Guidance on

Cost Assessment and Financing Schemes of Radioactive Waste Management Programmes

Work Package 12

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 847593.

http://www.ejp-eurad.eu/

Document information

Project Acronym	**EURAD**
Project Title	**European Joint Programme on Radioactive Waste Management**
Project Type	**European Joint Programme (EJP)**
EC grant agreement No.	**847593**
Project starting / end date	**1st June 2019 – 30 May 2024**
Work Package No.	**12**
Work Package Title	**Guidance**
Work Package Acronym	**WP12**
Deliverable No.	**12.4**
Deliverable Title	**Guidance on Cost Assessment and Financing Schemes of Radioactive Waste Management Programmes**
Lead Beneficiary	**SURAO**
Contractual Delivery Date	**M26**
Actual Delivery Date	**08/02/2022**
Type	**Report**
Dissemination level	**PU**
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To be cited as:

(2021): Guidance on Cost assessment and Financing Schemes of Radioactive Waste Management Programmes D12.4 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

Disclaimer

Acknowledgement

This document is a deliverable of the European Joint Programme on Radioactive Waste Management (EURAD). EURAD has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 847593.

Status of deliverable		
	By	Date
Delivered (Lead Beneficiary)	SÚRAO	19/10/2021
Reviewed (Reviewers)	WP12 Editorial Board (Piet Zuidema, Neil Chapman and Ole Kastbjerg Nielsen)	05/11/2021
Verified (WP Leader)	Jiří Faltejsek	19/01/2022
Approved (PMO)	Paul Carbol	31/01/2022
Submitted to EC (Coordinator)	Andra	08/02/2022

Executive Summary

The accurate assessment of future costs for disposal facilities and the provision of financial resources form fundamental prerequisites for radioactive waste management. According to the generally adopted "polluter pays" principle, the waste generator is liable to cover the cost of the disposal of radioactive waste (including spent nuclear fuel, if considered as waste) that arises from a particular current or past nuclear activity.

The principle of intergenerational equality requires that past and present generations should not leave unfunded liabilities resulting from their activities to future generations. In radioactive waste management, the time differences between revenue generation and future expenditures for providing for the final disposal of this waste may extend to over a century. This means that it is crucial to have a sound cost estimation methodology for final waste disposal in place to minimise the risk of transferring financial liabilities to future generations.

The guiding principle is to ensure that the future costs of radioactive waste disposal are well understood and accurately assessed so as to be able to ensure adequate financial resources to cover these costs. Due to the large time spans involved, estimations should be regularly updated and reassessed in order to provide as reliable a cost estimation as possible. This guide focuses on cost assessment as the basis for providing sufficient funding for radioactive waste disposal programmes. Although national radioactive waste disposal programmes are created according to specific national conditions and may have differing legal frameworks, sizes of nuclear power programmes or other nuclear applications, future plans and societal circumstances, the need for the consistent and reliable cost estimation of the disposal programme is common to all.

Cost estimations are needed for all projects, programmes and operations. Information on this topic is abundant, and guidance on various approaches and methods is widely available. However, the estimation of the costs of disposal programmes remains challenging due to their complex and societally sensitive nature and long implementation periods, and practical guidance on this issue remains insufficient. Countries that are just starting to develop their disposal programmes and which have little or no experience in this area may have difficulties in finding the relevant advice on how to perform cost estimations. This guide aims to describe the cost estimation process specifically focusing on radioactive waste disposal programmes, and to provide practical advice on how to conduct this process so as to result in a consistent, reliable and well-documented cost estimation. The guide suggests a stepwise approach to costing to make the whole process more transparent and easier to manage. The steps are interdependent and logically cover all the important phases in the cost estimation from defining the purpose and scope of the estimate, selecting the method and obtaining the input data, to performing the cost estimation and the consideration of, including suitable approach to, addressing cost uncertainties and risks.

Additional benefits for potential users comprise the presentation of practical examples of how the work scope of the geological disposal programme should be broken down into smaller, meaningful elements and hierarchically organised in the form of a Work Breakdown Structure (WBS), and a discussion on the possible cost uncertainties and risks related to the various WBS elements of geological disposal programmes. The presentation of selected lessons learnt and experience obtained from the cost estimation processes of a number of national programmes may also be helpful for gaining a better understanding of the process.

Although the cost assessment presented in this guide focuses on geological disposal programmes, with certain adaptations it can also be applied to near-surface or borehole disposal programmes since the principles are the same and, from this prospective, the guide may also be beneficial for small inventory disposal programmes.

Projects involving various types of disposal facilities and waste inventories have been underway for many years in countries that have different economies. How financing is to be arranged is normally

specified in national legislation, which stipulates the conditions that determine the scope of the calculation model used to arrive at the basis for the determination of fees, tariffs, levies etc.

According to national circumstances, countries may implement different financing schemes for radioactive waste management activities, all of which meet the aforementioned guiding principles. Taking into account the wide variety of financing solutions, this guide, instead of providing detailed guidance on financing, merely lists potential schemes and describes the financing of RWM activities from a pre-collected fund.

The Appendices provide further guidance information. Appendix A lays out examples of cost estimations to illustrate how the methodology works in practice. Appendix B includes a glossary of terms that are specific to costing. Appendix C describes the challenges and lessons learnt from past practices based on the screening of key references and provides references for further reading. The collected aspects in this appendix can assist end-users who are about to start cost assessment process and develop or improve their financing schemes for radioactive waste management.

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Abbreviations and Definitions

AP	Advanced Programme: Radioactive waste management programmes that are close to the implementation of disposal. They typically include programmes that are being licenced for construction or completing the site-specific and detailed site characterisation stages, and programmes that have produced comprehensive safety cases (and the related supporting evidence base) for detailed conceptual designs suitable for regulatory scrutiny and/or subject to international peer review.
DGR	Deep Geological Repository
DSRS	Disused Sealed Radioactive Source
EBS	Engineered Barrier System
EIA	Environmental Impact Assessment
ESP	Early-Stage Programme: Radioactive waste management programmes that are at an early stage of development with respect to the implementation of disposal. This typically includes programmes in the establishment stage or that are in the preliminary site evaluation and selection phase, or programmes that are yet to develop demonstrable competence for producing comprehensive safety cases (and the related supporting evidence base) for detailed conceptual designs.
EURAD	European Joint Programme on Radioactive Waste Management
GBS	Goals Breakdown Structure
GD	Geological Disposal
HLW	High Level Waste
IT	Information Technology
IMS	Integrated Management System
ILW	Intermediate Level Waste
KM	Knowledge Management
LLW	Low Level Waste
NGO	Non-governmental Organization
PPP	Purchasing Power Parity
PREDIS	EC Project: The pre-disposal management of radioactive waste
RE	Research Entity
RWM	Radioactive Waste Management
SAR	Safety Assessment Report
SF	Spent Fuel
SIMS	Small Inventory Member States: Member States that have a small inventory of radioactive waste typically containing medical waste, disused and sealed radioactive sources and, possibly, a small amount of spent nuclear fuel from research reactors.
TSO	Technical Support Organisation
URF	Underground Research Facility
WBS	Work Breakdown Structure

WMO	Waste Management Organisation
WP	Work Package

1. Introduction

The legal environment in the field of radioactive waste management (RWM) changed significantly with the adoption of Council Directive 2011/70/Euratom of 19 July 2011 that established a Community framework for the responsible and safe management of spent fuel and radioactive waste (Directive) [1]. The Directive, that was required to be transposed into the national legislation of Member States by 23 August 2013, foresaw in Article 9 that "*Member States shall ensure that the national framework requires that adequate financial resources be available when needed for the implementation of the national programmes referred to in Article 11, especially for the management of spent fuel and radioactive waste, taking due account of the responsibility of spent fuel and radioactive waste generators".*

National programmes should provide detailed cost estimations of all the waste management steps up to the disposal and post closure phase, including associated activities such as research and development. They should also provide information on financing schemes.

One of the main goals of the Directive is to avoid the undue burden of radioactive waste and spent fuel management being transferred to future generations. The Directive requires Member States to develop suitable organisational frameworks, including the definition of national programmes, that present the related costs over time and detail the financing schemes and the appropriate control systems in place, including regulatory inspections and reporting obligations.

While the Directive establishes rules for Member States to follow, it also provides them with appropriate flexibility concerning implementation. This is essential since Member States have their own specificities, e.g. the generation of different types of waste and in different quantities.

Through the obligation for Member States to keep their national programmes updated and subject to peer reviews, the Directive increases the transparency and quality of spent fuel and radioactive waste management and decommissioning funding mechanisms. Requirement (h) of Article 12 (1) of the Directive reads as follows: *National Programmes shall include (…) an assessment of the National Programme costs and the underlying basis and hypotheses for that assessment, which must include a profile over time.* [1]

Cost assessment provides the basis for the selection and application of the financing scheme and for the calculation of the adequate and timely accrual of the required financial resources. The ultimate goal is the coverage of short- and long-term liabilities related to spent fuel and RWM, including the management of legacies and the post-closure phase of disposal facilities. The cost assessment process is demanding since some of the costs are just estimated or are, as yet, unknown, and for which it is difficult to define the time of their appearance. This is especially the case for Early-Stage Programmes without the appropriate experience.

