or the government before decommissioning is conducted: risk management related with assumptions made due to uncertainties in technology, legal requirements, stakeholder's interests and licensing for decommissioning. In some cases, preparatory activities are included in the decommissioning plan.

Planning for decommissioning starts during the initial design of the facility and ends with the approval for site release by the regulatory body. During this time, a number of documents must be prepared to help ensure that the decommissioning process is carried out in a safe and efficient manner. In general, in order to show that decommissioning can be accomplished in a safe and efficient manner, a decommissioning plan shall be prepared. As part of a facility's initial authorisation, a preliminary decommissioning plan is developed to demonstrate the feasibility of decommissioning and provides assurance that provisions are in place to cover the associated costs. Throughout the lifetime of the facility, operating organisations are required to maintain and update the decommissioning plan [10].

In most countries, once a decision to permanently shut down the facility is made, a final decommissioning plan[6] is to be developed during the transition phase (some years before the planned permanent shutdown) and submitted to the regulatory authority (see requirement 11 of [11]).

These studies should identify the systems, equipment and infrastructure from the operational stage that will need to be maintained for use during decommissioning, should specify, and, if necessary, research any new systems, equipment and infrastructure that will need to be installed to support decommissioning.

[6] In some countries, there is not a specific document called "final decommissioning plan" required, but independent documents are drawn up with similar contents.

The following figure shows the role of the evolution of the decommissioning plan along the life of the facility.

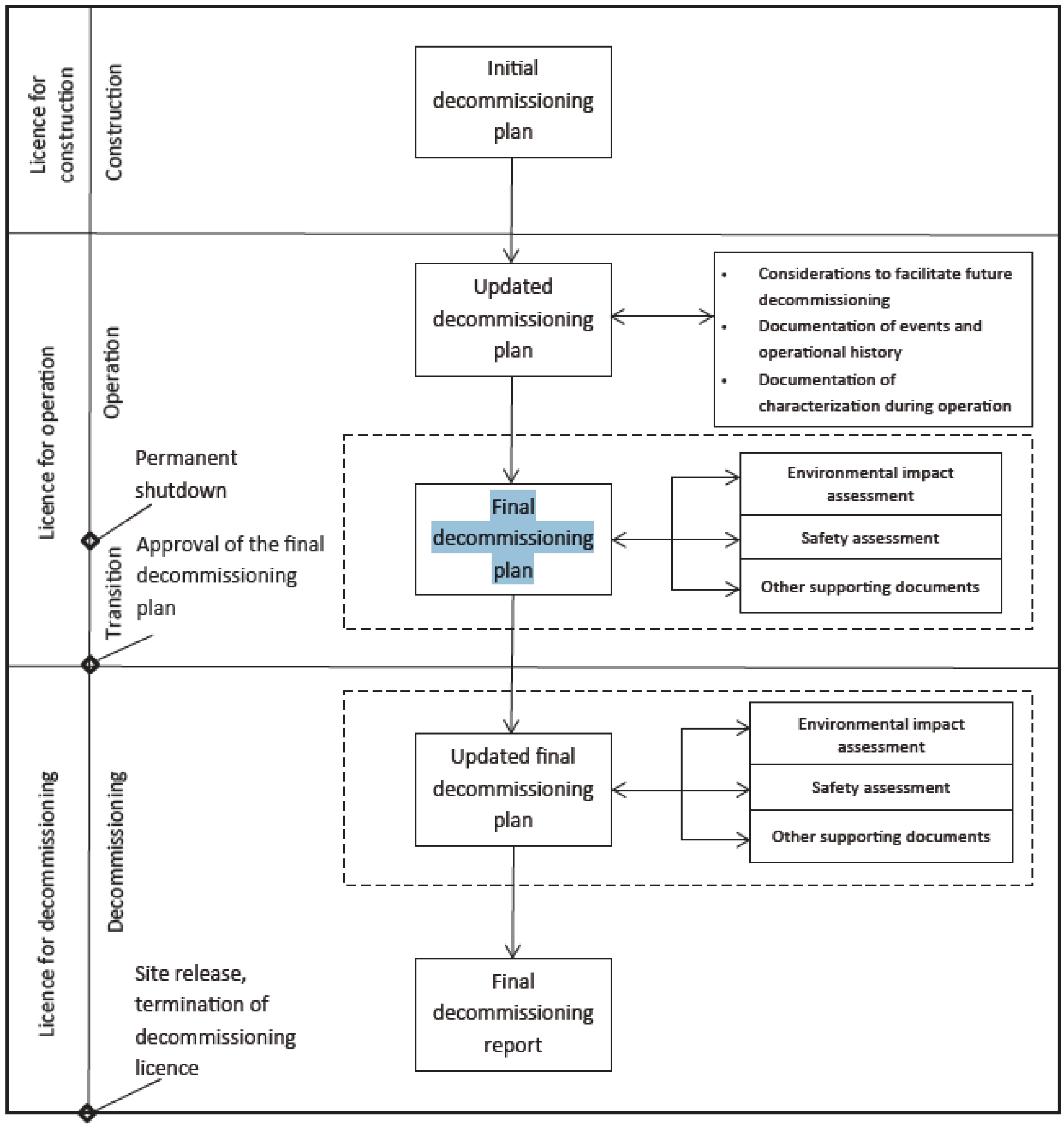


Figure 5-1: Relationship between the lifetime of the facility and the evolution of the decommissioning plan [7]

Guidance on the contents of decommissioning plans can be found in several international publications and national regulations, but in general, a decommissioning plan may include the following items [10], [31]:

- The facility description, site and life history of the facility, including radiological characterisation of the site.
- The decommissioning strategy and rationale for the preferred decommissioning option.
- The regulatory requirements and radiological criteria.
- General decommissioning project, timeframe and end-state. Scope of each phase in the proposed decommissioning, if a phase approach is applied.
- Information on the availability of services and decommissioning techniques.

- The material and waste management plan.
- The safety assessments, including the radiological and non-radiological hazards to workers, the public and the environment (as indicated above, safety assessment may be presented separately).
- The surveillance and maintenance programme.
- The environmental monitoring programme.
- Provision of the programme of the final radiation survey.
- Quality assurance provisions.
- Emergency planning arrangements.
- Fire protection plan (when required in a separate document)
- Physical security and safeguards arrangements.
- A final estimated inventory of residual contamination.
- Description of the organisation and responsibilities of personnel involved in the decommissioning activities, including the number of technical qualified personnel (personnel involved in radiation protection and safety), and the skills and qualifications of personnel.
- Cost estimates and source of funds.

When dismantling starts with spent fuel in pools, a Spent Fuel Management Plan is usually required to be submitted with the decommissioning plan.

One of the key components of the decommissioning plan is a safety assessment of the decommissioning activities, although this may be presented separately in supporting documents. The safety assessment facilitates the planning of work in a progressive manner aligned to the needs of the project, and it indicates the required steps in hazard reduction. The results of the safety assessment are important for decommissioning planning; therefore, both must be consistent and prepared together as neither can be completed without the other.

The main objective of the safety assessment is to demonstrate that the potential hazards arising from decommissioning have been identified, consequences estimated, and adequate measures proposed to ensure safety. Therefore, the safety assessment includes the applicable safety and radiological regulations and criteria, the identification and analysis of risks under normal operational and accident conditions, and preventative measures to be adopted.

When decommissioning is conducted in different phases according to the decommissioning plan, separate safety assessments are generally produced for each phase so that they are focused on current and near-term activities.

It is considered good practice to apply a graded approach to the decommissioning safety assessment, where the complexity and detail of the safety assessment are appropriate to the level of hazard and consequent risk presented by the planned work [10].

Appendix I of [10] includes an example index for of a decommissioning plan. In accordance with a graded approach, the level of detail for each chapter will depend on the complexity of the decommissioning project. Appendix C: Content Examples of Decommissioning Plans of this roadmap includes examples of a decommissioning plan contents in several countries.

6. Safety Case Strategy during the Post-Operational Phase

Every nuclear power plant, or other nuclear facility, are obliged by national and international regulations to justify that the facility is maintained in a safe configuration following permanent shutdown and, if applicable, until the approval of the final decommissioning plan. This demonstration can be referred to as the 'Safety Case'.

The safety case can be defined as the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a facility. It includes the totality of documentation developed by the licensee and is supported by a set of analyses demonstrating that possible hazards, events and accidents have been correctly identified, and that necessary safety functions are capable and available to keep the consequences of any such events within stipulated boundary conditions.

The safety case should be representative of the plant configuration, on-going activities and risks. After final shutdown reactor plants present a significantly lower risk to the public, but still include potential risks to workers, and involve a significant change of the focus areas. For this reason, the safety case carrying the evidence of safety should be adapted in the transition phase to correctly address the risks and their prevention in that situation. Further updates should be carried out when entering the dismantling and demolition phase.

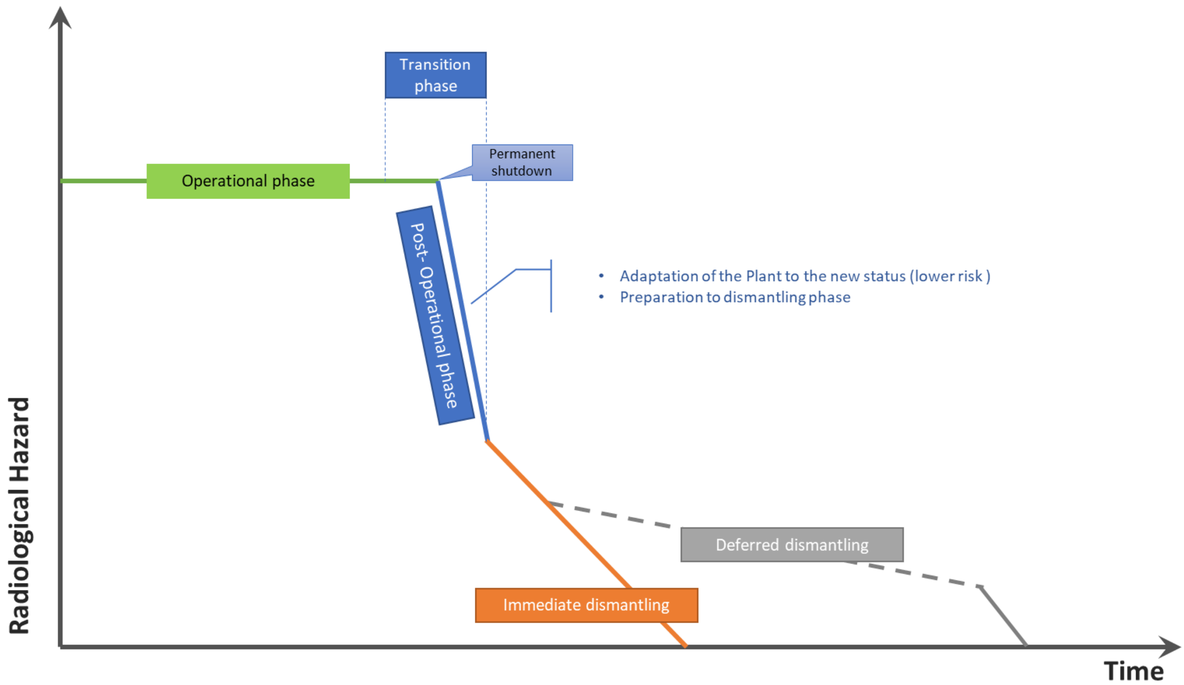


Figure 6-1: Evolution of radiological hazards with the time, not to scale (Adapted from Figure 1 [8])

Once a reactor is permanently shut down and defueled, regulations that are designed to protect the public against reactor operation-related design basis events (that include conditions of normal operation, anticipated operational occurrences, and design-basis accidents) are no longer applicable. For example, certain accident sequences, such as loss-of-coolant accidents and anticipated transient without scram, are no longer relevant to a permanently shut down and defueled reactor. In addition, some regulations may not be relevant to certain SSCs since the SSCs are no longer required to be maintained, to operate, or to mitigate certain accidents, events, or transients, whether they are safety-related or security-related [64].

Upon a licensee's permanent cessation of reactor operation and permanent removal of fuel from the reactor vessel, the licensee will typically submit a significant number of requests for licensing actions based on the reduced risk profile. For example, to eliminate unnecessary surveillance and procedures required by the Technical Specifications (TS) for systems not required after permanent cessation of the plant, they will be reviewed to remove sections that no longer apply, leaving mainly the TS related to the safe storage of the spent fuel and administrative/organisational items. Approval for the updated Final Safety Analysis Report (FSAR), including reclassification of SSC's important to safety, updated accident analysis and other changes due to the permanent shutdown status, will be also submitted. In addition, the reduction of requirements and staffing in the Emergency Plan (EP) will be typically applied and some plants have also applied for exemptions in on-site and off-site insurance requirements.

Nevertheless, other activities could be carried out during this phase focused on preparing the dismantling. [8] identifies and discusses safety concerns and considerations associated with the riskiest activities that are normally carried out during post-operational phase; these include:

- Handling and temporary storage of nuclear fuel.
- Drainage of systems.
- Cleaning and decontamination of systems.
- Shutdown of systems.
- Reconfiguration of systems.
- Implementation of new systems.
- Modification in auxiliary facilities
- Changes to confinement barriers.

The following figure shows the different steps for building a Safety Case during the post-operational period.

REFERENCE FRAMEWORK
Laws/Regulations/Guidelines/Classification scheme/Good Practices

MAIN SAFETY FUNCTIONS
- Subcriticality
- Decay heat removal
- Confinement

APPLICABLE ACCIDENTS
- Design Basis Accidents
- Post Initiating Events
- Design Extended Conditions

SAFETY REQUIREMENTS
Stepwise Reduction of Requirements

SAFETY ANALYSIS
- Deterministic Safety Analysis
- Probabilistic Safety Analysis
- Radiological consequences of accidents
- Assessment of Defence in depth

PLANT DESIGN BASIS
- Safety related SSC's required for prevention, detection and mitigation of incidents & accidents
- Classification of SSC's

IMPLEMENTATION OF A GRADED APPROACH
- Modified Safety Analysis Report
- Reduced Technical Specifications
- Post Operational limits
- System downgrade process
- Optimisation of programmes (maintenance & surveillance, ageing, equipment qualification)

Figure 6-2: Process of preparing the Safety Case for the post-operational period.

The following paragraphs include some considerations for the safety case strategy during the post-operational phase:

- **Immediate or Deferred Decommissioning**

  The strategy for adapting the safety case in the post-operational phase will be slightly different depending on the overall decommissioning strategy. In case of immediate decommissioning, the option to just maintain the safety case applicable for power operation can be considered for the post-operational phase. In a deferred decommissioning case, the length of the phase between end of operation and start of decommissioning gives stronger motivation to prepare a safety case specifically for the post-operational phase.

  For facilities that were shut down a long time before the start of decontamination or dismantling (long transition phases), a survey of equipment and buildings should be made to assess hazards associated with the deterioration of SSCs. In addition, consideration should be given to the materials of the physical barriers and process equipment for which mechanical properties might have changed during operation, owing to factors such as fatigue (e.g. from cyclic mechanical or thermal loading), stress corrosion, erosion, chemical corrosion or irradiation [2].