As part of the European Joint Programme on Radioactive Waste Management (EURAD), a Roadmap [2] is being developed which describes a high-level overview of the goals, typical activities and knowledge needed to implement RWM programmes aimed at geological waste disposal. As part of the EURAD Roadmap, a thematic breakdown of the knowledge and generic activities essential for RWM is systematically described in the form of a goals breakdown structure (GBS). It comprises Themes (Level 1), Sub-themes (Level 2) and Domains (Level 3), each of which are formulated as goals.

This guide supports Member States in terms of achieving the following Level 2 goal of the Roadmap GBS: to ensure that adequate financial means are available and can be adapted to the changing needs of the programme over many tens of years, from generation to disposal [2].

The document describes the stepwise approach to the cost estimation process and provides practical guidance on how to implement these steps in the case of GD programmes. The explanation is supported by several examples from three national disposal programmes that address differing aspects of the cost assessment process aimed at presenting how cost estimates are prepared in practice.

1.1 Objectives

The provision of financial resources to cover the costs of RWM forms a precondition for the implementation of a credible and sustainable national programme. This means that a solution exists for RWM that is economically feasible. Insufficient financial resources may jeopardize the implementation of the disposal programme [1], [3], [4].

Reliable methods for estimating the cost of the disposal programme that ensure that adequate funding is available and will be maintained until the conclusion of the disposal programme, including post-closure monitoring and institutional control, are crucial.

The lack of a systematic structure for the estimation of costs increases the barrier to responsible RWM and decreases the ability to review, compare and optimize the design and operation of the repository.

While attaining harmonisation across national approaches to cost estimation may be difficult to achieve, standardising the way cost estimates are structured and reported provides for greater transparency in the process and helps to build regulator and stakeholder confidence in the cost estimations and schedules.

The reliable assessment of future costs for radioactive waste disposal facilities is an important aspect of RWM. A consistent approach and methodology for estimating the cost of RWM, including disposal, is needed for both the national and international communities. It is important for newcomer countries which plan to begin the cost estimation process in the near future, as well as others such as early-stage programmes (ESP) and small inventory member states (SIMS), that information is available on cost estimation approaches, processes and tools. This guide is primarily intended for such 'targeted countries'.

Cost assessment is an iterative process that countries with radioactive waste should perform on a regular basis; therefore, there is a need for guidance on how to adequately and independently assess the costs for RWM and, in particular, for disposal, and on which financial schemes should be adopted for the collection of the appropriate funds.

Although there is an abundancy of technical documents available that address cost estimations and provide general information on the national examples of advanced countries, for countries that are about to start their activities in terms of cost estimation and developing/updating the financing mechanism for their RWM programmes, finding the information that is tailored to their needs is not so easy. Thus, this guide aims to better orient targeted countries in terms of suitably planning their activities in this field.

The guide provides advice on the cost assessment procedure tailored to the needs of ESP and SIMS. Moreover, it is intended to form a part of the active learning process on how advanced costing methodology can be applied in a way that enhances the development of the quality of the required cost calculations.

In order to better reflect to the needs of the target audience, the feedback of some potential end-users was asked, using a questionnaire. Based on the result of this survey, more emphasis was devoted to how the cost assessment could be performed in practice (development of a work breakdown structure, management of risks and uncertainties in the cost estimation etc.).

The key objective of this guide is to suggest a common framework in terms of a stepwise approach to costing, generally agreed methodologies for dealing with issues (e.g. the future value of money) and the reasonably detailed itemisation of cost elements. The guide is not meant to be a "common tool' for costing since national circumstances may significantly influence the cost assessment approach.

Details on various financial mechanisms can be found in a number of literature sources e.g. [4], [9], [20]. This guide describes only the financing of RWM activities from a pre-collected fund, which is the most commonly applied method.

The intended end-users of this guide include primarily waste management organisations (WMO) or designated organisations if no WMO has yet been established in SIMS and ESP countries (including countries that are initiating a new-build nuclear programme), which are, in most cases, responsible for conducting the cost calculations for their respective national programmes. The guide may also be beneficial for those entities (ministries, regulatory bodies and/or their technical support organisations) responsible for reviewing the cost calculations or those obliged to implement the “polluter pays” principle (e.g. waste generators).

The target audience may also include project managers and costing experts (who establish, revise and justify estimations) and those entities which are responsible for financing the national RWM programme.

1.2 Scope

The guide focuses primarily on the cost assessment methodology for geological disposal, but also includes selected information on how the national disposal programme might be financed. The scope of the guide is described for these two separate components in the following subchapters.

1.2.1 Cost estimation of geological disposal

The report provides general guidance on developing a cost estimation for radioactive waste disposal programmes (focusing on geological disposal), including more detailed advice on using a structured approach.

Initially, the guide explains the necessary prerequisites and boundary conditions for the disposal programme and its cost estimation, and emphasises the importance of a national RWM policy and national RWM programme, the existence of a national legislative framework and waste inventory, stakeholder engagement, etc.

Cost assessment is described as a process with several steps, starting with defining the purpose of the cost estimation, through developing the necessary basis for performing the cost estimation, calculating the base cost, addressing the risks and uncertainties in the cost estimation and the provisions needed for covering them, to final documentation and organising an independent review of the whole of the process. The guide provides a brief description of each of these steps including information on additional literature that contains more detailed information.

The guide continues with the presentation of an example of a WBS for a geological disposal programme, which provides a framework for cost estimation that is intended to be useful for countries and organisations that have just started or plan to start the cost estimation process in the near future.

One of the most important parts of the disposal programme cost estimation is the consideration of uncertainties and risks. The guide provides information on the most common uncertainties and risks in GD programmes and suggests how they might be addressed.

The guide emphasises that the cost estimation is an iterative process that requires regular updates and improvements in the input data, as well as transparency and quality assurance in the cost assessment process and the data and information management systems.

Appendix A provides several examples of cost estimations for various aspects of the disposal programme from different countries as illustrations of how cost estimations are performed in practice.

The guide does not include the following areas:

- The decommissioning costs of nuclear facilities: NPPs, research reactors and other RWM facilities, e.g. storage and treatment & conditioning facilities. The only decommissioning cost that is assessed concerns the decommissioning of repository support buildings as part of the closure phase.

- Pre-disposal costs: the cost assessment of predisposal activities will be addressed as part of the PREDIS project; therefore, those activities that are related to predisposal and are connected with disposal will be referred to in the respective PREDIS deliverable.
- Transportation costs related to the transport of the radioactive waste from generating facilities to the disposal facility.

1.2.2 Financing schemes

There are many different ways to finance RWM activities, including the geological disposal programme. Information on financing schemes is merely complementary to the cost estimation process, which represents the main objective of the guide. The guide lists a number of financial schemes as illustrations; however, the approach based on a pre-collected fund is described in most detail.

The guide provides a possible calculation as a base for the settlement of the financing scheme. The importance is highlighted of the justified assumption of the nuclear specific cost escalation rate and, based on the investment strategy of the fund, the determination of the expected rate of return – which can be applied as the nominal discount rate in the net present value calculation. Different approaches (nominal-term and real-term) are introduced for the net present value calculation. Detailed economic analyses that substantiate the calculation of the contribution to the fund are generally specific to national economies; hence, they are outside the scope of this guide.

1.3 Structure and content of the report

The content and the structure of the guide took into account feedback from the editorial board, end-users, consultants and reviewers. The report is structured as follows:

- Chapter 1 provides background information with the objectives and scope
- Chapter 2 presents the boundary conditions for the cost assessment
- Chapter 3 describes the cost assessment process
- Chapter 4 covers financing schemes
- Chapter 5 sets out a series of conclusions
- Appendix A: Examples of cost estimations
- Appendix B: Glossary
- Appendix C: Challenges and lessons learnt from past practices based on the screening of key references

2. Initial and boundary conditions of the cost assessment

The essential prerequisite for the implementation of a safe and sustainable radioactive waste disposal programme is the availability of financial resources to cover the costs of the required activities. Since the implementation of such a programme may take several decades or even more than a hundred years, and expands far beyond the time during which the respective nuclear activities provide benefits and revenues, financial resources need to be put aside to cover the related future costs, also known as long-term financial liabilities. By definition, financial liabilities are costs that will need to be covered in the future that result from past, current and future activities. A special situation relates to countries (some SIMS, e.g. Denmark) where the responsibility for financing rests with the state. There is no direct source of tax revenue from radioactive waste generators to contribute to the cost coverage of the RWM programme. Examples of various financing schemes can be found in chapter 4 of this guide.

Deep geological repositories (DGRs) will serve not only for waste from existing NPPs, but will also accept waste from future NPPs, which may cover part of the costs (the so-called 'rolling future'). There is a significant difference between having a long-term national facility that will cater for present and future waste and one that is intended only for legacy waste and waste from existing NPPs and which has to be financed before these facilities close.

Put simply, long-term financial liability in the field of RWM means paying for the final disposal of radioactive waste (including SF, if considered waste) and non-radioactive waste arising from a particular current or past nuclear activity.

Experience shows that there is a tendency to underestimate costs, which means that it is important to have agreed and transparent frameworks and procedures in place for conducting cost estimations and making regular updates [2]. In order to be able to make necessary provisions for covering future expenditure related to radioactive waste disposal, it is essential to develop a full understanding of, and to be able to recognise, such liabilities and to make a quality cost assessment of them so as to understand the funding requirements for these liabilities.