- **Stepwise Reduction of Requirements (as consequence of risk reduction)**

  The post-operational phase can be a phase with continuous or frequent changes in plant configuration and safety case. It would however be impractical to constantly revise safety case documentation, while a few relevant steps of change should be defined. Two main steps can be defined during the post-operational phase:

  1. The unit is permanently taken out of operation and brought to a state of cold shutdown. As a number of initiating events in the safety case applicable during power operation are no longer relevant, associated safety functions and systems will become unnecessary.
  2. Removal of spent fuel or reconfiguration of spent fuel supporting systems.
     a. For many plants, but not all, the second main change in plant configuration is when all fissile fuel has been removed from the unit. Remaining safety functions for reactivity control, safeguard systems and residual heat removal will then no longer be needed.
     b. In cases where decommissioning will commence with some spent fuel remaining at the plant, this step represents the situation when that remaining fuel has been arranged in line with the safety case for start of decommissioning. This scenario will have more safety functions remaining in the safety case, e.g. spent fuel cooling.

  Depending on the plant, if the post-operational phase is short, one option is to not adapt the safety case, i.e. to consider the safety case valid for power operation remains applicable during transition to decommissioning. The post-operational phase can be considered as implicitly covered, since operational modes "cold shutdown" and "empty core" are part of the standard safety case for an operational reactor.

  The driver to adapt the safety case for the post-operational phase is, however, to allow elimination of requirements that are no longer relevant. The reactor defueling fundamentally changes the licensing basis of the plant SSCs. Systems that once performed reactor safety functions or power generation functions are either no longer required to perform those functions or will be significantly modified in the permanent shutdown condition. Less systems remaining in service will reduce operational costs. In addition, existing SSCs may be reclassified and progressively removed from service and dismantled as the decommissioning progresses. Recategorisation and reclassification of SSCs is a critical task in decommissioning planning that requires a substantial level of engineering and operations work.

  Further preparatory activities as prerequisites for dismantling can be more easily undertaken during the transition phase. In the following decommissioning activity after the post-operational phase, the requirements and boundary conditions for the safety case will change again. The transition phase should be used to plan for how the safety case needs to be further adapted to enable optimised cost savings but still remain relevant at each time and configuration throughout the following decommissioning. This planning needs to consider that the plant is in constant change during decommissioning, but it will not be practical to update the safety case too often. A reasonable strategy would be to select a few key steps in the plant configuration and site conditions and demonstrate that all dismantling and waste handling activities can be safely implemented in each respective plant configuration.

- **Safety Assessment**

  The safety assessment as an integral part of the safety case and should be developed in a systematic manner using a graded approach, proportionate with the hazards associated with the facility and with the possible consequences of the activities during the post-operational phase. The framework defined for the decommissioning phase in [6] can also be applied for the post-operational phase.

- **Post operation SAR/TS (and other Revision of Plant Design Basis Documents)**

  The Safety Analysis Report and the Technical Specifications (SAR/TS) are key documents for the safety case. Adapting the safety case therefore implies to revise these documents.

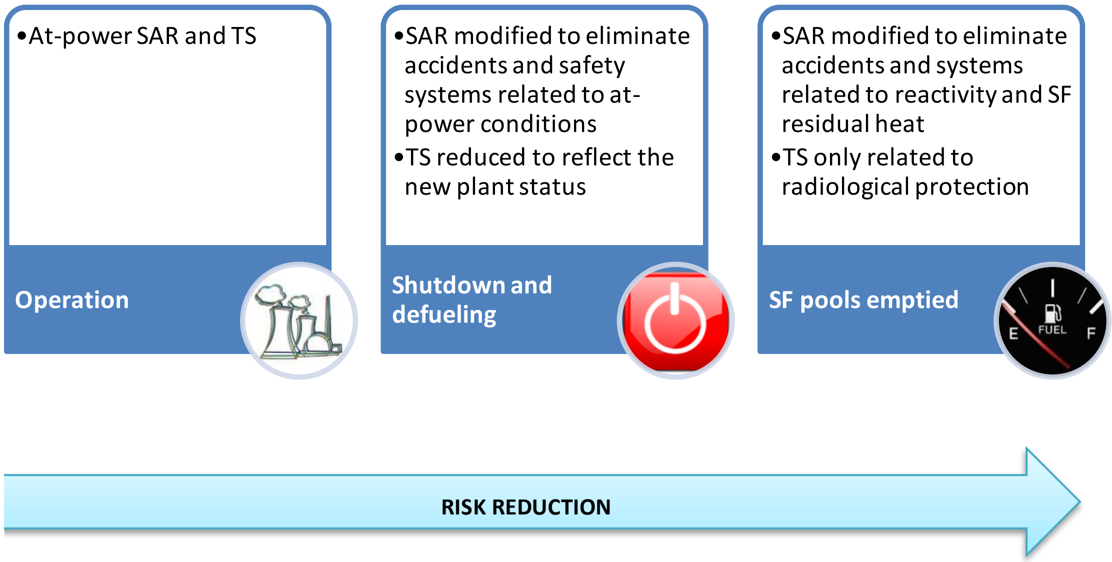


Figure 6-3: SAR/TS during post-operational phase created by eliminating no longer necessary parts from the at-power applicable version.

Two approaches are possible for the SAR/TS for the post-operational phase; a revision of the operational SAR/TR or a completely new SAR/TS. This second approach is more common when the post-operational phase is very short and Decommissioning Authorisation is granted almost immediately after final shutdown.

Other licensing documents that should be revised to reflect the actual status of the facility include the following:

- **Maintenance and Surveillance Requirements**

  For equipment and systems no longer needed according to the revised safety case, maintenance and surveillance requirements may be reduced accordingly.

- **Organisation and Emergency Preparedness**

  The emergency preparedness and capability to respond to events should be aligned with the hazards and possible consequences as defined in the SAR.

  The emergency preparedness with capacity to evacuate the site will likely have to remain unchanged as long as fuel remains in the last operating unit of the site.

  When fissile material has been removed from the unit and there is no risk for reactivity events, radioactive releases may still occur from existing radioactive waste and contaminated equipment and systems. Fire is a possible event that could generate such releases. If the hazard analysis demonstrates those possible releases to be significantly smaller than corresponding releases from possible accidents during operation, the emergency preparedness may be reduced or exempted accordingly.

- **Operating Training Programmes**

  Operating training programmes can be adapted according to the safety case and remaining safety systems still in operation.

- **Physical Protection**

  Access control and physical protection should remain on the same level as during operation if fissile material remains on the unit.

  Depending on national arrangements and regulations, the security classification of the unit/plant may be shifted to a less stringent category once all fissile material has been removed. Even after that, some IAEA safeguard obligations will remain.

7. Spent Fuel Management

Spent fuel represents more than 99% of the radiological inventory of a shutdown nuclear power plant and its removal from SFP leads to a first significant decrease of risks in nuclear safety after permanent shutdown. As indicated in [31], early removal of the spent fuel to an interim storage facility or reprocessing plant may facilitate decommissioning activities and significantly contribute to cost reduction, due to the reduced requirements to maintain dedicated resources and facility systems.

Defueling following end of generation is usually done within the operational safety case and associated operational procedures and practices. The site should think about what could be done during the phase of defueling and how to optimise its duration. One way to optimise fuel cost is to optimise the last cycles (composition of last cores).

The particular situation of damaged fuel assemblies must also be considered and anticipated before permanent shutdown. A different plan should be prepared, submitted for approval and separately conducted. Also additional non-fissile material in the pools should be anticipated in time.

7.1 Spent Fuel Removal from Pools

Spent fuel removal and shipping are routine NPP operations. Management should take advantage of the experience from former NPP operating staff using operational procedures, components and systems. This aspect is a further argument to focus on the fuel removal as early as possible after end of generation, while these resources and competencies are still at hand. The entire campaign for defueling and removal of all fuel from the pools to an external or on-site facility should be planned and managed as a project with a clear start and transition end-point. This is a difference in mind-set from regular fuel handling during operation, which is cyclic in nature.

When preparing the overall plan for fuel removal, attention should be given, when applicable, to external factors, e.g. facilities and actors for transport off-site and receiver capacity at external destinations (intermediate storage or re-cycle facility). Experience from Sweden, for example, is that the limiting conditions for fuel removal are not within the site boundaries but with those external factors. Likewise, risks associated to the logistics outside the site should be covered by the sites risk monitoring.

Fuel shipping to final disposal may be preferred. However, as disposal sites for spent fuel are not available, international practices may vary, for example:

- In France, Russia and Ukraine, spent fuel is sent to a reprocessing plant, and subsequent HLW is stored, waiting for national final disposal.
- In Finland, Slovakia, Sweden, Germany, Spain, and the US, spent fuel is stored in interim facilities located either near the NPP site, or centrally, waiting for the national final disposal facility to become available.

Plants should evaluate potential issues in the case that, after decommissioning of the plant, there is no spent fuel pool anymore to handle the spent fuel pool containers.

7.2 Decommissioning with Spent Fuel in Pools

Uncertainties with SF management solution have a very high probability of implying inefficiencies and therefore delays and extra costs in the project. If there is no certainty about the timely availability of the considered SF strategy, other alternatives should be defined in advance.

Before starting the decommissioning design, the licensee should be clear when the spent fuel can be removed from the reactor pools. In cases where it is not possible to empty the SFPs in a short time, starting decommissioning with spent fuel in pools is becoming more frequent in international projects for water reactors[7] and those countries whose national regulatory allows it (e.g. USA, Germany, Switzerland, Spain, etc.). By contrast there are other countries, like Russia, Sweden and Ukraine, where the dismantling cannot start until the SFPs are emptied. For example, the following plants have started or have foreseen to start the decommissioning with spent fuel in pools:

- In the US: Big Rock Point, Crystal River 3, Haddam Neck, Humboldt Bay 3, LaCrosse, Maine Yankee, Oyster Creek, Pilgrim, San Onofre 2&3, Trojan, Yankee Rowe, Zion 1&2[8].
- In Germany: **[Redacted Plant Names 4]**.
- In Switzerland: Mühleberg.
- In Spain: **[Redacted Plant Name 11]**.

On the other hand, the risks of dismantling systems and implementing decommissioning activities while there is spent fuel in the pools have to be analysed in accordance with the foreseen activities and potential accidents. In Germany [36], a regulatory framework was amended in 2015, amongst others in order to better reflect the approach "decommissioning with fuel elements or fuel rods present" as foreseen within the applications for decommissioning of NPPs in the post-operational phase.

The decommissioning project for Mühleberg in Switzerland [41] was designed in several phases; phase one was carried out at the same time that the spent fuel was removed from the pools. During the post-operational phase, a safety grade SFP cooling system was installed to substitute the coolant system in operation. The most relevant dismantling activities that were also carried out during phase one were the disassembly of reactor internals, disassembly of the containment vessel lid and the insulation hood of the reactor pressure vessel, and disassembly of emergency core cooling system/systems for decay heat removal.

As indicated in [31], in order to facilitate removal of SSCs that have formed part of the original facility for spent fuel handling and storage, a decision needs to be taken whether they can be modified to suitably cope with the new situation. Some operators (mainly US operators in the 90's) have elected to install a completely new SFP support system, sometimes referred to as an SFP island (SFPI). The SFPI is functionally and operationally equivalent to the original subsystems, however it is typically much smaller because there are lower requirements to manage the heat load represented by the spent fuel as this has already had time to cool and no new spent fuel is being produced. In addition, the modification of the SFP and supporting systems to be independent from other plant systems eliminates the risk that a SFP support system could be damaged by dismantling operations outside of the fuel building.

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[7] From a Graphite moderated reactor perspective, no dismantling will commence until Fuel Free Verification and all fuel removed from site

[8] Some of these plants (mainly those that were shutdown in the 1990s [46]) implemented a SFPI due to the uncertainties in the date when the SFP could be emptied.

If the associated SFP systems will be modified, all engineering and planning work associated with this modification should be completed before the date of permanent shutdown and the modification should be implemented as soon as possible after permanent shutdown to maximise the benefit of the modifications. Nevertheless, these modifications are expensive and require a licensing process that could be complex. The final decision should be taken only after conducting a cost benefit analysis at least considering the following factors [46]:

- Whether the decommissioning regulations allow dismantling activities to begin with spent fuel in pools.
- The cost of implementing the modifications.
- How many years the SFPI would need to be operational.
- If storage of the spent fuel in the SFP with the operational systems for the duration above would delay major decommissioning activities.
- If storage of the spent fuel in the SFP with the operational systems for the duration above would increase risk during decommissioning transition activities.

7.3 Reliability of Different Fuel Handling Tools

The handling of spent nuclear fuel is one of the most safety significant activities following the permanent cessation of plant operation. Although removal of fuel from the reactor is part of normal operations and fuel handling accidents have been considered in the operational stage of the plant, they have to be reassessed. Special attention must be paid to the safety assessment of fuel handling sequences that are different from those occurring during routine operation.

Cranes and other fuel handling equipment used during operation that are to be used during post-operation or decommissioning phases need to be tested and maintained to ensure their functionality and reliability during the required time. The operator should provide and anticipate a programme to improve reliability of the different components and material of the site involved in spent fuel expedition (in some countries this is five years in advance).

This aspect requires a significant amount of forward planning and investment for a graphite moderated reactor where the defueling phase is extended when compared to a water cooled reactor. Defueling activities may continue for in excess of three years placing a considerable strain on the fuel handling systems, so achieving maximum availability/reliability is of great significance.

7.4 Off-site Spent Fuel Management Risks

Spent fuel management is a significant part of cost after end of generation and critical path. It may be influenced by external factors such as availability of central storage facilities, availability of casks, requirements from off-site transport and future storage, processing or disposal facilities or public acceptance.

When the spent fuel has to be transferred to external facilities, requirements for future handling and transport and acceptance criteria for processing or disposal facilities have to be considered during post-operational phase in order to not jeopardise these future activities. Likewise, logistical issues outside the site should be also considered.

The site should consider these risks related to external factors (off-site fuel expedition, future storage, processing or disposal facilities). The risks and their impact should be identified, potential mitigation and monitoring measures anticipated, and margin included in the schedule.

8. Asset Management Optimisation

Nuclear Asset Management has been defined by the US Nuclear Energy Institute (NEI) as *"the process for making resource allocation and risk management decisions at all levels of a nuclear generation business to maximise value/profitability for all stakeholders while maintaining plant safety"* [57].

The overall objective of asset management during the post-operational phase is to maintain and prepare the asset for decommissioning at the lowest possible cost, but without compromising any safety requirements.

A nuclear power plant is an essential asset in terms of financial value as well as complex management. The value of the asset changes drastically when a plant does not generate electricity. From then on, there are only mandatory activities for decommissioning with significant costs, but no positive cash flow from electricity sales. Limiting the costs for maintaining the asset becomes increasingly important, as there is no longer an income to balance costs.

Asset management and its optimisation in this chapter refers only to tangible assets, i.e. in this case the physical plant to be decommissioned. It includes not only the transition phase but also the decommissioning period.

A general assumption is that the date for end of operation is known with at least a few years notice. In the case of an unplanned final shutdown, several of the principles and advice in this chapter will not be possible to apply.

The main areas to focus on in asset management are: fuel management optimisation, gradual shutdown and reconfiguration of systems and facilities, optimisation of associated programmes, the end-point of the systems and facilities, and the technical interfaces in order to isolate the facilities.