The cost assessment is determined and influenced by numerous national boundary conditions such as:

- national RWM policy;
- national RWM programme;
- national legislative and institutional arrangements;
- national inventory;
- existing RWM facilities and technologies;
- time horizon of the RWM facilities;
- stakeholder relations.

2.1 National policy

EU Council Directive 2011/70/Euratom establishes a Community framework for the responsible and safe management of spent nuclear fuel and radioactive waste to avoid imposing undue burdens on future generations. This Directive requires, inter alia, that Member States shall [1]:

- have a national policy;
- draw up and implement National Programmes for the management, including the disposal, of all spent nuclear fuel and radioactive waste generated on their territory;
- provide cost assessments for spent fuel and radioactive waste management in their National Programmes, including assumptions used and profile over time;
- have in place financing mechanisms to ensure that adequate funds are available.

The national RWM policy should cover all stages of SF and RW management, from generation to disposal, when the SF and RW results from civilian activities.

The national policy describes the general principles, requirements and goals which should be implemented in SF and RW management. It may also include specific policies such as:

- the back-end policy for the nuclear fuel cycle (for example spent fuel reprocessing or direct disposal);
- radioactive waste management policy;
- roles and responsibilities for implementing the policy;
- decommissioning policy for nuclear facilities (which can have a significant effect on the amount of radioactive waste and its properties and on the timing of waste disposal activities);
- role of shared solutions (e.g. dual track approach);
- transparency policy.

2.1.1 Polluter pays principle

According to the generally adopted "polluter pays" principle, the waste generator is liable to cover the cost of the disposal of radioactive waste (including SF, if considered waste) and non-radioactive waste arising from a particular current or past nuclear activity. Most of these liabilities will be addressed after the nuclear power plant or activity/process that generates radioactive waste has ceased operation and is no longer producing revenues; therefore, the operators (waste generators) are expected to have allocated funds to cover these liabilities as early as in the operational period. The amount of funds allocated depends on the extent or value of these liabilities and the financial schemes that have been implemented.

2.1.2 Dual track approach as an option

Countries may also consider sharing dedicated waste management facilities (including for disposal) with other countries. The pursuit of a multinational approach, however, needs to include a commitment to also implement a national solution, should such a multinational solution not finally be available. This is termed a "dual track" approach, where a multinational disposal solution is considered in parallel with a national solution. Being a partner in a collaborative repository development project thus does not remove the commitment for each participating country to have a national policy and programme.

A multinational repository may be a viable undertaking and could offer substantial benefits to the countries involved. One of the main benefits lies in the economies of scale accruing from the combined disposal operation. Other positive aspects concern resource and competence sharing such as the pooling of research and development expertise, technical problem-solving capabilities, repository siting experience and facility design know-how. Detailed information on the multinational repository concept and the dual track policy can be found in [5].

2.2 National disposal programme

Establishing a national disposal programme is an essential element in terms of implementing the overall policy and national arrangements for the safe and responsible management of SF and RW. National disposal programmes should define the various activities involved, including provisions for the necessary financial resources. Since the types and amounts of RW differ from country to country, the strategies for implementing policies often differ.

National programmes should detail which concepts and technical solutions have been chosen for each management step from the generation of SF and RW up to, and including, disposal.

The selection of a disposal option depends on technical factors such as the waste inventory, waste characteristics, the availability of suitable host media, the conditions in the country such as climatic conditions, site characteristics and non-technical factors, e.g. the radioactive waste management policy, national legislative and regulatory requirements, political decisions, local socio-economic factors and resource availability. The consideration of these and other factors in the selection of a preferred disposal option is outside the scope of this guide.

The various disposal options (e.g. near-surface disposal, caverns at an intermediate depth, borehole disposal facility, deep geological disposal) may have differing site investigation requirements, research needs, waste acceptance criteria, operational and post-closure monitoring requirements, and time periods for post-closure institutional control. All these aspects impact waste management and disposal costs and may be further influenced by country-specific socio-political considerations.

The cost estimation can also serve as the basis for comparing different waste management strategies, approaches and disposal options, as well as a tool for programme and/or facility optimisation ([3], [4]).

Concepts and plans for the post-closure phase, in particular related to institutional control, need to be considered in the early phases of the disposal project. Post-closure measures will depend on the nature of the repository as well as the national policy and legislation.

2.3 Legacy waste management

Although there is no official (e.g. IAEA) definition of legacy waste, it is usually understood to refer to radioactive waste generated through past practices such as defence programmes, research and development, fuel cycle and radiochemical activities. Other definitions include historical waste in old storage and disposal facilities that were either never intended to be a permanent end-state or are no longer considered adequate from a safety perspective.

Legacy waste management, particularly in countries with small inventories or small nuclear industries, may be ranked in a low position in terms of national funding priorities. The cost assessment for the disposal of these sorts of waste is often difficult since:

- the waste inventory, volume and activity is unknown or very uncertain;
- no final disposal option has been selected;
- the post-closure control period has not been determined or regulated.

It is not uncommon in the case of legacy waste for there to be a diverse range of waste owners or even a lack of clarity as to the owner of the waste since the original generators may have become insolvent or the liability may have been handed on to another party. Waste owners can, therefore, be a mixture of public and private entities. Generally, responsibility for any waste without a clear owner (sometimes referred to as orphan waste) defaults back to the state. The management and disposal of this waste are challenging, both technically and financially.

State budget financing may be the only feasible resource for covering the cost of the disposal of historic waste or other legacy waste for which there is no identified owner. Although the use of financing from state budgets may not fully adhere to the 'polluter pays' principle, such an approach can be justified in certain circumstances on the basis that all citizens benefit from the intervention of the state in facilitating safe waste disposal. In general, many citizens obtain benefit from the use of radioactive materials in non-power applications, including health, industrial safety and research applications.

Countries may prioritise funding and resources for legacy waste management based on the risk. This approach aims to provide the public with confidence that higher-level hazards are being managed promptly so as to reduce the risk of harm to the environment and/or the public (e.g. the UK).

Countries may choose to prioritise those legacy waste projects that are most likely to be achievable, for example simple waste streams, lower dose rate items or campaigns that require less funding. Success in such campaigns may lead to enhanced public and political confidence and provide waste management organisations with an opportunity to train the workforce before seeking funding for dealing with more challenging waste streams.

In some countries, funding also covers the cost of the disposal of legacy waste (e.g. Hungary). State budget financing may be the only feasible resource for covering the cost of the disposal of historic waste or other legacy waste for which there is no identified owner.

In some cases, the funding required for urgent legacy waste management is beyond the capabilities of the country. In such cases, it may be possible to seek assistance from the international community through, for example, the EU, IAEA Technical Cooperation Projects or specially-funded non-proliferation-related projects. Access to such schemes should be considered, especially in cases where there are immediate implications with respect to the safety of the public or environmental concerns. Site-specific funding plans should consider all the work required to manage the waste from its current state through to disposal.

2.4 National regulatory and organisational framework

Comprehensive and coherent national legislation is essential in terms of ensuring the safe, secure and peaceful use of nuclear technologies.

When dealing with long-term financial liabilities, it is expected that consistent legislative and institutional arrangements are in place and that the roles and responsibilities of the organisations involved in dealing with the various liabilities are clearly defined. These include the government, the regulatory body, waste generators and the organisation responsible for disposing of the waste.

From the cost assessment and financing point of view, the legislative system should regulate *inter alia*: who is responsible for the accomplishment, review and approval of the cost assessment, what mechanism is in place for the financing of RWM activities, how provisions for the long-term liabilities should be calculated [1], [6], [12],[34].

2.5 Inventory

The inventory of SF and RW forms the basis for the national RWM programme. It should include an inventory of all RW and SF and estimates for expected future waste arisings (forms, quantities, possible new waste streams etc.), including those from the decommissioning of all current and future nuclear facilities and radioactive material applications [35].

The comprehensive waste inventory contains the quantities, characteristics and location of the SF and RW to be managed. Its classification on the one hand, and the envisaged waste management and disposal routes towards the various endpoints on the other, need to correspond to each other so that all SF and RW can be included in the solution.

Radiological safety is typically addressed via safety assessments for the various waste management phases. In some Member States it may also be necessary to present an environmental impact assessment. In all cases, consideration should be given to the non-radiological hazardous substances in the waste.

It is possible that due to the inventory of non-radiological hazardous substances in some RW, disposal in a deep geological disposal facility may be preferable to disposal in surface or near-surface facilities. This aspect may have significant cost implications.

2.6 Time horizon for the implementation of disposal facilities

The timescale for the implementation, construction, operation and closure of facilities refers to the period over which a concept has been developed and the expected timescale for implementation, from facility construction through to closure.

Milestones and timeframes for their achievement form an integral part of RWM projects as established for each management step of the individual waste streams. In addition, they should also be defined for those tasks that are relevant for several or all the streams, as applicable. With respect to disposal projects, however, milestones and timeframes might be strongly influenced by socio-political processes and, possibly, by scientific-technical and geological findings [6].

Waste management programmes are invariably phased or staged due to the long duration of activities. Nuclear power plants, the main source of waste, run for decades; other nuclear technologies will continue, even if nuclear power does not; SF may be stored for decades, waste repositories take decades to implement and operate; post-closure safety must be assured for many thousands of years. Such timetables are so prolonged that many programmes define a series of phases, each of which may last many years. This implies the adoption of a flexible process in which the new knowledge gained during each phase is used to plan the content and duration of the following phases – as opposed to attempting to rigorously define all the milestones and deadlines at the outset.

As part of the EURAD Roadmap, the following phases have been identified for the implementation of a radioactive waste disposal facility [2]:

- Phase 1: Policy, framework and programme establishment
- Phase 2: Site evaluation and site selection
- Phase 3: Site characterisation
- Phase 4: Facility construction
- Phase 5: Facility operation and closure

When changes occur to policies (e.g. the lifetime prolongation of nuclear power plants, new-build programmes) that influence the national RWM programme, the consequences for the timing of the various RWM activities must be re-evaluated and the necessary programme elements – and the related cost assessments – updated accordingly.

2.7 Political and social factors

Political decisions and public acceptance are factors which may significantly affect disposal costs. Worldwide experience demonstrates how socio-political factors may act to increase both siting and construction costs.

Disposal programmes need to be conducted in concert with many stakeholders such as the government, regulatory authorities, waste generators, the public, the media, NGOs, the affected municipalities, neighbouring countries, etc. Stakeholder involvement concerns the activities undertaken to create a dialogue with a broad range of stakeholders and to include them in the development and implementation of the disposal programme.

The siting of disposal facilities often involves the provision of economic incentives to local communities, a cost which makes up a significant fraction of total costs in some countries. In addition, expenditure on communication, public relations and visitor reception facilities and information centres contributes to integrating waste management activities into the local environment and, therefore, can be considered a social cost.

Once the radioactive waste disposal facility has commenced operation, societal factors normally exert less influence than during the planning and construction phases. However, the operation of an existing repository may still be a political issue, and external pressure may result in stricter regulations and, consequently, changes to the operating conditions and costs.

The approach to stakeholder engagement and the identification of the relevant stakeholders is a country-specific issue since it depends on national legislation and policies, the decision-making process and cultural factors.

3. The cost assessment process

There are two basic questions that need to be responded before any attempt of cost estimation is made: **why are we doing cost estimation** and **what do we want to estimate.** These two questions are closely interlinked and interdependent.

When starting a cost estimation of future liabilities, we have to be clear what do we actually want to estimate and also when is the activity to be estimated expected to occur. This means that the scope of the work included in the cost estimation and the timing of considered activities have to be defined. Further relevant information on this topic can be found in EURAD Roadmap, Theme 1 on Programme Management [2].

Both, the scope and the timing of all the planned works and activities have to be well documented and described in a document known as the base or the baseline document. Such document is essential for clear understanding of what is included in the scope of cost estimate and what is not. Moreover, such document provides the basis for any future review and quality check of the estimated cost and also for the updating or upgrading of cost estimate at some later time.

An important role plays also the reason of why we are doing cost estimation. Is this to estimate or update the target value of money that will be needed in the future to cover financial liabilities related to RWM, is this for comparison of different disposal options and selection of preferred one or is this required to control the adequacy of funding?

> *Baseline document*
>
> *Baseline document is a document that defines the purpose of the cost estimate and describes the scope of work with all major activities and deliverables that are needed for the disposal programme implementation. It includes also a time schedule of all activities and presents and justifies all assumptions that are used in this scenario for the unknowns and not well-defined aspects of the disposal programme (e.g. the timing and duration of main activities, assumptions about the site and geological settings, some decisions or technical solutions not well defined in the disposal programme, …), all boundary conditions and limitations, sources of data used for cost estimate and their reliability.*
>
> *The baseline document is important for maintaining traceability, it is also basic document for any review or an update of the estimate.*

The cost estimation is a process composed of several steps. Each of the steps has its role in the process and contributes to ensuring that the estimates of costs are developed consistently and according to best practices. A short description of these steps is provided below.

3.1 Main steps in cost estimation

Step 1: Define the purpose of the cost estimate

Cost estimates are prepared for different purposes and needs. Different purposes require different accuracies of cost estimates, different levels of details in describing the disposal programme and different methods of calculating these estimates.

If the cost estimate is applied in the early stage of the RWM programme development to compare different disposal options and to help selecting the preferred one, the expected accuracy is rather low. In such cases the disposal options considered are not developed in great details, they are more or less at the conceptual level therefore also the cost estimate can only be very rough as the aim is to look at the relative cost and not the absolute cost.

On the other hand, the expectations for reliability and accuracy grow when we are estimating the cost of disposal programme with a purpose to define the target value for future funding of these liabilities. However, this can only be commensurate with the level of development of the disposal programme. For mature disposal programme close to the implementation, detailed cost estimate is expected.

Step 2: Develop the baseline document

The baseline document is the starting point of any cost assessment. It identifies and describes the scope of work included in the cost assessment with all activities, tasks, deliverables (documentation, buildings and other facilities, equipment, infrastructure etc.), other relevant items (e.g. fees, taxes, insurance costs, etc.) and the time schedule of these activities/tasks. It serves also as a fixed reference point for any later reviews, updates or upgrades.

A prerequisite for developing such baseline document is the existence of the RW disposal programme or, at least, the national RWM policy and framework with main requirements and guidelines. More details on this aspect including an example of a generic RWM programme and description of typical activities leading to geological disposal can be found in the EURAD Roadmap [2]. Knowledge and experience collected in the Roadmap from a range of disposal programmes provide a source of useful information for all involved in development and implementation of RWM programme.

In cases where the disposal programme is not well developed, and all details are not defined yet, the baseline document should include some assumptions and predictions. For example: if the timing of future disposal has not yet been defined, the baseline document should adopt some assumptions on time schedules. Assumptions will also be required on future quantities of waste that will be disposed of.

At the very beginning of the disposal programme the development of baseline document may be faced even with more challenging situation. The preferred geological environment for future repository may not be agreed (selected) yet or whether LLW should be disposed of in a surface or underground disposal facility or whether SF will be disposed of directly or reprocessed (see also [2], Theme 1 Overview). Many unknowns and open issues can also be related to the technical solutions for the disposal of the waste (about treatment and conditioning of the waste, the type of packaging, etc.). In such cases the baseline document is built on assumptions that fill these gaps and missing information (or several options might be considered). However, it is important that such assumptions are justified and well documented.

With further development of the disposal programme the scope of the work required becomes more specific, technical details more elaborated and time schedules better defined. This should be reflected also in the baseline document which is becoming more complex and detailed.

It should be borne in mind that the baseline document forms the basis for the overall cost estimation process and the resulting cost estimate. It provides the traceability of what was done and how was done. Whenever a review, an update or an upgrade of this cost estimate is needed, this document is the starting point for the new iteration (provides the necessary initial information). Therefore, it is essential that it provides accurate and detailed evidence of what was done including all the assumptions used, the boundary conditions and the limitations considered.

Every new iteration of cost estimate (including updates and upgrades) requires new iteration of the baseline document in which all the changes and new developments and assumptions are documented and explained.

Step 3: Select the method for cost estimation

Different methods for estimating the cost of a project exist. Most commonly used are analogy method, engineering build-up method and parametric method. Each of these methods has its strengths and weaknesses and fields of applications. Which method to use depends on the purpose of the cost estimation and also on how well defined is the programme and the scope of the work for which the cost estimate is made. In some cases, several methods can be applied for estimating the cost of specific parts or elements of the same programme or project. Description of these methods and guidance for their use can be found in different sources [7], [8]. The cost estimation methods that are usually applied in the field of RWM are also discussed in [9] and include:

- the analogy method,
- the engineering build-up or bottom-up technique,

- the parametric method and
- expert judgement.

They are briefly described in continuation.

Analogy method

The analogy method is particularly useful for rough cost estimate in the early stage of the disposal programme development when the programme is not well defined and more detailed and reliable cost calculation is not possible (for example: the analogy method is normally used for the initial estimate of the disposal costs, when the disposal programme is still at the conceptual level). As already the name indicates this method estimates the disposal cost using the analogy with other similar and comparable (but more advanced) disposal programme(s). The cost of this programme is analysed and then adjusted to the estimated programme for differences like quantities of waste, capacity of repository, time schedules etc. The method can also be used for benchmarking of parts of the cost estimate.

Weaknesses/limitations

Although this method seems relatively simple and straightforward, it has a number of application limitations:

- A comparable programme must exist;
- information on the cost of the comparable programme must be available;
- The comparable or analogous programme must be well understood.

This method can be applied only if a comparable programme exists and is sufficiently advanced to have a relatively accurate cost estimate. As we can only select among existing disposal programmes the list of candidate programmes is currently not very long. Moreover, each one of them is specific and unique and we have to find the one that most resembles the programme under consideration in terms of the geological environment, the type of disposal facility, the type and quantity of waste, the requirements for and approach to siting, the time schedules, societal aspects etc. The differences between the two programmes and comparable and non-comparable cost items must be identified and analysed so as to be able to make the necessary adjustments.

In addition, sufficiently detailed information on the cost assessment of the comparable programme is needed in order to be able to make necessary adjustments and modifications in a consistent and meaningful manner. Not only technical but also all financial assumptions and predictions used in the comparable programme cost estimate must be known and well understood. For example: it has to be clear whether one is dealing with overnight cost, constant cost or discounted cost, what is the reference year for which the calculation is made, what discount rate is used, is contingency included or not. It is also necessary to consider the currency in which the cost of the comparable disposal programme is estimated and how the conversion to another currency is made. The study and analyses of disposal costs in different countries [10] revealed that it is very difficult to reasonably compare their costs because of great differences in approaches, disposal solutions, decision-making processes and technological and economic aspects.