8.1 Fuel Management Optimisation

8.1.1 Optimise Fuel Use for the Last Cycles

Core designs are typically based on multi-cycle scenarios and the detailed fuel design (enrichment level, amount of burnable poison, etc.) needed for this is determined and ordered years in advance. To optimise fuel use for the last fuel cycles, the time for final shutdown must be defined several years in advance. In that case, the level of enrichment in fresh fuel can be successively lowered during the last few cycles and the costs for uranium and enrichment services reduced.

The optimisation should take into account the value of electricity generation, the cost for enrichment and fuel fabrication, the cost for performing refuelling outages, and cost for storage and disposal of spent fuel. The optimal strategy will be determined by these parameters. High value of generation in combination with high cost for fuel would promote a strategy of planning shorter cycles and additional refuelling outages to maximise energy extraction from existing fuel. Low fuel cost on the other hand, could lead to a strategy of purchasing surplus fuel to guarantee production at high power and long cycles until end of operation.

8.1.2 Use of Remaining Fresh Fuel

Depending on how well in advance the end of operation is known and how well the use of fuel during the last cycles have been optimised, there may be a surplus of fresh fuel at the end of operation. Considering the financial value, it is worth some efforts to find an alternative use the fuel. The ideal solution is to find an operational unit that uses fuel of the same design. If differences are minor, modification of the fuel assembly to fit another unit could be considered. The last option would be to return the fuel to the manufacturer, for retrieving the uranium in manufacturing other fuels.

A more far-going variant on this theme is to reuse irradiated fuel in another unit. Fuel elements designed for generation in four to five cycles that have been used in only one or two cycles contain enough remaining energy to make the idea interesting. To achieve this, special safety analyses and licensing of the entire operation must be completed: transport of irradiated fuel from one unit to another, receiving and using such fuel in the operating plant. Experiences from Sweden (fuel transferred from **[Redacted Plant Name 6]** 1 to **[Redacted Company Name 7]**) and Greifswald (fuel transferred to **[Redacted Plant Name 8]**) have demonstrated that this is a realistic possibility. Possible impacts on the spent fuel management liabilities and guarantees from the fuel supplier are factors that must be carefully addressed.

8.1.3 Defueling Logistics and Controls

The defueling strategy may differ depending on the existing framework; local (site) or national storage, wet or dry storage, recycling/reprocessing or once-through process. In all variations of those however, a goal will often be to empty the spent fuel pools as soon as possible; in some countries (like Sweden or France) it is a regulatory requirement to have the spent fuel emptied before starting dismantling activities. In countries and situations where this is not the case, the defueling activity should consider to reach arrangements that allow decommissioning to start without any increased risk to damage the fuel remaining in storage at the unit.

Logistics for removing fuel from the unit should be planned together with planning for core operation during the last cycles. Depending on the system for transportation and storage of spent fuel, limitations may exist in terms of required decay periods before a fuel assembly may be subject to transport.

Characteristics of spent fuel (such as radioactivity inventory, burnup, defect etc.) need to be analysed and databased prior to defueling from the unit.

8.1.4 Damaged Fuel Management and Disposition

Damaged fuel is an irregularity that requires special handling, special tools, and special arrangements for transportation and storage. Since this is a non-routine activity and one of the barriers is weakened or broken, handling of damaged fuel carries a higher risk for radioactive releases than regular fuel activities. Therefore, a special risk assessment should be completed in line with recommendation four of [69].

To reduce the risk of disturbances during the fuel removal activity following final shutdown, damaged fuel should, as much as possible, be repaired or incapsulated and removed from the unit prior to final shutdown.

8.2 Gradual Shutdown and Reconfiguration of Systems and Facilities

Based on the needs stipulated by the safety case (see Chapter 6) and the chosen decommissioning strategy, there may be some systems and plant components that are no longer necessary. To optimise asset management costs, these should be permanently taken out of service and dismantled as soon as possible. In the "cold and dark" strategy, most systems related to the real estate infrastructure can be turned off. This scenario implies that alternative temporary solutions will be used during dismantling (comparable to the situation during the building period, before permanent systems are installed).

However, this choice of strategy must be based on a plant-specific assessment and analysis of the conditions. The amount and character of service functions necessary to realise the chosen decommissioning strategy may justify maintaining existing systems in service. If the decommissioning strategy is in the direction of “cold and dark”, it could be efficient to replace some existing systems with mobile or temporary solutions already during the transition phase.

8.3 Optimisation of Associated Programmes

8.3.1 Last Outage Scope Adjustment

Maintenance and control programmes can be optimised in the last outages by reducing maintenance on equipment and systems that will be permanently taken out of service or declassified after final shutdown. As explained in Chapter 6, it is important, though, to have a safety case and SAR/TS for the post-operational phase prepared to be the basis for such optimisation. Equipment and systems that will be credited for safety functions also in the transition phase (and perhaps later during dismantling) must be maintained, controlled and verified to be fit for duty. Likewise for equipment no longer needed after final shutdown, maintenance and controls must not be reduced in a way that can put their proper function at risk during the remaining phase of operation.

8.3.2 Adaptation of the Maintenance Programmes

When a final decision has been made to shutdown the unit, all (maintenance) programmes must be reviewed well in advance before permanent shutdown of the plant in order to reduce the maintenance cost. Based on a risk analysis, main equipment (turbine, generator, etc.) and some preventive maintenance can be adapted to visual inspections or corrective maintenance. Also the replenishment of spare parts has to be reviewed in accordance with the adapted maintenance plan.

The maintenance strategy can be further optimised when operation has ceased and the transition phase has started. Periodic testing and a spare part strategy should be driven first by ensuring reliable functionality of all systems and equipment credited in the applicable safety case for post-operational phase (see Chapter 6). Secondly, all other functions needed during the transition phase shall be properly maintained and verified.

Remaining systems not required for safety or other functions neither in transition nor later on in decommissioning can be excluded but should also be considered in terms of potential interaction hazards and appropriate actions taken to mitigate these risks.

The strategy must be selected with consideration of the overall decommissioning strategy. Immediate decommissioning will allow more far-going reduction in regular maintenance, while the deferred strategy may require more systems and functions to remain covered by a long-term maintenance programme.

Finally, in case of uncertainty, it is advisable to apply conservative decision making. It is, in most cases, a smaller problem if some systems and equipment are maintained and it later turns out unnecessary, than the other way round; systems that turn out are needed have not been sufficiently maintained to stay fit for use – in particular if the matter would be of any safety significance.

8.3.3 Reuse or Recycling of Usable (spare) Parts

Several parts from a final shutdown unit can be useful as spare/replacement parts in other units still in operation. Other possibilities include commercial value, i.e. to sell spare parts to other nuclear power plants. Furthermore, to take material samples for research (destructive testing not possible in an operational unit).

It is suggested to create an inventory to identify parts that are valuable enough to motivate the effort of recycling/selling. This analysis should be done well in advance of the final shutdown in order to plan for removal of usable components during the transition phase. Focus should be placed on components subject to obsolescence on other similar units and/or components of significant commercial value. Experiences from Sweden indicates that too high cost for removing and requalifying components for reuse in other units excludes many objects of potential interest from the sales catalogue.

8.4 Optimisation of the Actual Projects and Modifications Portfolio

When a final decision has been made to shutdown the unit the actual portfolio of all projects and modifications has to be reviewed well in advance before the permanent shutdown of the plant. Based on a risk analysis, some projects and modifications can be ceased or adapted in scope in order to reduce the cost.

8.5 Separation of Common Services and New Functionalities for a Multi-unit Site

A power plant can be a multi-unit site, typically hosting two to six reactor units, with shared common functions and site infrastructure. Examples of common functions are substation, reserve electrical supply auxiliary systems (N_2, H_2, chilled water), site security and access control, waste treatment facilities, fresh water supply, information systems, etc. If the unit to be first decommissioned exercises control over such common functions, and those will be required for the continued operation of other units, such control must be transferred to units in operation or to a separate entity for such control beside the reactor units on the site.

The first step, in arrangement of site infrastructure to prepare the decommissioning of a unit, is to identify all such dependencies between the unit to be firstly dismantled and the rest of the plant.

When common functions and interconnections between the units have been identified, the next step is to define which separation activities are necessary and plan for these. If the necessary separation is not performed in time so that the unit to be decommissioned and the unit(s) to continue operation are made independent of each other, the decommissioning start may be delayed which will increase costs.

8.6 Transition Phase End-Point

A documented definition of the intended facility end-point to be achieved after the post-operational phase should exist. This should cover all aspects of the facility to enable a controlled transition into the decommissioning phase. The end-point should not compromise future decommissioning activities. Key aspects to be covered include (see Appendix B: Key Content for Transition End-Point Documentsfor more details):

- Spent fuel removed from spent fuel pools, if possible.
- Operational waste (liquid and solid) removed.
- Organisational transformation to efficiently undertake new task completed.
- Workers trained for decommissioning.
- Material and waste management infrastructure to support decommissioning established.
- All resources needed for decommissioning in place, including machinery, materials and contractors.

- In a multi-unit site separation of common services, etc.

9. Plant Characterisation

9.1 Objectives and Scope of Characterisation

Characterisation refers to the process of gathering information to support decision making throughout the decommissioning project. It is one of the key activities in decommissioning preparation but also throughout the entire decommissioning project. It plays a key role in providing the necessary confidence and understanding about the initial/current state of the facility. It also provides important input for both the dismantling and material and waste management planning [31]. The success of this task is critical to ensuring the decommissioning is completed on budget and on time.

Characterisation of plant and operational waste accumulations should begin as early as possible before permanent shutdown. It is an initial step in the decommissioning process and defined as all tasks to identify radioactive contamination and hazardous substances regulated by law at a permanently shutdown plant and perform qualitative and quantitative analysis of them. It functions as one of the key elements required to effectively establish and implement decommissioning plans.

The following paragraphs are mainly focused on radiological characterisation in view of its importance in the preparation of the decommissioning project.

In general, the term “radiological characterisation” represents the determination of the nature, location and concentration of radionuclides at a nuclear installation. In general, objectives of characterisation during the different phases of the plant life cycle are described as follows [37]:

- Determine the type, isotopic composition or mixtures and extent of contamination in structures, systems, components and environmental media.
- Support dose modelling to develop dose-based clearance and release criteria for materials, buildings and the site.
- Provide the basis to select decontamination techniques.
- Support evaluation of which remedial actions will be needed, including the extent of decontamination that will be required.
- Define the material and waste management strategy.
- Select radiation survey instrument and sampling and analysis methods in next characterisation step.
- Provide the required input data for the safety analysis of the decommissioning operations, support an impact assessment due to decommissioning operations and accidental situations, and underpin decisions about the types of safety and radiological protection required for the protection of workers, the general public and the environment.
- Identify potential health issues to be raised by hazardous materials during decommissioning.
- Verify that the facility and the site will ultimately meet release of all of the regulatory controls.
- Minimise uncertainties and assumptions made in the decommissioning plan.

As indicated in [37], radiological characterisation is critical to inform decision making and investments during all phases of the life cycle of a nuclear installation. There are different considerations for design, construction, operation, transition, decommissioning – the major material and waste management challenge – and finally site release of all of the regulatory controls. Radiological characterisation to support the decommissioning process is required with different aims and intensity throughout the different phases, but in particular during the transition phase when operation has ceased, and during the implementation of decommissioning.

This chapter is limited to characterisation performed during the transition phase, which consists of a Historic Site Assessment (HSA) and Initial Characterisation (or scoping and characterisation surveys according to [59] wording) that are described in 9.2 and 9.3 respectively.

The following figure provides an example of the different steps in the site characterisation for a decommissioning project, the duration of each step differs from project to project and country to country.

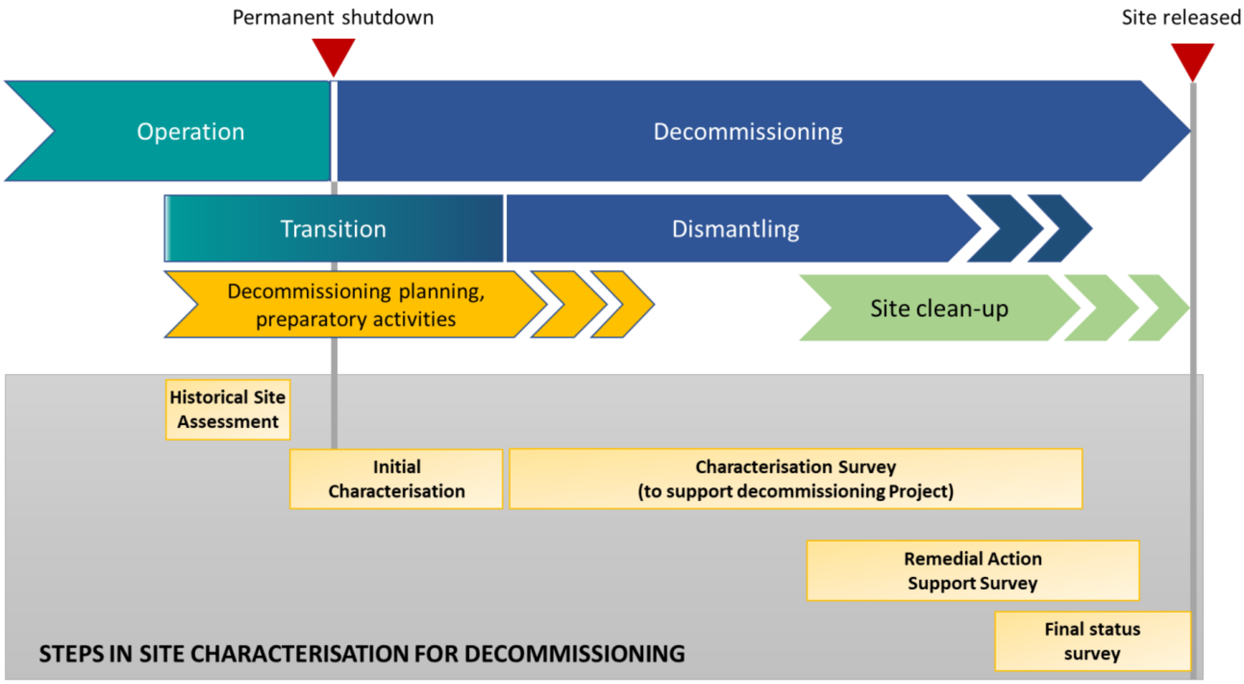

Figure 9-1: Steps in site characterisation process for decommissioning - Adaptation of figure [31]

Guidance for characterisation also varies from country to country. References [19], [37], [43], [60], [61], [62], [66], [67] and [68] are considered relevant for designing, implementing and assessing radiological surveys.

9.2 Historical Site Assessment

The HSA is an investigation to collect existing information describing a sites complete history from the start of site activities to the present time [61]. During the HSA process, additional information is collected to categorise the site or areas within the site as impacted or non-impacted and to make preliminary site classification assessments.

The main purpose of the HSA is to summarise the extent and nature of contamination at the plant to facilitate more thorough and efficient site characterisation efforts during decommissioning. As such, the HSA is a very important tool to minimise the risk that unidentified contamination will be discovered during decommissioning [47]. HSA preliminarily evaluates the extent and nature of contamination concerning a site and its surroundings based on operation history during its lifetime. The main objectives of HSA are as follows [61]:

- To identify potential sources of contamination.
- To determine whether or not specified areas on the site (with specified material and/or radioactivity contents) pose a threat to human health and the environment.
- To differentiate impacted areas from non-impacted areas.
- Non-impacted areas that have no reasonable potential for residual contamination and thus no radiological impact from site operations.
- Impacted areas that have some potential for residual contamination.
- To provide input to scoping and characterisation survey designs.
- To identify additional potential sites containing radioactive material related to the site being investigated.

A HSA is conducted on SSCs, buildings, land of surface, subsurface and ground water in the site through document review, plant inspection and personnel interviews.

During operation, information on contamination events related to radiological and non-radiological hazardous materials should be managed and kept in a comprehensive and organised manner preferably in a form of electronic files or a database in order to minimise time and costs for the HSA as well as to ensure its reliability. Contamination events associated with ground water and buried pipes at a plant experienced with fuel defect need to be specifically addressed for developing characterisation plans.

It would be beneficial to start preparation for characterisation early, before the decommissioning phase, when the decision is made to permanently shut down the plant to provide better information collection in order to guide and thus minimise overall dismantling and decontamination efforts. EPRI recommends that HSAs be drafted one cycle before the permanent shutdown and initial characterisation be completed three to six months before permanent shutdown or during the last outage [44]. Then it needs to be updated, complemented in consideration of operation history for the last cycle, and measurements in areas difficult to access due to radiation level or structural barriers during operation are to be added.

It should be noted that the compilation of the history of pollution events at the site, associated with radiological and non-radiological hazardous materials, is not always eased by the fact that the construction of most facilities would have been carried out more than 40 years prior.

In summary, the HSA process allows the site to classify the areas and develop a preliminary site classification map which clearly indicates the location of the impacted and non-impacted area (extremely low probability for residual radioactivity). The results of the HSA are used as a basis for initial characterisation of the plant. An example of HSA from Humboldt Bay Power Plant in the US is illustrated in the following figure.

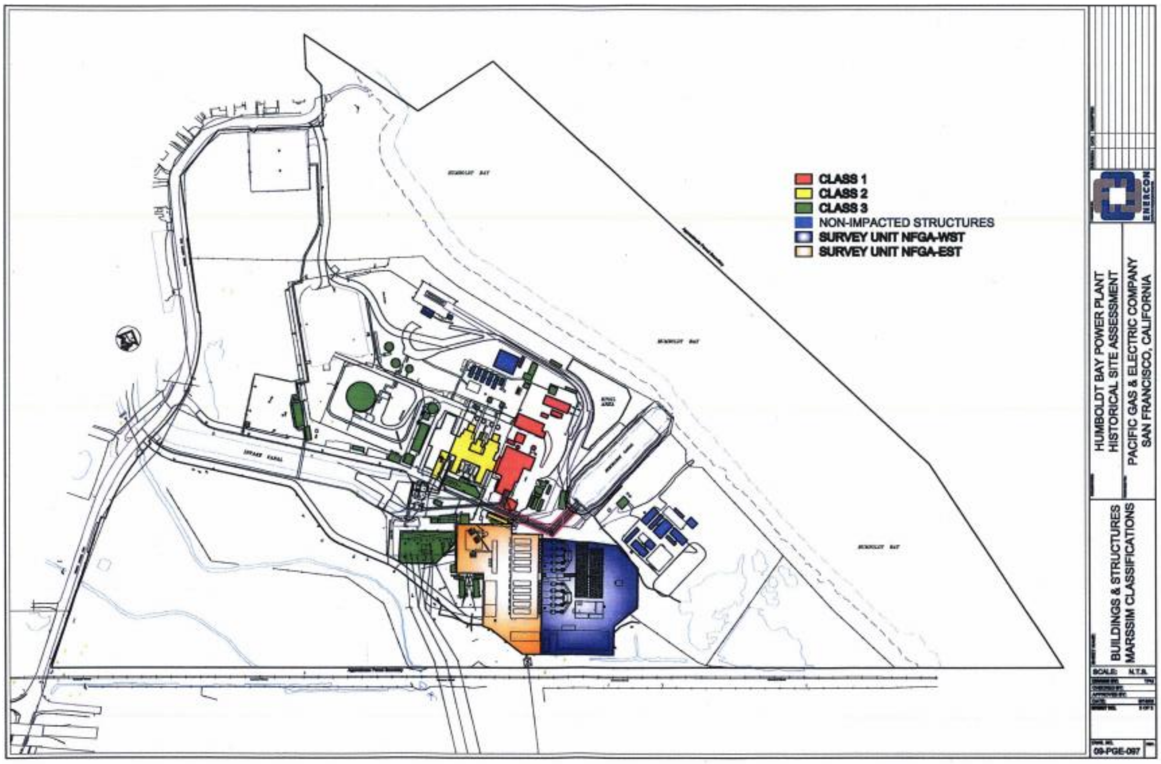

Figure 7.2: An example of site classification at Humboldt Bay Power Plant in the US [73].

9.3 Initial Characterisation

Initial Radiological Characterisation is performed to elaborate results of a HSA in a more detailed and reliable manner while characterisation continues to proceed during the dismantling phase, restoration and final site release.

If the information obtained during the HSA is limited, a scoping survey may be necessary to narrow the scope of the characterisation survey. It is focused primarily on potential radioactive areas assessed by the HSA through collection of samples and measurements. The objectives (as described in [61]) are as follows:

- Perform a preliminary risk assessment.
- Provide input to the characterisation survey design.
- Support the classification of site areas.
- Obtain an estimate of the variability in the residual radioactivity concentration for the site.
- Identify non-impacted areas that may be appropriate for reference areas.
- Estimate the variability in radionuclide concentrations when the radionuclide of interest is present in background.

Scoping characterisation is conducted using a limited amount of surface scanning, surface activity measurements, and sample collection (smears, soil, building materials etc.) on results of the HSA and professional judgment. A scoping survey is not required if the HSA information meets the requirements for designing subsequent surveys.

Based on the HSA and scoping survey results, a characterisation survey is planned with the primary objective of determining the nature and extent of residual radioactivity material [59]. Other objectives are to:

- Evaluate remediation alternatives.
- Provide input to pathway analysis/dose or risk assessment models for determining site-specific release levels.
- Estimate the occupational and public health and safety impacts during decommissioning.
- Evaluate remediation technologies.
- Provide input to the final status survey design.

The characterisation survey includes taking both systematic and judgment activity measurements and performing surveys of different media (e.g., surface soils, interior and exterior surfaces of buildings).

Characterisation methods are summarised below [19]:

- Calculation of neutron induced activity in such as reactor vessel and reactor internals - often with additional verification of theoretical activation calculations with nuclide analysis of irradiation specimens installed in reactor.
    - The results of the neutron activation analysis are used to categorise their radioactive waste class and thus provide basic information for their segmentation, packaging/transportation and disposal.
    - In addition, activation level of the biological shield concrete is estimated by computer calculations and by analysing its core samples to determine to what depth the shield is activated in order to minimise radioactive waste.
- In situ measurements: Scanning and analysis of samples
- Correlation method:
    - Activity level of gamma nuclides (60Co and 137Cs) which are easily identified and detected can be scaled to estimate hard-to-detect nuclides such as 99Tc, 55Fe, 90Sr, 129I etc.).
    - Its applicability must be evaluated considering production mechanism and physicochemical behaviour of the radionuclides and relying on statistical methods. Correlation depends on the waste stream of the facility and correlation factors for decommissioning may be different from ones used in operation.

Regarding direct measurement, special care should be taken so the results are not affected by high dose caused by spent fuel in reactor core such as measurements made after defueled from reactor.

In addition to radiological characterisation, identification of hazardous materials such as asbestos, lead shield, Polychlorinated biphenyls (PCB), hydrocarbons etc. should be performed. The absence of this knowledge can cause significant delays in the decommissioning schedule and consequently lead to increased decommissioning costs. It should be conducted as early as possible in parallel with radiological characterisation.

10. Material and Waste Management Optimisation Planning

Nuclear plant decommissioning involves the management of significant amounts of material and waste in a very short time. As indicated in [31], decommissioning projects are waste-driven projects to a large extent. Each and every one of the main steps in a decommissioning project involves or needs to consider material and waste management aspects.

Decommissioning material refers to any solid and liquid arising during decommissioning while decommissioning waste refers to material with no further use or value and which, therefore, is disposed of. However, both material and waste are referred to commonly, and in this document, as waste.

According to international experience the most relevant cost drivers of decommissioning are overall schedule (through staffing costs) and waste management, therefore any optimisation must go hand-in-hand with greater efforts to optimise time and waste management. The handling of both issues requires the ability to forecast needs well in advance and to have an efficient solution for the management of all materials before they are produced. If a final solution for some waste streams is not available, it is advisable to also consider interim solutions, such as interim storage on-site or using off-site capacities.

Ensuring that waste management infrastructure has the capacity and capability to handle the decommissioning waste without implying any schedule restriction is a logistical challenge that needs to be carefully planned, being one of the main activities to be carried out during the preparation phase. The main purpose of preparing a logistic and waste management plan well in advance is to avoid bottlenecks during the decommissioning caused by dismantled materials and waste that hinder the decommissioning progress. If large components are to be managed off-site, special logistical means may need to be considered.

As indicated in [32], there are a number of factors that may influence optimisation of waste management, including waste volumes, cost, decommissioning schedules, clearance levels, recycling options, dose and discharges or making the best use of the available infrastructure. These considerations do not exist in isolation and may influence each other. They will also vary from country to country, depending on the policy, strategy and regulatory environment, and on individual country constraints (such as limited disposal capacity or stakeholder concerns). The strategy could be defined following a multiple attribute decision analysis[9] method.

In general, waste management optimisation should focus on reducing the waste volume for disposal in compliance with the waste acceptance criteria. As indicated in [32], applying the waste hierarchy has been shown to be a success factor; initially seeking to avoid waste generation, and then to minimise disposed volumes through reuse and recycling of materials, as well as having waste treatment facilities available to enable reuse and recycling. Taking into consideration the great volume of material produced during a decommissioning project, it is essential to focus the efforts ensuring that maximum flow is moved into the conventional category.

Another thing to consider is that most plants have operational waste in on-site storage installations pending on management at the end of operational life. Experience has demonstrated that if a waste management plan (evaluating waste volume, variety, composition, treatment, and conditioning) covering remaining operational waste and the forecasted decommissioning waste is developed and implemented prior to final shutdown, there is a greater likelihood that operational waste will be adequately conditioned

[9] Multiple attribute decision analysis- making preference decision (such as evaluation, prioritisation, selection) over the available alternatives that are characterised by multiple, usually conflicting attributes

in time and by then the dismantling is not delayed. Furthermore, it will also reduce the risk for delays of the decommissioning due to waste management issues [31].

Therefore, anticipation in the definition of the waste management routes can contribute not only to optimising the decommissioning project but also looking for a common solution for the operational and decommissioning waste, reducing the cost and the risk of delays. Large components[10] coming from plant upgrades or replacement of major equipment during operation (e.g. steam generators, heat exchangers, pre-heaters, vessel head) are a clear example of elements that can be managed in the same way during operation and decommissioning.

In addition, the availability of characterisation laboratories with enough capacity (if possible, on-site) has also been identified as a success factor to enable effective application of the waste hierarchy, facilitating the quick selection of appropriate waste treatment, conditioning, and disposal routes over the entire waste management life cycle.

The following paragraphs propose a systematic methodology to design and optimised waste management strategy that could be a basis to prepare the waste management infrastructure required for the decommissioning project. Both activities should be in the scope of the transition phase.

10.1 Design of an Optimised Waste Management Strategy

Strategic waste management planning should take place throughout the whole decommissioning programme or project life cycle. A strong project planning process, which includes consideration of waste arisings and their management at all stages of the project, along with suitable logistics and data management systems, has been identified as a success factor during decommissioning planning. However, there may also be safety, financial or schedule constraints to optimising the management of radioactive waste and materials [32].

In order to design an optimised waste management strategy, it is absolutely necessary to discuss and have common understanding of permanent plant shutdown among all the stakeholders (decommissioning licensees, regulatory bodies and disposal site operators) well in advance.

[10] Large component can be defined as any part of a nuclear facility that may be removed without being cut, that is conditioned in a non-standard package for disposal or storage and that requires specific consideration by local regulators due to its weight, its volume or the extent of its radiological contamination [35].

The design of an optimised waste management strategy should be carried out following a systematic approach that could be summarised with the following scheme:

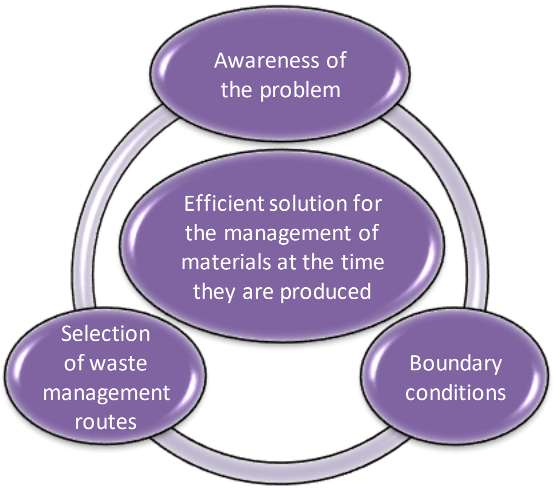

Figure 10-1: Scheme for definition of an optimised waste management strategy for decommissioning

10.1.1 Awareness of the Problem

The awareness of the problem requires understanding **"**what we have", "where we have it" and "when we have it".

The first two questions are answered with an effective characterisation that will allow understanding of the problem to be faced, not only from a radiological and non-radiological hazardous material point of view but also for radwaste and planning optimisation. Characterisation refers to the process for the determination of the residual activity in all relevant media and structures, providing a reliable database of information on quantity and type of radionuclides, and their physical and chemical states.

Lessons learnt also show the importance of understanding the initial state of the facility after permanent shutdown. Effective characterisation processes enable categorisation of waste and should be carried out at the right time and to the right extent. Characterisation also enables early and robust inventories of radioactive waste to underpin project plans and to allow external service providers to make commercial decisions on supporting infrastructure investments [32].

Once the nature, location and concentration of radionuclides at the nuclear installation are estimated, the next step consists of knowing the flow of materials through the facility along the decommissioning project. It depends strongly on the decommissioning strategy, but it is needed to size the waste management facilities. As indicated in [70], an important parameter is the need to secure availability and capacity of waste routes. Short-term bottlenecks or any delay in the removal of the waste from the site often has an impact on other site activities. If possible, at least two alternative waste routes should be identified for the main categories of waste and kept available throughout the decommissioning project. All routes should be directed to the material final destination, if possible, but it is more important that waste is removed from the site so that other site operations are not impeded. Waste forms without a disposal route should never be generated.

One of the recommendations in [31] is to develop a logistical concept in accordance with the materials and waste management strategy, the dismantling strategy and the facility modification strategy. Preferably, and where possible, the planning of the logistics should begin to be explored when the facility is still in operation.

When the selected alternative is to use on-site facilities, the capacity of the processing and storage facilities have to be sized taking into consideration the flow and logistics of materials.

10.1.2 Boundary Conditions

When selecting waste management routes (described in 10.1.3), the following boundary conditions should be taken into account:

- Radioactive Waste Classification

  Various schemes have evolved for classifying radioactive waste according to the physical, chemical and radiological properties. These schemes have led to a variety of terminologies, which may differ in each country. In order to address these issues, the classification of radioactive waste was subject of international standards on the safety of radioactive waste management [1]).