Good understanding of the comparable programme and the informed interpretation of the applied solutions, assumptions, predictions, and other relevant features/decisions used in this programme are essential for meaningful adjustments of the cost estimates in the considered programme. In initial stages of cost calculations of the disposal programme when the team is still unexperienced the assistance of experienced experts is advised.

Expected accuracy

The accuracy of estimates calculated by this method is low. The order of magnitude estimate can be expected.

Engineering build-up method

For more mature disposal programme with better defined scope and time schedule more reliable and accurate cost estimate is needed. In such cases, the engineering build-up method, also called the bottom-up method, is used. The method is well known and commonly used in project management. Its main principle is to break (divide, decompose) the entire programme or project into smaller components/activities/tasks/items to obtain a so-called work breakdown structure (WBS) and then estimate the cost of each component. The cost estimate of the complete programme is the sum of the costs of individual components.

Such approach has several advantages:

- By breaking down the disposal programme into smaller and more specific components the entire scope of the work becomes clearer and can be more systematically structured and organised.
- Planning and allocation of responsibilities for executing the work becomes easier.
- New developments and changes in the programme can be more easily introduced and followed.
- Traceability through new iterations is easier and more efficient.
- The WBS provides also an excellent tool for cost estimation.

Expected accuracy

The accuracy of this method depends on the level of disposal programme development. The more specified the programme becomes the more detailed breakdown of the scope can be made and more accurately the cost estimated. In the earlier stage when some parts of the disposal programme may still be at more generic level the cost of the less detailed components may still be estimated by the analogue method. Nevertheless, the overall estimated disposal cost is expected to be more accurate than the one calculated applying the analogue method only. With each iteration or update and more and more detailed and specified disposal programme the level of accuracy is also improving.

Parametric method

The parametric method, sometimes referred to as the top-down method, estimates the future cost of a project or programme based on the experience gained from and the analysis of similar completed and implemented projects or programmes. The method develops the statistical relationship between the main cost drivers of the project / programme and their costs based on historical data. This cost estimating relationship is then used to estimate the cost of the programme by entering its specific characteristics into the parametric model. The parametric approach is based on the assumption that the same factors that affected cost in the past will continue to affect costs in the future.

Weaknesses / limitations

The application of the parametric method requires access to a sufficient amount of historical data, which has been collected from many already completed projects and programmes of broader range. Since not many disposal programmes have already been implemented to date and very little historical data are currently available, the parametric method is not very applicable for estimating the cost of disposal programme. However, it still can be used to estimate the cost of specific elements of the disposal programme.

Expected accuracy

The accuracy of the parametric cost estimation method depends on the availability and quality of the historical data used and on the extent of the validity of the statistical relationships between cost and programme's attributes.

Expert judgement

The expert opinion or engineer judgement approach relies on the subject matter experts to give their cost estimates on particular item or element. Usually, a group of specialists is consulted until a consensus can be reached regarding the cost of a programme, project, task, or activity.

Although such estimate is generally considered to be subjective, the expert judgement is commonly used in combination with other cost estimation methods in order to fill the gaps in the absence of real data or to select the appropriate cost numbers (e.g. unit prices) from other (completed) projects. In the early stages of disposal programme development, when the availability data and information isl very limited, the expert judgement is often the only option available to get the first rough cost estimate. Also, in the later stages when more specific data on the programme become available, the expert judgement can still be applied for some less developed parts or elements of the programme.

Weaknesses / limitations

One of the weak points of this approach is the lack of objectivity. There is also a concern that the most dominant expert will prevail the group opinion and its cost estimate.

Expected accuracy

This approach is not considered very accurate nor is it suitable as a primary estimating method.

Step 4: Prepare the Work Breakdown Structure of the disposal programme

In the next step, the scope of the work, described in the baseline document, is broken down into smaller meaningful elements. Such hierarchical decomposition of a programme or project into specific components or elements is called the work breakdown structure (WBS). These components can be programme or project phases, deliverables, or work packages. By breaking the programme into smaller parts, the scope of work becomes more manageable and transparent (see also [2], Theme 1 Overview).

The Work Breakdown Structure is a well-known project management tool and is described in many documents ([7], [11]). It can be used as a planning tool to assist in defining and organizing the scope of the work and the deliverables. It can serve as a monitoring and controlling tool. WBS also provides the framework necessary for a detailed cost estimation and control.

The WBS is a tree structure with several levels of elements. It can be done in many different ways. Most commonly used are deliverable-based WBS and phase-based WBS. The main difference between the two approaches concerns the Elements that are identified in the first level of the WBS. In first case these elements are the main deliverables and in the second case these are the main phases of the programme or project.

The level of details provided in the WBS depends on the maturity of the disposal programme and the information available on the scope of the work, the schedules, the technologies, and the boundary conditions in the baseline document. In compliance with this the cost estimation method should be selected. For example: for cost estimate based on the engineering build-up method a more detailed WBS is needed than for the analogy method.

In the process of preparing the WBS first the level 1 elements are identified and then further broken down into lower-level elements (level 2, level 3, …) to end-up with a tree structure with several levels of elements. How far to go by breaking down the elements and when to stop this process depends on individual programme or project. The decomposition is continued as long as it makes the scope of the programme / project clearer and more manageable, and it is stopped when further breaking down just increases the amount of unnecessary effort to manage.

The WBS should be considered to be an evolving document. As the programme matures, the scope of the work becomes more defined and the WBS reflects more details.

Step 5: Perform the cost estimation

When the WBS is decomposed to sufficiently small items to make cost assessment feasible and practical the cost estimation process can start. Cost estimate is made for each individual WBS item and then these partial results are summed up to get the cost of the entire programme at the price level of the calculation year (referred to as the base year or the reference year).

For the cost estimate of the WBS item it is essential to have data on the quantities or duration of the WBS item and the estimated unit costs. The quality of the collected data is of significant importance for the credibility of the cost estimate. Poor quality data cannot result in good quality of cost estimate. Obtaining the relevant high-quality data is often the most challenging, time-consuming and costly activity in the process of cost estimating.

Once the estimate is complete, the data need to be well documented, protected, and stored for future use.

Obtain the data and develop a cost database

Data collection

The cost estimate of the individual WBS items is possible only if data on quantities or activity durations and their estimated unit costs are available. Data are a prerequisite for any cost estimation.

The collection of data is a time consuming and lengthy process that requires good understanding of both, which data are relevant, useful and meaningful for the required cost estimation and how to obtain them. Specific problem appears when data are not available or are incomplete. In such case the only option is to rely only on experts' judgement.

When collecting the data, it is of vital importance to have a full understanding of what the collected data mean and represent. Without this understanding the data may be misinterpreted and wrongly used.

The collection of the actual cost data, any other data relevant for the cost estimations or conditions that can affect the data continues throughout the programme implementation. This is important for any potential future use of these data in new cost estimates.

Sources of data

Data can be collected from various sources: from other disposal projects and DGR programmes, from databases of past projects in other relevant fields (e.g. civil engineering construction, industrial manufacturing), by interviews and surveys. Direct contacts with manufacturers and vendors of equipment and materials, consultants, engineering companies or service contractors may also provide useful information on prices.

Types of data

Many different types of data are required:

- labour costs and costs of various types of work involved (i.e. excavation work, construction of underground and aboveground facilities, construction of roads and other infrastructure),
- equipment and material costs, consumables, supplies, and
- programme data including the time schedules for all activities.

With respect to labour costs or costs of works it is important to clarify whether the overhead costs are included or not. Programme and schedule data include parameters that directly affect the overall cost, like start and duration of activities, completion and delivery dates, testing periods and so on. Obtaining the cost data for the equipment may be particularly challenging since the equipment specific to the disposal project may still be in the planning or development phase.

Quality and applicability of the data

The quality of the data is directly related to the quality of the cost estimate.

Data obtained from original sources which can be traced to an audited document, i.e. primary data, are in general considered to be more reliable and of better quality. Sometimes the data are derived rather than obtained directly from the source. This means that the data have been changed from the original data to meet the specific needs. They are known as secondary data and their overall quality is lower. If only secondary data are available, it is essential to understand what these data represent, how they were derived, what they include and what not, how old they are, what adjustments were used etc. Data collected from other programmes have to be verified against their applicability for this particular cost estimation. For example: if the cost of rock excavation is based on the use of technology that is not foreseen in the disposal programme it is not applicable for this particular cost estimation.

It is also necessary to have a good understanding of the data taken from the databases of other relevant projects: what the data actually mean, what definitions have been used and under what assumptions have been developed, what uncertainties they bring etc.

Normalisation and adjustment of the data

Historical and other data collected from many different sources often need adjustment and normalisation to ensure that they are consistent and comparable with the other data used in the estimate.

For example: the collected cost data may be expressed in different sizes and units. Before being used the data have to be converted to the equivalent units like €/m^3, €/m, €/kg etc.

The cost data may also be expressed in different currencies and before applying them they must be converted into the selected currency. When selecting the conversion rates careful consideration should be given also to the time component of the converted data.