  The waste classification is normally related to the final disposal option. Some countries have incorporated the very low-level waste category in their legislation (such as France, Spain, and Sweden) using a disposal design for this type of waste less demanding regarding engineering barriers than in the case of low and intermediate level waste disposal facilities. Other countries (such as Germany) have foreseen underground disposal facilities for the two categories incorporated in the legislation (non-heat and heat generating wastes).

  The activated material with high (and possibly long-lived) radionuclide content (mainly coming from reactor vessel internals, remnants of liquid radwaste processing, resins from primary coolant purification, and fuel reprocessing) require special consideration and are generally classified as radioactive material that is not suitable for near-surface disposal.

- Clearance Levels

  The term “clearance” refers to removal of radioactive materials or radioactive objects within authorised practices from any further regulatory control by the regulatory body.

  Clearance and subsequent recycling and reuse of different types of materials has been applied on a large scale where the practice is allowed by national regulations. The key drivers for the development of recycling routes are generally the unavailability of disposal facilities and a comparison of the costs between recycling options and disposal options.

  Metals, building rubble, concrete blocks, soils and electrical cables, are the most relevant materials candidates to be cleared in a decommissioning project. Unrestricted use/unconditional clearance or restricted use/conditional clearance levels are the two options that most countries incorporate in their national regulations. The clearance process will thus contribute to optimising the volume of radioactive waste from decommissioning that requires final disposal.

  There are four international documents that provide high-level guidance for relevant competent authorities when establishing clearance levels:

  - The underpinning document for clearance is IAEA RS-G 1.7 [5].
  - Two other leading reference documents are published by the European Commission:
    - Radiation Protection 89 [52]
    - Radiation Protection 113 [51]
  - EU Council Directive 2013/59/EURATOM [50]. Adoption of this directive by member countries is in progress.

  A significant number of countries have developed national regulations that are based on these international regulations and guidance. Some countries have directly adopted these guides and others used them to regulate on a case-by-case basis.

Any waste management strategy needs to establish from the very beginning the clearance policy that would apply during decommissioning. [9] and [28] summarise the monitoring process for compliance with exemption and clearance and the most relevant aspects regarding the recycling and reuse of materials arising from the decommissioning of nuclear facilities.

The clearance methodology needs to be agreed with the regulator as early as possible.

- Disposal Facilities

  One of the most relevant restrictions for a decommissioning project is the lack of an appropriate repository for the large amounts of waste generated during the process. Although it could influence the choice of strategy (e.g. deferred dismantling), the absence of a final repository should not be an obstacle to early dismantling, unless factors other than waste disposal and costs intervene in the decision-making process.

  Any decision taken on decommissioning waste management routes needs to consider:

  - Disposal availability and capacity for different waste streams.
  - Waste acceptance criteria:
    - Physical, chemical and radiological requirements.
    - Package/container characteristics:
      - Type.
      - Maximum size and weight.
    - Possibility to accommodate large components in the disposal facility (as in the case of the US, France, Finland, and Sweden).
  - In the case that there is no repository established, the waste acceptance criteria should be anticipated to allow facilities to progress with waste treatment and conditioning activities.
  - Disposal costs:

    Disposal cost is a key parameter to define the waste management strategy. Normally, in countries where disposal costs are relatively low, less effort is made during decommissioning in clearance, decontamination or treatment. All these processes are time consuming and therefore will have a direct impact on the schedule but are completely justified if disposal costs are very high or the disposal capacity is very limited.

    The option of a very-low level disposal facility (shallow land disposal, landfill) could reduce the disposal cost in a decommissioning project, taking into consideration the great volume of waste than can be classified as very-low level category.

- On-site/Off-site Processing Facilities

  The aim of waste processing is to reduce the volume to be disposed of and to process radioactive waste into a form that is suitable for disposal or for long-term storage pending the development of suitable disposal routes. Typically, this process will cover several steps and technologies, including:

  - Sorting, segregation and size reduction.
  - Decontamination.
  - Volume reduction treatment.
  - Conditioning/immobilisation.
  - Packaging (for storage, transport or disposal).

The processing facilities have to process not only solid radioactive wastes but also liquid and gaseous effluents accruing through the decommissioning.

The current capacities and capabilities of the existing on-site waste management infrastructure, as well as the availability of the off-site alternatives, will be analysed in the first steps of the project.

The processing capacities should not be the bottleneck of the dismantling project. When evaluating the needs, it is important to size the process in such a way that material and waste treatment can be decoupled from the dismantling activities.

- On-site Storage Facilities

  There is a requirement for the large amount of materials that are managed in a decommissioning project to be secured in available storage areas for different classes of materials due to the following reasons:

  - As a short temporary solution because it is difficult to achieve “just-in-time” transport to the final destination (repository, off-site processing facility, etc.).
  - As a longer solution if a radioactive waste repository is not available when needed.
  - As decay storage to reduce the radiological category of the material.

  Analysis will be conducted of the capacity, location, handling systems, accessibility, etc. of existing storage facilities (including those for hazardous wastes) and the licensing restrictions (if any).

- Regulatory Framework

  Legal requirements have a significant influence on the selection of waste management routes. In most countries, national regulations often relate to nuclear safety, dose limitations of radiation exposure, transport and disposal requirements, whereas specifications for handling, treatment, conditioning and storage are imposed by competent organisations. Each disposal facility has specific criteria for acceptance based on applicable local legislation.

  The selection of waste management routes needs to integrate the requirements imposed by different regulatory authorities, waste acceptance criteria imposed by disposal sites and assure compliance with them during design, construction and operation of waste management facilities. During selection of a waste management route, the site operator must be able to demonstrate the application of the principles of ‘Best Practicable Means’ (BPM) or ‘Best Available Techniques’ (BAT).

  The transport regulatory requirements (both national and international in case of external treatment option) are especially relevant for decommissioning projects when implementing a concept for external treatment or direct disposal of large components.

10.1.3 Selection of Waste Management Routes

Waste management routes refer to the activities and logistics for managing the material from the initial inventory to the envisaged material final destinations. The potential material/waste route options have to be analysed for all categories produced during dismantling (radiological and non-radiological including hazardous wastes).

The preference should be to select the waste management routes balancing the safety requirements (radiological and industrial safety) and the achievement of the material final destinations at the lowest possible total cost.

10.1.3.1 Waste Route Alternatives

When selecting the waste management routes, two main aspects have to be analysed:

1. What processing technologies and procedures will be used to minimise the volume of waste to be disposed.

2. Where the processing facilities will be located (onsite or external facilities)

In relation to the first aspect, any alternative should follow the principle of waste hierarchy and represented in following figure, where the main driver is to prevent unnecessary waste from being created optimising the volume of waste requiring disposal.

In addition, the best combination of licensed packages and segmentation strategy needs to be looked for in the design of the dismantling strategy.

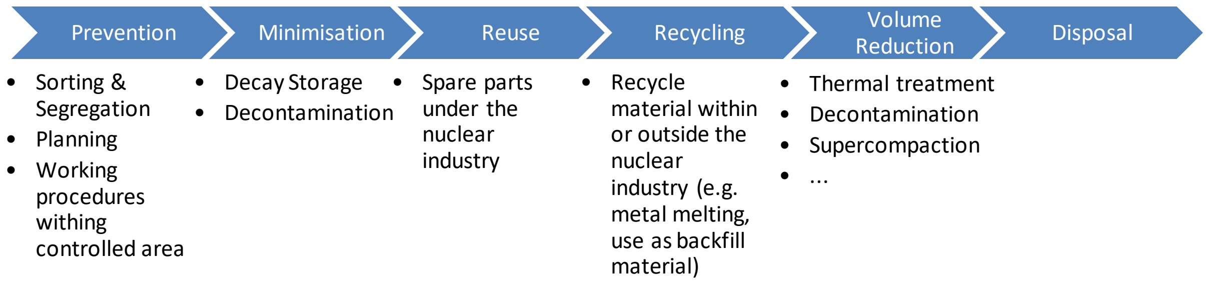

Figure 10-2: Scheme of the waste management hierarchy.

To answer the second aspect (where the processing facilities will be located), there are different possibilities:

- On-site facilities (existing or new buildings and facilities).
- External facilities (centralised or commercial facility).
- Mobile facilities that are transported from site to site for specific waste treatment operations.

During the decision making process, several aspects have to be analysed:

- Status and capacities of existing buildings and facilities that will determine the level of required investments.
- Transport requirements and distance to the centralised facilities.
- The ownership of the plants, a utility with several nuclear units spread over a number of sites may decide to develop a centralised waste treatment facility as part of a fleet approach. It is also possible for a number of utilities to cooperate with each other to adopt a fleet-wide approach for their combined plants [70].

10.1.3.2 Methodology for selection of waste management routes

The optimal strategy should be determined by comparison of the relative advantages and disadvantages of each option. Once the inventory is known and the boundary conditions clearly stated, the following step can be taken for a systematic approach for selecting the waste management routes. Cost base approach or multi-attribute decision analysis are different tools that are commonly used for waste management routing selection.

The selected strategy should be based on two basic pillars:

- Avoid the generation of waste streams/waste packages without a disposal route: “a package that cannot be disposed of should not be created”.
- Ensure availability and capacity of routes for all waste streams before starting dismantling activities.

When analysing the cost items, it is important to include all cost elements, both those directly related to the waste management activities, and those decommissioning costs that are impacted due to the waste management route selected:

a. Cost directly related to the waste management activities
    - Fixed costs for the waste management facilities; include all costs that are not directly related to the volume of the managed waste, for example:
        - Licensing.
        - Design, construction, operation, maintenance, decontamination and dismantling of waste management facilities (including disposal facilities).
        - Overhead or management of waste management contracts.
        - Rental of equipment or land lease.
        - Security costs (decommissioning duration dependent).

      When the facilities are used in different projects, the fixed costs must be shared.
    - Characterisation, processing, packaging, interim storage, transport and final disposal costs.

b. Decommissioning costs affected by the selected waste management option including savings due to reduced project duration.

10.2 Summary of Key Elements

It is internationally recognised that decommissioning projects are waste-driven projects to a large extent. Each and every one of the main steps in a decommissioning project involves or needs to consider material and waste management aspects.

The following paragraphs summarise the key elements for material/waste optimisation during decommissioning:

- There is not a common solution applicable for all countries and all sites. A wide range of waste routes are available and used worldwide. The preference should be to select the most efficient routes for achieving the material final destination in a cost-effective manner, taking short-term and long-term risks and consequences (including environmental impact) into account [70]. This cost-effectiveness should be measured not only with the direct waste management cost but should also take into consideration the impact of the defined waste management strategy on the overall decommissioning project.
- The design of an optimised waste management strategy should be carried out following a systematic approach. This would start with the understanding of initial state of the facility after permanent shutdown (physical and radiological inventory), and take into account the flow of materials along the decommissioning project, and the boundary conditions (national and site specific). The process will conclude with the selection of waste management routes through a cost-benefit analysis.

- One of the most relevant restrictions for a decommissioning project is the lack of an appropriate repository for the large amounts of waste generated during the process. Although it could influence the choice of strategy (e.g. deferred dismantling), the absence of a final repository should not exclude an early dismantling option.

- All routes should be directed to the material final destination if possible, but it is more important that waste is removed from the site so that other site operations are not impeded, therefore interim solutions can be an option if final repository is not available.

- Applying the waste hierarchy may be a requirement but it has also been shown to be a success factor. This entails initially seeking to avoid waste generation, and then to minimise disposed volumes through reuse and recycling of materials, as well as having waste treatment facilities available to enable reuse and recycling.

- An efficient solution for the management of all materials at the time they are produced should be implemented before starting dismantling activities. Short-term bottlenecks or any delay in the removal of the waste from the site often has an impact on other site activities. If new facilities are needed, it is advisable that they are in operation before starting dismantling.

- Ensuring that waste management infrastructure has the capacity and capability to handle decommissioning waste without implying any schedule restriction is a logistical challenge that should be carefully planned before plant shutdown. The main purpose of preparing a logistic and waste management plan well in advance is to avoid bottlenecks during decommissioning caused by dismantled materials and waste that may hinder decommissioning progress.

- The management of large components should require special consideration in the waste management strategy. If the repository could directly accommodate large components, there will be no need for total segmentation in order to package in authorised containers. This may avoid costs and doses to workers, but transport and logistical restrictions have to be taken into account in the final decision.

- During decommissioning the management of reactor vessel internals require special consideration. The high (and possibly long-lived) radionuclide content of these components generally requires them to be classified as radioactive material that is not suitable for near-surface disposal. When defining the most cost-effective disposal strategy for this type of waste, the best combination of licensed packages and segmentation strategy needs to be found.

- In the design of the dismantling strategy, it is advised to seek the best combination of licensed packages and segmentation strategy.

- Although the adaptation of existing buildings (e.g. turbine building) for waste management could reduce the initial investment cost, it could have implications on the decommissioning schedule. An independent waste processing facility provides relevant advantages in separating dismantling from waste management which may be a significant advantage for the comprehensive decommissioning project. Nevertheless, both alternatives are not incompatible and need to be analysed in detail during the design phase.

- The use of integrated waste management strategies and waste management plans during operational and decommissioning activities help to articulate the waste management requirements and costs over the life cycle of the decommissioning programme, as well as to identify any gaps in knowledge, skills or infrastructure requirements [32].

- If operational waste is stored on site (e.g. large components coming from plant upgrades or replacement of major equipment during operation), it would be possible to look for a common solution and prepare the waste management plan covering remaining operational waste and the forecasted decommissioning waste that should be developed and implemented prior to final shutdown.

- Performance indicators may be used to examine those aspects that are crucial for systematic assessment of the progress of decommissioning. Due to the relevance of waste management in a decommissioning project, it is advised to include specific key performance indicators (KPIs) related to waste management as a project management tool (e.g. amount of radioactive waste produced; proportion of decommissioning materials reused or recycled, etc. [3]). These KPIs and the processes for collecting the necessary data needed to measure progress should be developed in advance of the start of decommissioning activities.

11. Change Management for the Transition

The purpose of change management is to implement strategies for effecting change, controlling change, and helping people to adapt to change.

Change management should cover all aspects including technical, organisational, and competences. The site should also consider prioritising time for overall change management, involving not only managers, but also plant teams and employees. To be appropriate, this strategy for change management must be established and periodically reviewed and adapted with current situation. The topics covered should include:

- What will the change of structure be?
- What support will be required?
- What will the timeline/schedule be?
- Who should be involved?
- What will the goals and targets to measure progression of the transition look like?
- How to communicate and align all levels of management.

Change management must include periodic meetings, action plans and metrics (key performance indicators or KPIs).

Reference [3] provides practical guidance on the selection of KPIs for a decommissioning project. Some examples applicable for transition phase are:

- Project milestone forecasts and achievements.
- Number of outstanding licensing issues.
- Percentage of decommissioning funds used.
- Rate of planned expenditure during remainder of financial year.
- Manpower costs.
- Percentage of staff and contractors sourced locally.
- Amount of radioactive waste produced.

The site should identify principles for performance indicators of the different phases. Some employees should be involved in change, for example through workshops, and a survey should be used on a regular basis to measure personnel engagement.