Another example of data normalisation is an adjustment of the cost units for the inflation. For each unit cost it is important to know from which year the data originate and then by inflating or deflating them adjust them to the base year for which the cost estimate is made. Sufficient attention should be given to the selection of inflation rate since it directly affects the credibility of the cost estimate. More details on this can be found in [7].

Cost categories

Very convenient for any further cost analysis, adjustment or update is grouping of collected data on costs into cost categories, such as labour costs, investments costs (equipment and material costs), expenses (consumables, supplies, insurance, taxes, etc), contingencies[1] (see subchapter 3.5.4.1).

In disposal programme cost estimation, it is also useful if the distinction between fixed and variable costs is made. Variable costs are those that vary (usually proportionally) with the amount of disposed waste while fixed costs remain the same regardless of the amount of disposed waste. In addition, step-fixed costs may be identified. A step-fixed cost is changing with the amount of waste as a step function. Such

[1] Contingencies are provisions for costs that cannot be predicted, but that can reasonably be expected to occur within the defined scope of the programme.

distinction is very useful and helpful when considering the optimization of costs or when updating the cost estimate.

Data documentation

Once the data have been collected, analysed, categorised, and normalized, they must be documented and stored. All information on durations of activities, quantities of various items and unit costs used in cost estimation of the WBS items that have been collected should be stored in cost database. Also, all assumptions that were used need to be recorded and documented. The responsibility for the creation and maintaining of such database should be clearly assigned. This is important for keeping the traceability and transparency of this process.

In the early stages of the disposal programme when first cost estimated are performed, the cost database may be relatively modest, but it develops with the maturity of the programme and new cost iterations.

This database provides an important input documentation and reduces the effort required for future updates of cost estimates. However, proper quality assurance and traceability of collected and stored data is required to ensure good and reliable cost estimates.

Calculate the overnight cost of WBS elements

The costs of the WBS elements are assessed on the basis of current costs. The overall disposal programme cost estimate is provided as a single value or a point-estimate once all the elements have been assessed and summed together. This cost estimate is based on today's costs and the resulting cost of the disposal programme is known as the overnight cost. The overnight cost of the programme is the cost as if the programme was completed "overnight." In reality, the WBS items costs are distributed over the entire lifetime of the disposal programme which may take several decades or even a hundred years. This time distribution of the costs is important and has to be properly considered when determining the provisions that are needed today to finance the disposal programme that may expand far into the future. This will be discussed in more details in Chapter 4.

Step 6: Conduct uncertainty and risk analysis and make provisions for them

Since cost estimates are predictions of the future programme costs, uncertainties are unavoidable part of them. Cost estimates are particularly challenging for disposal programmes because they are:

- scientifically and technically complex, politically sensitive and exposed to many societal challenges and eventual changes and modifications during development and implementation;
- they expand over very long time periods and any forecast for such long periods is uncertain;
- during the development of the disposal programme many aspects are either not well-defined or are yet to be defined and thus require certain assumptions for performing cost estimates which may change over time.

The sources of uncertainties are therefore various. They can be:

- economic (changes in labour rate assumptions, currency exchange rate fluctuations, electricity price variations, etc.,),
- political / societal (fundamental change in the policy on waste disposal, delays due to difficulties in achieving public acceptance, etc.),
- legal / regulatory (new requirements for disposal, changes in licensing procedures and requirements, taxation changes, etc.) or
- technological (the need for more detailed site characterisation, design changes due to unexpected characterisation results, changes in manufacturing or construction processes, the use of new materials, changes in the waste inventory, new technology, etc,).

These uncertainties and the associated risks need to be properly addressed and incorporated into the cost estimate to ensure that adequate provisions are set aside to cover the cost impacts of these uncertainties and risks.

Step 7: Document the estimate

When the cost estimate is completed, it is important that the whole process with all input data, assumptions, databases, methods used, and results is well documented to provide traceability and to be available for reviews and audits as well as for future iterations of cost estimates.

Step 8: Perform an independent review of the estimate

An independent review of cost estimate can crucially contribute to establishing confidence in the estimate. Generally, an internal review is conducted followed by an external review. The independent reviewer should verify and, if necessary, modify and correct an estimate to ensure that it is valid and credible.

3.2 Main cost elements – Work Breakdown Structure

The Work Breakdown Structure is an essential and very practical tool for performing detailed cost estimations and plays an important role also in estimating the cost of disposal programmes. Therefore, based on several disposal programmes and the respective WBSs an attempt was made to summarize the approaches and develop a more generic WBS for geological disposal that would be useful for countries and organisations that have just embarked upon or plan to launch the cost estimation process in the near future. Although the WBS presented herein is intended for the cost estimation of geological disposal programme, it can also be applied to for near-surface or borehole disposal programmes with certain adaptations.

The WBS is presented from the perspective of the WMO or other organisation that is responsible for the development and implementation of the disposal programme. Activities of other institutions and organisations like various regulatory bodies, ministries, local communities and other parties that are also involved in the process of development and implementation of the disposal programme are not considered here.

3.2.1 A WBS for a geological disposal programme

The scope of geological disposal programme is broken down into two levels only to keep the WBS relatively simple and understandable. At level 1 the WBS (Figure 1) contains the following elements:

Figure 1 – WBS of a geological disposal programme, level 1

The decomposition to level 1 is not following the geological disposal (GD) programme phases. Level 1 elements are focused on costing and are designed in a way that facilitates the cost estimation by grouping activities of the same or similar type regardless of GD programme phases in which they appear. For example: monitoring element includes activities that belong to pre-operational, operational and post-operational phase, similarly are structured other level 1 elements.

Clearly, this is just one way of preparing the WBS. Other approaches are also possible. Regardless of the approach chosen, it is important that it includes the entire work scope of the GD programme and that none of important activities are omitted. At this point it may be very useful to look at the activities in the WBS set out in the EURAD Roadmap Goals Breakdown Structure (GBS) for RWM Themes [2]. Although the structure is not the same for some elements the GBS for RWM Themes provides a more detailed breakdown of the various activities with recommended actions in different phases.

Each of the level 1 elements is further broken down into level 2 elements. Elements at level 2 are still complex and comprise many activities. For cost assessment further decomposition of elements is needed to level 3 and even deeper. However, breaking down to level 3 is not made here. Rather, the activities to be considered and potentially included in each of these level 3 elements are listed and accompanied by short commentaries. The decision as to which of these activities are relevant for a particular programme and purpose of cost estimation is left to the potential users.

The level 1 elements are not specific only to geological disposal. They are relevant for any disposal programme. Further decomposition of the level 1 elements is more specific to the type of disposal programme. If this WBS is applied for any other type of disposal programme, the differences between the programmes should be identified and the relevant adjustments made.

Short descriptions of the level 1 and level 2 elements for a geological disposal programme are provided below.

3.2.1.1 Disposal programme management

The **programme management** cost element is common to all disposal programmes. It includes all those activities that are needed for the efficient management of the project or programme from the organisational, financial, and administrative perspectives. The content of this element may vary from programme to programme due to programme specific aspects or legal and regulatory requirements therefore this element may be further subdivided in a number of ways. However, in general, the decomposition of this element described below offers a good starting point when developing the WBS. For more details see also the EURAD Roadmap: National Programme Management [2].

Level 2 elements:

Project management

This sub-element covers those activities and tasks that are essential for managing the project from the development stage to the final implementation of the disposal programme (the planning of activities, administrative and financial management, procurement of activities and services, IT, legal affairs, documentation etc.). Governance, which captures the costs associated with the ongoing maintenance of the various governance and oversight processes of the WMO, should also be included in the project management element. This is usually part of the running costs of the WMO responsible for the programme implementation.

Licencing

Licencing processes and requirements are country-dependant. The repository licensing process involves the granting of authorisations at various stages of the development and implementation of the disposal programme and may include different authorities. Licencing fees may also be required. If, in addition to the repository, the site characterisation or underground research facility or encapsulation plant are part of the disposal programme, separate licencing procedures will apply in most cases.

An important part of the programme management concerns also the planning and organisation of all necessary activities related to the licencing procedures that apply at the various stages of the disposal programme implementation. These may include cooperation with different technical support organisations (TSO) and research institutions.

Maintenance and periodic revisions of the programme

The development of a disposal programme is an iterative process. With each iteration it becomes more specific and detailed. Even when the programme is fully developed and approved it still needs regular periodic reviews and revisions to include necessary modifications and updates. These may be of a technical nature, there could be new regulatory requirements or financial considerations.

National inventory of spent fuel and radioactive wastes from all sources and activities, as well as estimates of future waste quantities accompanied by waste characteristics and other important details must also be maintained and updated as it is a necessary input for the development and implementation of the disposal programme.

Revisions are normally planned but occasionally unplanned revision may be required.

International cooperation

The development and implementation of a disposal programme is a complex process that requires a knowledgeable, skilled and experienced team. When initiating the disposal programme it is unreasonable to expect to have sufficient experience at the national level. In this respect international cooperation and the exchange of experience with countries and organisations with more advanced disposal programmes is particularly valuable. Cooperation between countries with less advanced programmes can also be very useful, since they often share the same challenges. This international cooperation can take different forms: from the exchange of experts, on-the-job training, participation at international training courses, in different workgroups or platforms, participation in the relevant EU, IAEA or other international research projects, peer review missions, etc.