11.1 Cultural Change

The transition from operation to decommissioning implies relevant changes in the way to work that needs to be assumed by the organisation. The following table summarises some of the most relevant culture differences during operation and decommissioning, including an example of mitigating actions that could be implemented to minimise the impact during decommissioning phase.

	Operation	Decommissioning	Mitigating Actions
Type of work	Process driven focused in operation	Project driven focus on cost control and schedule	
Hazard Profile	Stable; well characterised; radiological hazards dominant; potential (inventory) for significant off-site effects; well-known working environment	Frequently changing; often not well characterised; industrial safety issues become more dominant as the radiological hazard is decreased; off-site effects due to removal of inventory; changeable working environment	Increase training for specific tasks
Work Control and Planning	Frequently performing routine tasks; focused on operation and maintenance; relatively short-term tasks	Tasks or job oriented; new first-of-a-kind tasks; work planning for workplace safety critical	Up-front detailed planning; well defined schedule; revise technical specifications
Hazard Analysis	Operation-oriented; generally stable	Dynamic; mainly task-oriented; changeable	Daily safety briefs for teams; job hazard analysis; rad work permits
Workforce Experience	Familiar with facility operation and routine work according to approved design	New missions; limited experience; sub-contractors may not have process knowledge of facility operations; knowledge may need to be maintained for long periods	Increased training for specific tasks
Contract Management	Licensee managed and operated	Often short term contractor involvement; high level of dependence on contractor performance; need for strong project management	Budget and schedule control; detailed cost tracking
Staff	Long-term and stable employment with routine objectives	Changeable according to the decommissioning tasks and phases	Succession planning
Reliance on Permanent Structures	Constant with regular maintenance	Interim facilities and degradation of structures	Cold and dark planning[11]; revise safety cases; remove systems and components
Regulatory Oversight	Routine inspections; amendments to license	Focused inspections; rapid approvals often required	Good inspections require more training/supervision
Stakeholders	Routine communications with stakeholders	Dynamic and changing set of stakeholders (e.g. contractors, public)	Early open communication; proactive, not reactive

Table 11-1: Cultural differences between operation and decommissioning (adaptation of table 1 from [10])

The change management strategy for the transition phase will strongly depend on the decommissioning strategy and corporate model.

[11] Cold and dark condition: no heating, lighting or other service functions

11.2 Organisational Changes

The organisation needs to evolve as it moves from an operational stage to a decommissioning stage. The first objective of this organisation transition is to ensure that, during the transition and throughout the decommissioning, an effective and competent organisation remains in place and in charge of the facility.

In order to adapt to its new activities and objectives, a modification in different stages of the organisation has to be gradually implemented based on the decommissioning plan (organisation, staffing requirements, qualification, and finance).

The organisational structure follows the strategic orientation of the company (immediate or deferred dismantling, in-house staffing or outsourcing, development of new business segments in decommissioning and waste, etc.).

Different organisational principles can lead to a new organisational model. A core skills-oriented model where operations, post-operation and remaining operation stays within the operational part of the organisation; or a business purpose-oriented model where operations is split from the remaining operation/dismantling/waste management. The goal is to have an effective and efficient organisation, in which the different roles, responsibilities and interfaces are clearly defined and managed. An important milestone for organisational change is the remaining operation with or without fuel.

As indicated in reference [22], at the beginning of the transition phase, it is very important to establish a dedicated project team, which does not need to be large or employed full time and could also be a separate from the operational organisation. Their technical and safety expertise should include knowledge of system reconfiguration or retirement, spent fuel and waste management, plant history, licensing and other decommissioning aspects. Standard project expertise such as cost estimation, time and work scheduling are also important.

This team may report to the site manager (or similar role) but should not be responsible for the day-to-day operations of the plant; the team may grow and increase their responsibilities as the project progresses. Reference [22] includes examples of organisations during the transition process.

In order to minimise uncertainty and ensure a sufficient level of detail is available to communicate both internally and externally, early development of organisational plans for each phase should be factored into transition planning. The steps below provide guidance on developing holistic organisation plans [10], and are dependent on the decommissioning model and strategy as well as the company governance model:

- This work must be run by the management team and shared with all managers.
- Develop one organisation per phase: generation, post-operational and decommissioning.
- Identify required competencies and key positions, including emergency situations.
- Optimise the minimum required for each department and job.
- Validate the organisation with a regulator, if necessary.
- Consider the business model and, if needed, revise contractor strategies.
- Discuss and negotiate with trade unions.
- Consider safety and security goals.
- Review the tracking system of the site, determine new KPIs.
- Consider a redundancy strategy.

11.3 Communication Strategy

Change management must include an open, close and honest communication strategy with stakeholders. The information shared should include all necessary details about the transition, even if everything is not precisely defined at each state. "You should communicate what you know, but also what you don't know". The goal is to establish early confidence and trust in the project.

When you communicate in times of change, always remember that not everybody is in the same position in the change-curve at a certain moment in time.

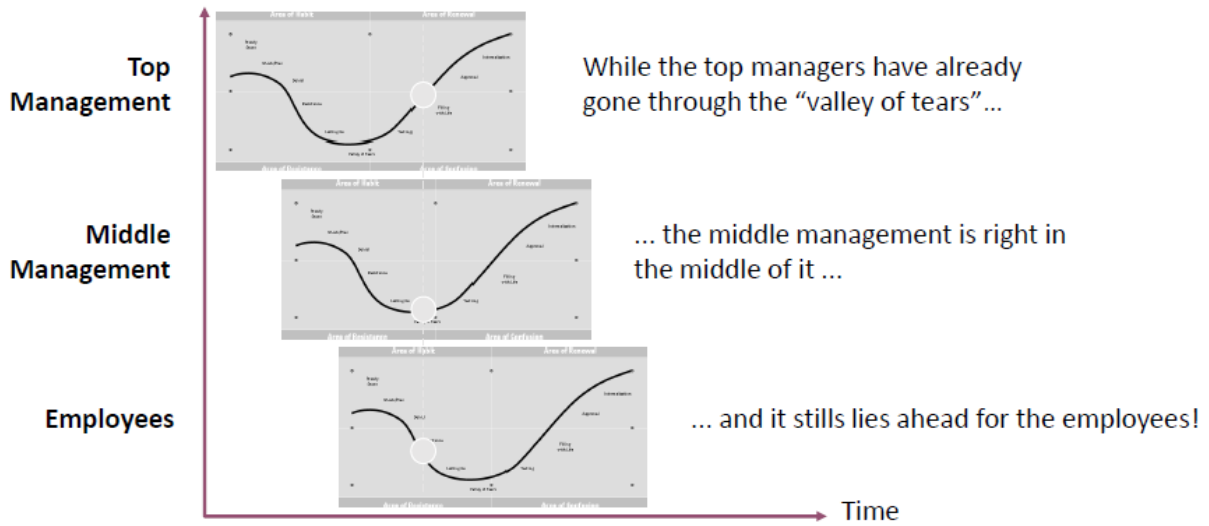

Figure 11-1: Transparent, planned communication (reference: Oskarshamn presentation, WANO TTD I-WG Meeting in November 2020).

The communication will be both internal and external.

- Internal communication is for internal stakeholders which could include: employees, managers, teams, labour unions, and contractors. It is essential to the success of change management to make the process for transition to decommissioning visible, and give meaning to what is going on and what will happen.
- External communication is for external stakeholders which could include: regulators, local governments, and local residents. Depending on countries and situations, this communication must be adapted in time and substance (timing decision by the company, several years before final shutdown).

Decision making about end of generation is an important topic that will lead to an announcement to external stakeholders. Therefore, the impact on the power grid, local society, economic aspects and people should be taken into consideration. It could also be interesting to share the experience with other transition to decommissioning sites, in order to benchmark different ways of approaching this kind of situation.

External Stakeholders	Content
Local Government	What are the milestones for the end of generation? Explain what happens on the site after end of generation (technical, social aspects, contractors) How will the plant guarantee nuclear safety during the decommission phase? Explain the impact for the local area? (people leaving the local area, local government financial assistance, decrease of taxes, etc.)
Media	What are the milestones for the end of generation? Explain what happens on the site after end of generation (technical, social aspects, contractors)
Power Market	Respect of rules for this information (transparency). What will be the impact on generation capacity?
Regulatory	What are the milestones for the end of generation? Explain the decommissioning strategy.
WANO and IAEA	Adjust with WANO periodic international review (WANO Peer Review/Follow-up Peer Review) schedule in relation with end of generation. Identify topics and ask for a support mission if necessary (MSM).

Table 11-2: Example of topics to discuss with external stakeholders.

The following points include some good practices examples of communication regarding HR management:

- Reinforce nuclear safety standards.
- Identify and communicate the technical vision for the future; set new challenges for each phase.
- Reinforce resources dedicated to HR.
- Develop non-technical skills, add new competences (change management, interpersonal).
- Include a plan to reorganise the site regarding managerial structure, integrated management system and the building.
- Benchmark with others and share experience.
- Include a consultation process related to the employee impact perspective.
- Involve managers, teams, employees in change management.

Reference [12] includes experience and lessons learnt on stakeholder involvement and related issues in planning for and managing the decommissioning of nuclear facilities, and also describes who the stakeholders are and how their involvement can affect the decommissioning project.

11.4 A Leadership Programme

Leadership in the transition phase is a challenge; management should be aligned and trained; "the leaders themselves are also affected by the change and should lead by example". The approach starts with demonstrating experience in nuclear and consists of orientation, focussing on effective (new) activities by inspiring and maintaining confidence. For the lead of change and culture, excellent people managers are needed to facilitate clear top-down and bottom-up communication to give perspectives and understand staff concerns.

Change management should be associated with a strong leadership programme, providing the necessary support to managers. 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

It is important to consider the change in culture from the operating to decommissioning mindset while staying safe, responsible, and professional.

The main goal of the leadership programme is to maintain a high level of safety, even in this specific state of mind due to transition to decommissioning. Employees and managers must stay focused on this priority and the leadership programme must think about how to change the culture from operating to decommissioning, with the same nuclear safety standards and high level of engagement. The idea is to keep motivation and key competencies in the different phases. This will be developed in Chapter 12 'Human Resources Strategy

It is necessary to develop non-technical skills (soft skills) and build new competences for managers, such as empathetic leadership skills. This way, they will be better equipped to approach their employees' difficulties.

The leadership programme should also plan time for meetings or individual dialogue, encouraging existing staff and keeping involvement and motivation.

It is essential to identify a vision for the future, in both a technical and social aspect. This way, new challenges for each phase are identified, and employees and managers better understand their responsibilities, what they will have to do and why.

Key messages and keys to success should be set and shared with the managers as a tool to maintain strong communication during the leadership programme.

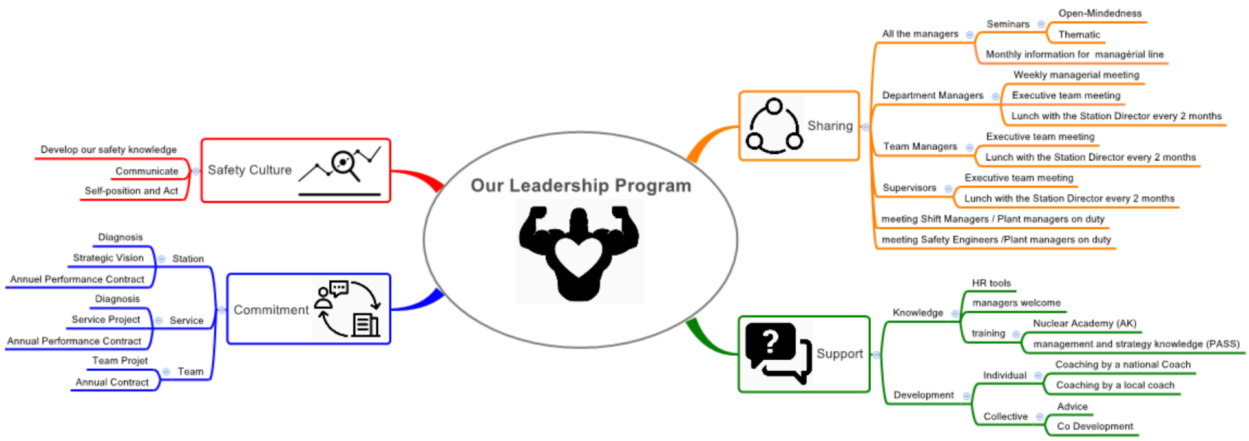

*Figure 11-2: Example of leadership programme structure (***[Redacted Plant Name 10]***)*

12. Human Resources Strategy

In the decommissioning process an integrated Human Resources (HR) strategy, approved by management, should be developed to support the change in staffing and competences. The HR strategy should take into account the following conditions:

- Changing of staffing skills and competences towards decommissioning.
- Securing and development of competences.
- Financial restrictions or economic situation of the company.
- National labour laws.
- Contractor strategy.

The HR strategy also depends on the size of the company, the number of plants on one site, as well as other plants or industrial activities in the surroundings. Managers and employees must be informed about the HR strategy and it should be shared with the unions to be negotiated if necessary.

The approach strongly depends on the selected decommissioning strategy (immediate or deferred). A long decommissioning process could lead to the loss of human resources and knowledge. In order to mitigate these effects, it is recommended to maintain a policy of training, retention and the transfer of knowledge.

In some countries or facilities the site license is transferred to a new organisation or company and the operator is not an actor in the decommissioning phase. In this case boundaries and responsibilities must be clearly defined with the operating organisation, and a strategy for the handover process clearly defined. This should include early discussion between the site operator and the decommissioning organisation in order to define likely resource requirements at the point of transfer so that this can be incorporated into the HR strategy and internal communication plans.

As a consequence of a possible new organisation setup, the need for staffing and required competences will change during the different stages according to the decommissioning plan. There may be personnel reassignments to new positions and also the incorporation of external personnel from to subcontracted companies. The modifications to the organisation should be suitably planned and managed, such that the best possible organisation and assignment of personnel to job positions is achieved. Criteria for the HR transition should be well defined in order to keep, develop and/or release people. The recruitment and competence policy should be revised as a consequence.

It is important to have insight into the expectations of the personnel, especially with regard to their interest in new decommissioning roles, early retirement options, changing companies, or changing their role within the company. Employees support the history of the site through their individual and collective skills and knowledge and, where possible, this should be retained. Managers should have deep discussions with personnel and build a safe and responsible HR strategy in accordance with the different phases.

At an early stage of preparation for decommissioning, a future plan should be created to enable opportunities for each individual in order to clarify the road forward from an employee perspective. Active involvement and communication between the company and employees in considering these options may contribute to a better working environment, more motivated staff and a more efficient organisation.

To avoid early departure of critical staff and competences, a retention plan should be set up with motivational measures. When the site license is transferred to another company, the retention strategy will need to be carefully managed in terms of transfer of staff to ensure optimum retention for the new license holder.

In order to have a clear view on the workforce and competence management, a plan should be set up with the future needs for personnel and contractors in terms of remaining O&M activities with multidisciplinary teams, major decommissioning projects, as well as the decrease in staffing needs. When decreasing the number of people, it is important to have the necessary resources and competences to fulfil the roles and responsibilities in a safe and efficient manner, while taking into account the financial restrictions.