Countries with small waste inventories might also be interested in multinational disposal option and thus engaged in some research and planning activities for a shared repository.

Integrated management system

For complex programmes or projects such as disposal programmes, it is advisable to introduce an Integrated Management System (IMS) which combines and integrates multiple management systems used by an organisation into one single system with processes that cover all the requirements of the relevant standards. For example, the IMS can simultaneously handle the requirements of quality management system standards (ISO 9001), environmental management system standards (ISO 14001), and the Safety Management System (ISO 45001). IMSs for nuclear facilities are normally also subject to rules and regulations concerning radiation and nuclear safety. Attention should also be given to the knowledge management and records keeping throughout the entire duration of the disposal programme as well as to the long-term knowledge preservation after the repository closure.

The development and introduction of the IMS is demanding in terms of both time and human resources. Moreover, obtaining certification from an accredited body may also incur a fee.

Human resources management

The development and implementation of disposal programme requires expertise in various fields. Human resources management must be planned for all programme phases. Careful planning and timely strategic decisions on how to assure proper expertise, competences, and skills at the required time are essential. Consideration should be given to the regular WMO staff: which competences already exist inhouse and which should be developed, which additional experts and administration personnel will be required inhouse and which activities will be outsourced. Additional training and education for the staff as well as for potential outside consultants and contractors or various implementing organizations should also be included. On a longer-term, scholarships for students in the relevant fields might also be considered.

3.2.1.2 Stakeholder engagement

Stakeholder engagement is an important component of the disposal programme which may have a significant impact on its successful implementation and also significant cost implications. It covers a range of activities aimed at establishing good relationship and effective two-way communication between the implementor and the relevant stakeholders. Stakeholder engagement is of particularly high importance during the siting phase.

Level 2 elements:

Public participation and communication

The public participation and communication element covers a broad range of activities involving various types of stakeholders. It is important to identify the relevant stakeholders and to prepare a public involvement and communication strategy with approaches and activities for their engagement during all the phases of the disposal programme. One should also be aware that some stakeholders may not be identifiable or may appear later in the process, e.g. social media influencers, bloggers etc. They can pop up at any time during the process and obtain significant influence on the process. It is important to remain vigilant, to follow the situation closely and to be ready to include new stakeholders.

Special emphasis should be given to the site selection phase. The activities during this phase may include publishing of various materials (leaflets, newsletters, studies, etc), organisation of workshops and consultation events, providing information to the media, establishing and running of information centre, etc. Attention should also be paid to the decision-making process for the site selection and confirmation which may be designed as a multi-step process and may require strong engagement with the various stakeholders at each step.

Local communities

Establishing a good communication and dialogue with the local communities that are affected by the site selection process is of paramount importance. The transparent presentation of the planned activities, open discussions on their concerns, suggestions and requirements forms the basis for addressing their views.

Many different tools and activities are available for the engagement of local communities, from organising workshops and consultation events, public debates, public hearings, site visits, etc.

Various incentives and benefits including financial incentives may also be offered to stimulate and enhance the involvement of local communities in the site selection process, which should be reflected in the cost assessment.

Selection of tools and mechanisms should be adjusted to the national context, the legal environment and the overall decision-making process.

Authorities, government, …

During the development and implementation of the disposal programme many interactions with safety and regulatory authorities, government and other bodies are needed. In some countries most of these interactions are part of the regular procedural framework that covers the development, approval, licencing, and implementation of the disposal programme and incurs no additional costs for the implementer, while in others, fees or other compensations have to be paid to cover these costs. A plan of such interactions, accompanied by details of various requirements, actors, timing and essential input data should be prepared based on national legislation and procedures.

Waste generators

Waste generators should be involved in the development of the disposal programme. They provide important input for the programme on existing and expected waste quantities, the status and future treatment of the waste, the spent fuel strategy etc. Waste generators have clear interest in the disposal programme since it has impact on their own activities and plans. Good communication and regular exchange of information with waste generators is of mutual interest and benefit. Since waste generators are required to provide the funding for implementing the disposal programme, it should be considered good practice to involve them in the review of the cost assessment.

Other stakeholders

The implementation of the disposal programme may involve other relevant stakeholders. Because of potential cross-border effects and environmental impact of the disposal facility, consultations and information sharing with the neighbouring countries may be needed. Regular reporting under the IAEA Joint Convention on the Safety of Spent Nuclear Fuel and on the Safety of Radioactive Waste Management [12] and, concerning EU Member States, regular reporting to the European Commission according to the Council Directive 2011/70/Euratom [1] should also be considered.

3.2.1.3 Siting

Siting is a process of searching and selecting a suitable site for the disposal facility and the other facilities that are part of the disposal programme (e.g. the encapsulation plant, the storage facility). If the disposal programme assumes more than one site for the disposal programme facilities, e.g. the encapsulation plant and the repository may be located at different sites), more than one siting process may be required.

The siting process consists of several stages. Each stage includes a number of activities as indicated below. For additional information see also the EURAD Roadmap: Siting and Licensing Theme [2].

Level 2 elements:

Concept and planning

During the conceptual and planning stage, an overall plan for the site selection process is developed, covering all the stages from the site evaluation through site selection to site characterisation. All important factors which may influence the selection process should be identified. Safety, design and legal bases, and a method for the public participation should also be defined.

Site evaluation and site selection

At this stage large areas are examined to get general information on the potential suitability of the geological formations for disposal. The survey is based on currently available field research results and data provided by literature searches, monitoring, remote sensing, geographic information system (GIS) application etc. By national geological screening and desktop studies focused on distribution and properties of potential host rock for geological disposal, rock structure, groundwater, natural processes, and natural resources unsuitable areas are eliminated and areas with potentially suitable sites identified.

In the next step, few candidate sites (usually no more than 5) are selected. This can be done either by ranking of potentially suitable sites by applying an agreed set of criteria or local communities may volunteer to host the disposal facility.

Site characterisation and confirmation

During the site characterization stage, the investigations are carried out at the candidate sites to collect site specific data to confirm the suitability of the site(s).

The site characterization should also identify the site conditions to be monitored during the pre-construction, construction, operation, closure and post-closure phases.

Based on the results of the site characterization all the candidate sites are evaluated, their ability to meet all safety requirements assessed and the preferred site(s) identified.

Once the decision on the preferred site for the repository has been made, some arrangements must be made in order to ensure the continuation of the siting process. The land should either be purchased or easements put in place so as to allow further detailed site investigations.

If a site characterisation or an underground research facility is planned as part of the disposal facility, its construction should commence during this stage in order to carry out relevant site-specific research activities and investigations.

During this stage the detailed site-specific data required for the design, safety analysis, environmental impact assessment and licencing are obtained and based on these results the confirmation of the site suitability can be concluded.

Spatial plan

If the disposal facility is not included in the national spatial (land use) plan an action may be needed to incorporate the construction of such facility into the plan. The procedure for the drafting and adopting the national spatial plan depends on country-specific rules and regulations and may include the requirements for e.g. a comprehensive environmental impact assessment, study of alternative solutions, consultation with spatial planning institutions and neighbouring countries, public hearings, etc.

3.2.1.4 Site investigations and RD&D

Site investigations and RD&D activities can be expected to continue throughout the entire lifetime of the disposal programme. The scope and content of the RD&D programme vary from country to country and the approach adopted to the disposal programme. In the early stage of the disposal programme, RD&D activities may include studies on alternative options for the disposal of spent fuel and radioactive waste. During the siting process staged site investigations and other RD&D activities are carried out in support for the development of the safety case and the EIA. RD&D activities are also likely to continue during the construction activities and sometimes also during the operation of the repository. More details on RD&D activities can be found in the EURAD Roadmap: Geoscience Theme and Engineered Barrier System Theme [2].

Level 2 elements:

RD&D prior to site selection

RD&D at this stage may include studies of alternative solutions for the management of spent fuel and radioactive waste (e.g. fuel reprocessing, the construction of a regional or multinational repository, the selection of the type of canisters for the disposal of spent fuel and radioactive waste, options for encapsulation of the spent fuel, the exploration of new materials and waste forms etc.).

Site investigations during the site evaluation and selection stage

Field investigations are usually not included in this stage. Unsuitable areas are eliminated and areas with potentially suitable sites identified by using national geological screening and desktop studies that focus on the distribution and properties of the potential host rock for geological disposal, the rock structure, the groundwater, natural processes and natural resources.

Site investigations during the site characterisation and confirmation stage

The site investigations at this stage include the on-site surface investigations and measurements, the seismic surveys, the monitoring of the relevant parameters, the on-site drilling of boreholes and in-situ testing in boreholes.

Once the preferred site has been selected, the site investigations and measurements on the surface and beneath the surface continue at the site to obtain more accurate data on the geological and hydrogeological parameters and the physical and mechanical properties of the rock to confirm the site suitability.

RD&D activities for the support of the safety case and technological solutions

During the implementation of the disposal programme other RD&D activities may be required in addition to the above mentioned, e.g. for the further development and updating of the safety case, for verification, improvement or updating of the various technological and logistical solutions (e.g. the EBS, the demonstration of the waste emplacement).

The relevant experiments can be conducted in the underground research facility. Depending on the national policy and disposal programme such a facility may be part of the future repository. Alternatively access to an underground research facility in another country may be sufficient and more suitable for conducting of the necessary RD&D. Whatever the national decision, it is important to be aware of the broader implications (concerning e.g. safety, licencing, public and political acceptance of the repository, construction, operation) as well as the financial impacts which must be carefully considered in the cost assessment.