Develop individual development plans by merging future needs with individual ambitions and competences. Identify training needs (project management, radiation protection, waste management, logistics, etc.), develop training programmes and perform training. By involving people leaving the company with an adapted training programme, this should also create motivation and a positive environment. A systematic approach to training in accordance with IAEA standards should be adopted. Preservation of the knowledge is necessary for future decommissioning; involving more existing senior members of staff in training new generations will facilitate desired levels of knowledge transfer.

From the operation phase to the decommissioning and dismantling phase, a change process and change in mind-set is needed towards a positive attitude. Negative effects or attitudes are caused by the uncertainty of the professional future or elimination of job functions and well-known activities. To prevent or mitigate negative effects, a change management policy, aimed at motivating personnel and creating a positive attitude by inspiring and motivation, should be installed. Change management is explained in more detail in Chapter 11 ‘Change Management for the Transition’.

Nuclear safety is the overriding priority while industrial safety becomes more important (shift in activities). Standards will not change and professionalism will be needed as during operations. There is a need for excellent human performance because some plant protections may not be in place anymore and the situation changes on a daily basis. There is also a need for experts with good safety awareness and an adequate training programme for the new competences.

13. Retaining Knowledge and Information

Knowledge management is essential to ensure a successful transition to decommissioning. This includes well-trained and competent staff with operational and decommissioning knowledge as well as the plants detailed data required for a safe and efficient transition. It is a fact that, during the lifetime of a facility, the uncertainty of knowledge related to decommissioning will decrease in time; it should be managed in each phase of the lifetime of a facility.

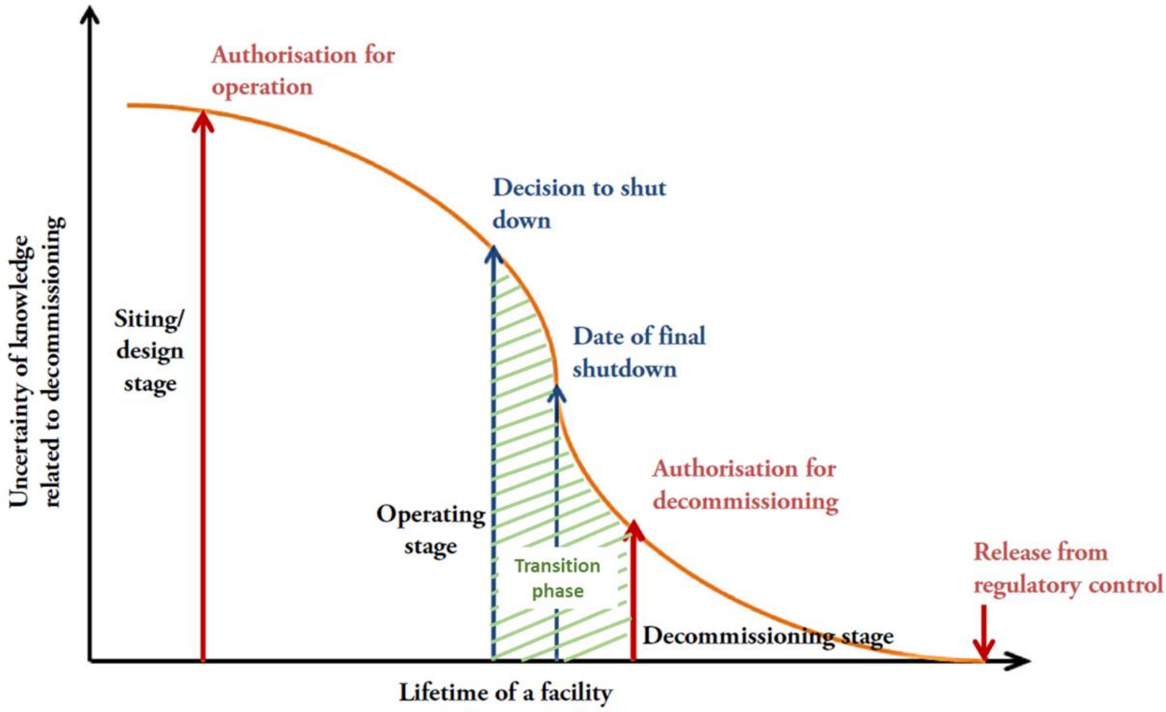

Figure 13-1: Evolution of the uncertainty of knowledge needed during the planning and conducting of a decommissioning project (not true to scale) – Adapted from reference [31].

It is important to be timely (start when the plant is still in operation) with the preparation of transition to decommissioning for optimal knowledge integration of the personnel and the HSA information (herein referred to as "records"). Knowledge management plans should include the following:

- **Operating Experience**

  Regardless of the experience level of the team in charge of decommissioning, one of the first activities undertaken should be to collect the available feedback of experience nationally and internationally. This will help the project team to recognise the critical aspects of a decommissioning project and will provide some benchmarking information.

- **Staff Interviews**

  Interviewing experienced staff during the planning is a best practice in order to fill any important information that may be missing, such as leakages, contamination (radiological or non-radiological), incidents, etc. [16].

- **Retention Plan**

  It is important to stay focused on the 'people issues' in preparation for decommissioning. When an announcement of plans for final shutdown is made, personnel attrition will sharply increase as employees begin to seek long-term opportunities elsewhere. If the departure of personnel is excessive, the ability to run the plant to the desired shutdown date may be in jeopardy. The key to retaining staff until shutdown is a personnel retention programme. Ideally, this programme needs to be in place when the shutdown announcement is made or shortly thereafter [44].

- **Historical Site Assessment** (see 9.2) and radiological characterisation (see 9.3)
- **Operational Data**

  Necessary information is more likely to be directly accessible while the plant is operational, records are intact, and their location is known. Timely access to reliable information can speed up decommissioning planning, reduce uncertainty and risks in the planned work, and result in cost and schedule efficiencies.

- **Available Personnel Resources**

  Personnel resources (with historical knowledge and expertise) are still available while the plant is in operation. However, soon after the shutdown announcement, some people will wish to leave. With retiring employees' knowledge and experience leaving, the younger employees' workforce for future transition and decommissioning tasks are affected. Personnel may be unsettled by questions related to their own areas of expertise, when they start to face threat to their employment. If, however, due to the decommissioning strategy, there is a long period of inactivity, due to a deferred dismantling with many years of safe storage, and plant resources are not available anymore, it is even more important to have accurate and easy-to-find records. Part of the "brain drain" might be mitigated by contracting dismantling companies with nuclear experience.

- **Use of Current Operating Knowledge**

  By starting timely, the site can maximise the utilisation and effectiveness of current operating knowledge, personnel and operating systems or programmes to reduce hazards at the facility, with emphasis on processes and systems for which the skills and knowledge required are unique.

13.1 People-related Knowledge Management

The importance of trained and experienced facility personnel during the transition to decommissioning phase is important when it comes to critical activities such as spent fuel handling, cleaning and shutting down the systems, and preparing the plant to its decommissioning or safe storage period . Therefore, prolonging the deployment of competent operating staff personnel can be an important contributor for a safe and cost-effective transition to decommissioning.

Key competences should be identified well in advance; one example is the fundamental engineering design knowledge that is essential for subsequent considerations in the licensing process as well as considering later changes to the design basis to support facility modifications.

In the case that the operator is in charge of the transition to decommissioning, a plan to retain knowledgeable, skilled and experienced personnel should be developed before permanent shutdown of the facility and, as mentioned in Chapter 12, a strategic retention plan should prepared. To enable this and to avoid experienced personnel leaving the facility, the HR strategy should give professional perspective to the employees and manage them towards it [31].

Together with other retention measures, it is important to:

- Maintain necessary competences and skills for the nuclear facility and its remaining lifetime until decommissioning completion.
- Ensure the retraining of employees by anticipating the needs of the site.

- Promote the transfer of skills and "experience feedback" within the organisation.
- Maintain collective memory/sub-conscious knowledge.

13.2 Record-related Knowledge Management

The availability and accessibility of accurate and detailed historical data about the plant (e.g. the modifications that have been made, the fuel and waste management records, the radiological conditions, the operational records and details of events that may lead to the unplanned contamination of systems and structures) is necessary for a safe and efficient transition to decommissioning. The planning, cost-estimates, risks, and safety analyses of the activities during transition to decommissioning will be more precise and reliable with the input of these records.

The unavailability of information can have the following consequences [22]:

- Site and facility characterisation and background will lead to delay, more resources and equipment required, lack of accurate information for preparation activities and ALARA planning.
- Complete as built drawings, a technical description of the facility will lead to extra time/money spent on reconstructing the record and calculations and could cause delay.
- Procurement Specification records and information on the composition of materials through the lifetime of the plant will lead to difficulty on waste estimation and Characterisation and could cause delay.
- Environmental releases records (over the lifetime of the facility) will lead to lack of assurance on off-site and on-site contamination, leading to delay and increasing of uncertainty scenarios of non-identified contaminated areas.
- Abnormal occurrence reports will lead to an increase of unknowns and risks, cause lack of confidence from the regulatory body and the public; Unexpected waste arising and workforce dose/chemical exposure; leakages of radioactive materials during operations not well documented. This could cause delay and lead to an increase in cost and resources needed.
- Records of termination of pipes/cables/vessels will lead to unexpected hazards arise which could cause additional waste to be generated, e.g. vessels of liquids, cells of material etc.
- Claims from contractors due to lack of data to the contractors could lead to additional and unexpected costs.

Documentation typically collected and archived for transition to decommissioning is given in references [21], [16] and [31], referring to detailed recommendation of record keeping such as design, construction and modification data; operation, shutdown and post-shutdown data (see also Appendix A: List of Design, Construction & Modification Data).

14. Estimating Costs and Funding

14.1 Timing

Decommissioning is a huge logistical challenge, and early preparation is of the utmost importance, not least from a financial perspective.

A successful decommissioning project is performed in a safe and cost-effective manner and an essential prerequisite for success is planning for decommissioning as early as possible. In many countries, the first decommissioning plan is required along with the construction permit of a nuclear facility, and updates must be submitted to the authorities at specified intervals. Normally, these plans also contain a (generic or site-specific) cost estimate of decommissioning.

Even if the decommissioning cost estimation is not a regulatory requirement, early planning is essential and therefore highly recommended. A preliminary decommissioning cost estimate in the planning phase of a nuclear power plant can also serve as a reminder of the importance of preserving all design documentation including details of the plant data. Information loss (e.g. piping or cabling volumes) during operational years may cause additional costly efforts later on when preparing for decommissioning.

In earlier phases of planning, the focus of cost estimates should be on the extent of cost items needed to be included in decommissioning costs. A common understanding on the split between operational costs during the decommissioning phase and decommissioning costs is needed both internally and externally. Later on, when more relevant data is available, focus can be shifted to the detail and accuracy of the cost estimate.

Updating decommissioning plans (and related cost estimates) regularly, can considerably ease the planning phase, also in cases of sudden premature shutdowns (e.g. due to economic or political reasons).

Decommissioning preparation costs include operational costs, transition phase costs, and dismantling costs.

As a minimum, a detailed and reliable decommissioning cost estimate is required to make a decision on the decommissioning strategy, and for which different strategy alternatives with estimated costs are compared. This comparative feasibility study should also include scenario and sensitivity analyses in relation to various parameters/factors, part of which are financial. This strategy is preferably decided prior to final shutdown of the plant.

14.2 Estimating Costs

14.2.1 Total Decommissioning Costs

Decommissioning is an intrinsic part of the overall life cycle cost for a nuclear power plant. The IAEA with the European Commission, and the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD), jointly developed a methodology (ISDC) for cost estimates of decommissioning projects [24]. Part of this methodology also refers to the activities during the transition phase, as indicated in the appendix of [22].

However, it must be remarked that direct comparison of decommissioning cost estimates generated for different plants is challenging, even if the results are presented using the ISDC.

Decommissioning costs may be estimated in a number of ways; the more common estimating techniques are as follows [24]:

- **Bottom-up technique** - e.g. starting from material quantities required for executing each discrete task performed in accomplishing a given activity, different cost items – direct labour, equipment and overhead costs – can be derived.
- **Specific analogy technique** - e.g. based on the known cost of an item used in prior estimates as the basis for the cost of a similar item in a new estimate, adjustments are made to account for differences in relative complexity of performance, design and operational characteristics.
- **Parametric technique** - e.g. cost estimating relationships are defined based on correlations between cost drivers and other system parameters – such as design or performance – as found from statistical analysis of historical data.
- **Cost review and update technique** - e.g. cost estimate is constructed by examining previous estimates of identical or similar projects for internal logic, completeness of scope, assumptions and estimating methodology.
- **Expert opinion technique** - e.g. several subject matter experts are consulted iteratively until a consensus cost estimate is established – this may be used when other techniques or data are not available.
- A combination of the above.

The bottom-up approach, in which the overall decommissioning project is generally divided into discrete and measurable work activities, is widely adapted in estimating decommissioning costs and is widely adopted in estimating decommissioning costs and usually provides a sufficient level of detail.

The following elements have been found to drive costs in the actual decommissioning of nuclear facilities [29]:

1. The decommissioning strategy, e.g. the scope of work through to the end-state of the site.
2. Assumed duration of the dismantling and clean-up activities.
3. Regulatory requirements, including details of reporting and clearance levels.
4. Stakeholder demands.
5. Characterisation of the materials and waste inventory (physical, chemical, radiological).
6. Waste processing, storage and the availability of final disposal facilities.
7. Obligations associated with management of spent nuclear fuel, including on-site storage before disposal.
8. Clean structure disposition and making the site available for new developments.
9. Contingency application and use in the estimates.
10. Availability of experienced personnel with knowledge of the plant.

The last item on the above list underlines the importance of efficient knowledge management as a cost driver. In an optimum case, experienced employees are available to share their knowledge and experience for decommissioning purposes. In other cases, transferring knowledge (including tactical knowledge as much as possible) of older generation employees before their retirement into such a form that the younger generation can utilise it later on, is important.

In addition, high-quality documentation control with up-to-date data is needed for accurate cost estimates. Collective memory and written/digitised data should together provide necessary information for reliable decommissioning cost calculations. The better the accuracy of the input data, the higher the reliability of the decommissioning cost estimate.

The most important considerations to ensure stable decommissioning cost estimates include [29]:

1. Avoiding changes in strategy and scope (e.g. the decommissioning strategy and the end-state of the site).
2. Fixing regulatory standards during the decommissioning planning phase to avoid delays during active decommissioning.
3. Early development and availability of a national radioactive waste policy and infrastructure.
4. Accurate characterisation of materials and soil (information already required during operations).
5. Good estimation of future interest rates (as the decommissioning cost is always a discounted value, which depends on the interest rates).

Shortcomings in pre-decommissioning planning and changes in scope during decommissioning are important cost and cost uncertainty drivers. Scope and schedule stability ultimately result in risk and cost stability. Another prerequisite for a stable cost estimate is also stable national boundary conditions for decommissioning, meaning that also political aspects can affect the foundations of a decommissioning plan and consequently the decommissioning cost calculation.

Because project management and site operation is the largest cost element, allocation of roles and responsibilities is critical. In particular, waste management is an indirect driver of project costs; proper waste identification and routing will benefit the overall decommissioning cost and schedule [70].

According to [45] and [49], based on data from decommissioned US NPPs, the cost of decommissioning is highly influenced by overall staffing costs, which relates to the total length of decommissioning. The figure below shows that staffing costs make up, on average, 43.5 % of the total decommissioning costs in the US. By shortening the length of the transition phase (e.g. by optimising the defueling operations on the 'critical path'), the overall length of decommissioning can be shortened. The parallel execution of post-operational and dismantling activities, if allowed by the licensing framework, could also lead to a reduction of the overall decommissioning schedule. This leads to reduced cost of decommissioning.

Figure 14-1: Example of breakdown of decommissioning costs for a PWR/BWR in the US [49].

Typical costs contained in each category in Figure 14-1*: Example of breakdown of decommissioning costs for a PWR/BWR in the US [49].* are as follows:

1. Removals: Includes field labour for removal and decontamination, equipment and specialty subcontracts.

2. Waste: Includes packages and equipment, disposal, shipping and on-site labour to perform these activities.

3. Staffing: Includes all labour other than that included in the removals and waste category. Includes utility and contractor labour. Often referred to as the "hotel costs".

4. Other: Includes all costs not captured in the above three categories, such as insurance, taxes, and licensing fees.

It should be noted that costs are based on unit costs in the US which may differ greatly from that in other countries (e.g. waste disposal costs are typically much higher in other countries as compared to the US).

In addition to the deterministically assessed decommissioning costs, additional provision is needed to allow for uncertainties.

According to a joint report by NEA and IAEA [30], uncertainties fall into four broad categories:

1. "Routine variability", e.g. of environmental or working conditions, due to the dynamic and hands-on nature of many decommissioning activities.

2. "Insufficient knowledge", e.g. due to lack of relevant experience or insufficient data.

3. External events or "risks" that are unpredictable, but whose likelihood and impact can be examined through risk analyses.

4. Financial uncertainties such as interest rates (the payment to the fund depends on the future interest rates).

Basic elements of a cost estimate, including in-scope and out-of-scope uncertainties, are illustrated in the figure below.

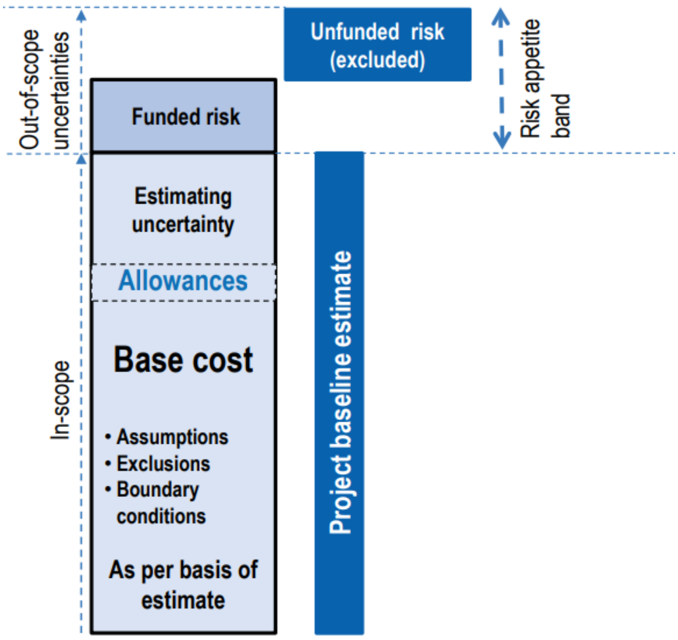

Figure 14-2: Basic elements of a cost estimate [30].

The definition of contingency (as used in [24]) is “specific provisions for unforeseeable elements of cost within the defined project scope”. In Figure 14-2*: Basic elements of a cost estimate [30].*, the term "Estimating uncertainty" is used for a provision to cover similar type of uncertainties associated with the defined project scope.

Estimating uncertainty can be calculated using either a deterministic approach, or by using a probabilistic approach.

The concept of classification of cost estimates can be used as guidance to reflect the quality of the underlying data, the completeness and reliability of the estimate (e.g. a cost classification scheme) developed by “AACE International”, as shown in the table below, adapted from [27].

	Primary Characteristic	**Secondary Characteristic**			
Estimate Class	**Level of Project Definition** (expressed as % of complete definition)	**End Usage** Typical purpose of estimate	**Methodology** Typical estimating method	**Expected Accuracy Range** Typical variation in low and high ranges (a)	**Preparation Effort** Typical degree of effort relative to least cost index of 1 (b)
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgement, or analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study of feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget authorisation, or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -50% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%	5 to 100

Table 14-1: AACE international cost classifications [27]

The below figure illustrates how the global cost estimate and its different components (including uncertainties and risks) will evolve over time as the decommissioning project progresses [30].

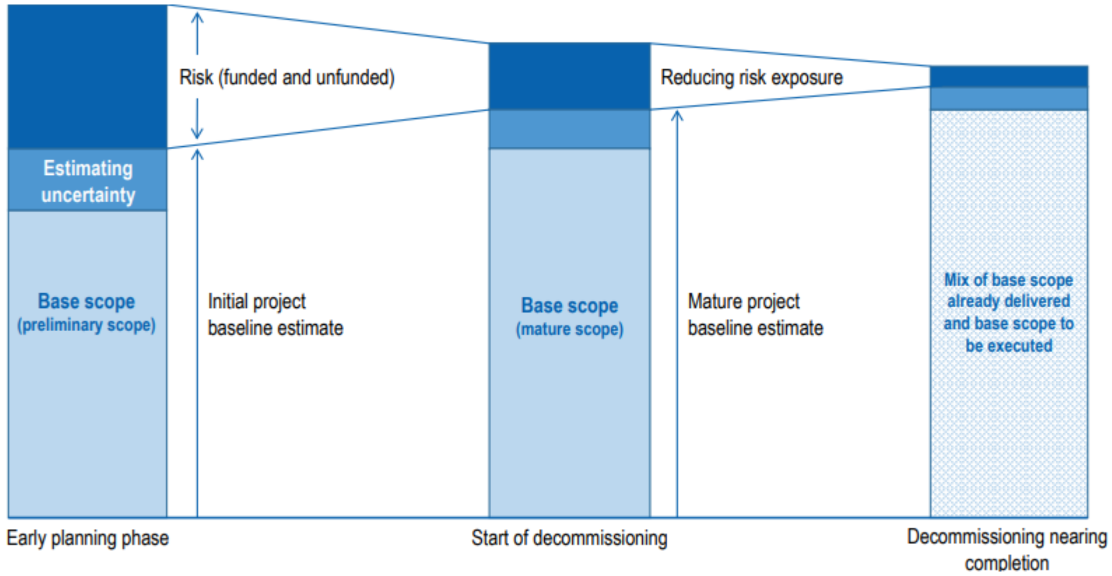

Figure 14-3: Change in-scope maturity and relationships between elements of a cost estimate over time [30].

Risk analysis is a method for addressing risks that extends beyond project scope in the cost estimate. It is done through conducting analysis that allows systematic identification of risks potentially causing an increase in cost, or opportunities that can result in a decrease in costs, and factoring these into the cost estimation process [26].

14.2.2 Post-Operational Phase Costs

During the post-operational phase, activities are planned and carried out which lead to simplified operation, reduced surveillance and maintenance requirements and lower operating costs. This can be achieved by identifying those plant systems which will become redundant after final shutdown. Further consideration should be given to systems that are needed after shutdown, but which are costly to operate and maintain, e.g. the capacity of the ventilation system needed to control contamination in shut down facilities can be greatly reduced [22].

Cost reductions will also take place as a result of changes to technical specifications as the licence is amended. Cost savings can be achieved from reductions in [22]:

- Labour
- Power and fuel consumption
- Consumables
- Surveillance and maintenance
- Regulatory and technical requirements (including inspections)
- Training
- Recycling of material and components
- Nuclear insurances and taxes

If a graded approach is utilised, in accordance with global risk reduction, security costs and nuclear liability insurance can be reduced when the plant is shut down and fuel elements are moved off-site.

On the other hand, there are additional, specific preparatory activities and related costs during the transition phase related to: alternative strategy studies, decommissioning planning, licensing, contracting, spent fuel and material and waste management, decontamination, adjustments to staffing, plant controls, and power supply, etc.

Partial dismantling may also be possible, e.g. removing piping and insulation may also save time on the critical path of the decommissioning, and result in overall decommissioning cost savings.

Several case studies, and a bibliography of national and international guidance documents are presented in [31].

14.3 Financing/Funding

A variety of financing mechanisms are in place to cover the costs of nuclear reactor decommissioning, but the adequacy and robustness of these mechanisms are largely untested because of the limited number of completed nuclear power reactor decommissioning projects [29].

The "polluter pays principle" is largely applied in the nuclear industry. Based on this principle, the licensee - or the owner(s) - of a nuclear reactor is required to secure appropriate funding for decommissioning.

In most cases the fund is built up year by year, either over the entire expected lifetime of the facility or over a shorter period, and is based on calculated decommissioning costs [26]. National and/or licensee's risk appetite defines in which extent risks must be covered by the fund.

Because financing programmes are based on many different regulatory and legal systems, there is no international standard or universal best approach to ensure the availability of decommissioning funds [29]. However, a simple truth is that to be prepared for a sudden premature shutdown and immediate dismantling strategy, a front-end-weighted funding scheme is recommended.

The scope of the fund also differs nationally, e.g. in relation to transition phase activities that are covered by the fund, and whether or not they are covering all or part of the material and waste management costs. Consequently, it is important to ensure that the parts that are not covered by the national fund, are covered by separate provisions [71].

Reference [33] includes useful information on a conceptual framework for financially and politically sustainable financing arrangements for the back-end of the nuclear fuel cycle. It has 12 country case studies on funding arrangements prepared in collaboration with NEA member countries and a synthesis of elements of good policy practice.

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Appendix A: List of Design, Construction & Modification Data

Linked to Chapter 13 'Retaining Knowledge and Information'.

Design, Construction and Modification Data

- Site Characterisation, geological and background baseline radiological data
- Complete drawings and technical descriptions of the facility as built, including design Calculations
- Construction photographs with detailed captions
- Schedules of any construction modifications and their drawings
- Procurement records that identify the types and quantities of the materials used in construction
- Engineering codes
- Equipment and component specifications, including pertinent information (i.e. the supplier, weight, size, materials of construction, etc.)
- Facility construction material samples
- Facility design inventories of chemical and radiological material flow sheets
- Quality certifications
- Safety cases for the operation of the facility
- Environmental impact statements
- Pre-operational facility testing and commissioning records
- Licensing documentation and operating requirements
- Preliminary decommissioning plans

Operation, Shutdown and Post-shutdown Data

- The license and licensing requirements
- Safety analysis reports
- Technical manuals
- Details of environmental releases
- Facility logbooks
- Operational experience data & lessons learned
- Facility and/or site radiological survey reports
- Operating and maintenance procedures and records
- Abnormal occurrence reports
- Decontamination plans and reports

- Technical specifications (limits and conditions)
- Design change reports and updated drawings
- Hazardous material inventories
- Process and service interfaces with other facilities
- Process flowsheets, including for services
- System, structure and component inspection records
- On-facility waste management records
- Site hydrology and groundwater contamination records
- Records of equipment terminations (e.g. piping and cables) during operation and at shutdown
- Records of staff leaving debriefings
- QA records
- Fuel geometry, performance (i.e. damage) and accounting records
- Records of neutron fluxes and distributions
- Records of material and waste management strategies and locations of waste
- Records of radiation sources and their locations
- Samples of irradiated and embrittled materials
- Relevant laboratory test reports

Appendix B: Key Content for Transition End-Point Documents

Linked to Chapter 8 'Asset Management Optimisation'

- Fuel
    a. Intended fuel inventory within core and pools, if any.
    b. Extent, location and identification of known failed or damaged fuel.
    c. Other non-fuel inventory items in the pool.
    d. Transfer flasks and vehicle status.
- Systems Status
    a. Active /inactive system status.
    b. Residual operation life of a system.
    c. Presence of irreplaceable elements in a system.
    d. Isolation location and methodology for utilities (electricity/air etc.). Vessels or components drained or not.
    e. Decontamination status.
    f. Presence of hazardous substances like asbestos, chemicals etc.
    g. Configuration of emergency systems (nuclear and non-nuclear).
    h. Lifting equipment status.
    i. Ventilation system status.
    j. Radiation Surveillance systems status.
    k. Radiological classification of areas.
- Register of any contaminated asset or land.
- Characterised assets with focus on residual contamination present and any associated risks to decommissioning from residual contamination/inventory.
    l. Handling of movable equipment, tools etc.
- Infrastructure
    a. Layout and boundaries of security fencing/controls.
    b. Roads/gates and bridges.
    c. Workshops.
    d. Welfare/canteens/change rooms.
    e. Waste routes and waste handling and storage. Liquid effluent controls. Chemistry controls. Chemical controls.

f. Configuration of cranes/lifting systems.

g. IT system status.

h. Telephone network and communications routes.

- Radwaste Inventory

a. Register of existing orphan waste (contaminated asbestos etc.).

- Spare parts inventory and potential re-use

a. Do an inventory of your plant assets with valuable equipment/components to be identified.

b. Use those internally within the fleet or consider using some valuable equipment somewhere else in the fleet.

c. Sell to market – within nuclear industry/within energy branch/to other industries.

- Define how to proceed to permanent separation for multi-unit site

Appendix C: Content Examples of Decommissioning Plans

Linked to Chapter 5 'Decommissioning Plan'

France

- An updated dismantling plan with the dismantling stages and the final site state
- A document containing the description of the installation before its final shutdown and dismantling
- An environmental impact assessment report
- A preliminary safety report relating to the final shutdown and dismantling
- A risk management study
- The general rules of surveillance and maintenance to be observed
- An update information of its technical capabilities to carry out dismantling operations
- Information of financial capabilities

US

- Description of planned decommissioning Activities.
- Schedule of planned decommissioning Activities
- Estimate of expected decommissioning and spent fuel management costs
- Environmental Impacts

South Korea

- Project management including cost estimation and financing plan
- Status of site and environments
- Decommissioning strategy and methods
- Design features considering easiness of dismantling
- Safety assessment
- Radiation protection
- Decontamination activities
- Radioactive waste management
- Environmental impact assessment
- Fire protection

Russia

- Preparation for decommissioning and maintenance of the unit in a safe condition
- Organisational and technical measures implemented in preparation for decommissioning
- Unit decommissioning information system

- Changes in operating conditions after the final shutdown of the unit
- Spent nuclear fuel management after final shutdown
- Removal of radioactive and hazardous process media from the reactor facility and associated systems
- Decontamination of equipment, systems, building structures, premises and buildings
- Disposing of operational radioactive waste
- Lists of systems and elements for the preparation and implementation of the decommissioning of the unit
- Ensuring radiation safety of workers (personnel), the public and the environment
- Education and training of workers (personnel) for the decommissioning of the unit
- Fire safety
- Preparation of documentation for the decommissioning of the unit
- Decommissioning of the unit
- Organisational and technical measures implemented at the stage of the unit decommissioning
- Sub-programme of works on radioactive waste disposal during unit decommissioning
- Sub-programme of works on decontamination of equipment, systems and building structures
- Disassembly work sub-programme
- Sub-programme of works on disposing reusable materials
- Sub-programme of works on elimination of consequences of possible accidents
- Sub-programme of works on radiation, dosimetric and industrial environmental control
- Physical protection works sub-programme
- Sub-programme of works on preservation of equipment, systems and building structures
- Sub-programme of works on the cost estimation of decommissioning works
- Sub-programme of works to ensure funding for decommissioning

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