3.2.1.5 Monitoring

Monitoring programme development and implementation is an important part of the disposal programme. It consists of activities and measurements that are needed to evaluate the impact of the repository and its operation on the environment and vice versa. It commences during the site characterisation phase before any activities are performed on the site and continues long after the closure of the repository. The monitoring programme provides baseline information for the assessment of the zero state of the candidate site(s), for the evaluation of the design and construction feasibility of the disposal facility as well as for the operational and long-term safety of the repository.

Level 2 elements:

Pre-operational monitoring

Monitoring in the pre-operational phase is focused on parameters that are primarily related to the undisturbed geological, hydrological and hydrogeological, environmental (biota) and geochemical aspects of the site. The investigations and monitoring for the underground facilities are initially performed from the surface and later from the underground, using the site characterisation or underground research facility, access tunnels and shafts. Pre-operational monitoring is important since it defines the radiological and non-radiological baseline conditions of the site (the zero-state of the site).

During the construction phase the monitoring is focused on the stability of the construction and its influence on the environment. It consists primarily of geotechnical (deformations, near-field disturbances etc.), hydrogeological and geochemical monitoring.

Operational monitoring and surveillance

During the operational phase after the emplacement of radioactive material in the repository, the monitoring programme is extended to include also the monitoring of radioactivity. Monitoring activities during the operation and closure phases are carried out by the repository operator.

Monitoring programme also includes also surveillance that refers to the physical inspection of the facility to verify its integrity and capability to protect and preserve the passive barriers. The Surveillance testing is conducted periodically to verify that structures, systems and components continue to function or are capable of performing their functions when called upon to do so [13].

Post-operational monitoring

Post-operational monitoring is conducted after the closure of the repository. The scope and duration of this monitoring period are usually defined by national regulations and regulatory body and may include various measurements - from radioactivity on the ground surface and in deep boreholes to groundwater table levels, the flow, chemistry, temperature, etc., in boreholes or inspection wells to geochemical and hydrogeological measurements.

3.2.1.6 Safety Assessment, Safety Case and Environmental Impact Assessment

The **safety assessment and safety case** along with the safety analysis report (SAR) are required at different stages of the disposal programme to assess the behaviour of the future disposal system and to affirm that the repository will be safe after the repository closure. The safety case and the SAR are essential components of the documentation necessary for applying for the required permits and licences. More details on the Safety Case and the activities involved can be found in the EURAD Roadmap: Safety Case Theme [2].

Level 2 elements:

Generic Safety Case and Safety Assessment

The generic safety assessment and safety case must be developed before any site-specific data are available. They are based on generic information on potential geological formations and the conceptual design of the disposal system. The assessment aims to demonstrate the compliance of the concept with existing safety criteria and/or to provide some guidance for the site selection and on the further development of the repository / EBS concept based on a range of potential geological situations.

Preliminary Safety Case and Safety Assessment

During the site characterization stage, the first non-generic safety assessment is performed based on site-specific data. It is carried out to assess whether the site is potentially suitable for disposal.

Based on the results of the safety assessment and other relevant evidence and arguments, the preliminary safety case should be developed to affirm that the facility will provide for the required safe isolation and containment of the radioactive waste over the long-term.

Safety Case and SAR for construction

Before commencing the construction, the safety case must to be updated with the new data and findings from the previous stages. The emphasis is on the safety analysis report prepared with the aim to assess safety of the disposal facility. The safety analysis report is included in the application for obtaining the construction license.

Safety Case and SAR for operation

The safety analysis report must be updated in accordance with changes that occur during the subsequent stages of the facility, i.e. during the construction, commissioning, operation, decommissioning and closure phases. Updated SARs form a part of the licencing documentation required at various stages of repository development (commissioning, operation, end of operation, decommissioning and closure).

Environmental Impact Assessment (EIA) report

Although environmental legislation and regulations vary from country to country, geological repository is generally considered to be a facility with potential environmental impact and for which an environmental impact assessment is required. Based on the baseline data the EIA report provides the detailed analyses of the proposed project and its potential environmental, social and economic impacts.

3.2.1.7 Design

The **design** of the repository and the entire disposal system is developed in several steps. The steps and requirements relevant for each step may vary from country to country but it is common to all to start with the conceptual design and progress to the detailed design as a precondition for obtaining the construction license (more details are available in the EURAD Roadmap: Disposal Facility Design and Optimization Theme [2]; see also [3]). Depending on the licencing and approval rules and procedures in place, additional design documentation may be required to supplement the conceptual and detailed design following the granting of the construction license, as is presented below.

Level 2 elements:

Conceptual design

The conceptual design is usually developed for a generic site before any site-specific data becomes available. The conceptual level considers the underground disposal facility, the surface buildings (nuclear and non-nuclear), access facilities and on-site and off-site infrastructure. Underground research facility or encapsulation plant should also be included if they form a part of the disposal programme.

Based on the conceptual design the authorities can formulate and document the design conditions to be fulfilled when preparing the documentation for application for the construction licence.

Detailed design for the construction licence

The detailed design of the repository is required in order to obtain the construction licence. If separate construction licences are required for each construction stage, i.e. for the characterisation or underground research facility, for the repository (above-ground and underground) and for the encapsulation plant, separate design documentation and applications for construction licence need to be prepared and submitted.

Detailed design for construction

Depending on the national rules and requirements, additional design documentation is usually required with specific instructions on the implementation of the construction works.

Detailed design for operation

The design documentation to obtain an operating licence includes among others as-built drawings, certificates of the materials and the equipment to be used, declarations of conformity with requirements, changes from the certified licence and detailed design, operational handbooks, etc.

Even after the operation phase has commenced, the design process is likely to continue due to the ongoing need for optimisations and modifications to the design.

Design for closure

The final closure design is required before approval can be granted for the closure of the repository. According to the national regulations and requirements, this may also include a plan for the decommissioning of the surface buildings of the repository.

3.2.1.8 Other actions / documents

Prior to the construction and operation of the repository, **other actions / documentation** may be required in accordance with national regulations and the requirements of the relevant authorities. This includes also formal opinions and consent of various authorities at different steps of the approval process.

Level 2 elements:

Investment programme and documentation

An investment programme and documentation are generally required for all complex investment projects, including radioactive waste disposal programme or project. The investment programme may include various studies and analyses of the technical and financial aspects of the proposed project, from pre-feasibility and feasibility study to the reports on the progress and effects of the investment project, that form the basis for the investment decision-making process. **Protection and Rescue plan (Emergency preparedness)**

A protection and rescue plan (emergency plan) are required for all facilities that store or dispose of radioactive material. The plan must be included in the applications for construction, commissioning and operation licences.

Physical protection (security) plan

Geological repository intended for the disposal of radioactive waste also requires physical protection. The physical protection plan must be prepared, and security measures ensured from the beginning of the repository construction to its closure. In the case of the disposal of spent fuel, the safeguard measures should also be considered [14].

3.2.1.9 Construction

Construction works can start after the construction license has been obtained from the relevant authority. For the EU Member States, the procedure includes also consultation with and obtaining of an opinion from the European Commission, as required by article 37 of the Euratom Treaty[2].

Level 2 elements:

Construction management

Construction management usually includes assurances on health and safety at work on construction sites, physical protection measures, the supervision of civil construction work, technical inspections and similar. Such aspects should already be included in contracts concluded with the suppliers, at least to a partial extent.

On-site and offsite infrastructure

Offsite infrastructure includes access roads, electrical power and water supplies, telecommunication connections. On-site transportation routes and connections should also be considered.

Above-ground facilities and structures

The surface facilities that are part of the disposal facility may include various buildings: production, service and reception buildings, offices, a waste acceptance and control building, research laboratories, workshops, utility and water facilities, visitor centre, etc.

Other surface facilities and installations include an explosives store, a meteorological station, monitoring facilities, roadways, parking areas, rock storage, etc.

Construction of an underground research facility

If an URF (or site characterisation facility) is considered in the disposal programme as an initial step towards the repository, then it will be constructed prior to the construction of the repository in order to obtain additional data relevant to both the repository construction and the engineering solutions employed. The URF may be designed in a way to serve as an access route to the repository during the construction and later to become an integral part of the repository. In such case practically the same regulatory requirements will apply to the URF as for the repository, which must be considered when designing and planning the URF and also when preparing the cost assessment.

Underground facilities and structures

Underground construction works include the excavation of underground ramp, shafts, service area, disposal tunnels, galleries, deposition boreholes etc. as well as the various technological systems (the ventilation system, radiation monitoring system, water management system, instrumentation and control system, physical protection systems and other mechanical and electrical systems).

Other disposal facilities or services

Depending on the disposal programme and the purpose of the repository, a number of other facilities may be needed to complete the disposal system. If the repository is intended for the disposal of spent fuel, its encapsulation may be planned to be performed on a national level in a separate encapsulation plant or encapsulation services could be contracted out to a foreign provider.

In the case of national plans, the encapsulation plant can be built at the repository site or at another site. If constructed away from the repository adequate transportation links should be considered and constructed.

Canisters for encapsulation can either be purchased from a producer or, if that is not possible, fabricated by a dedicated facility following agreement on the technology transfer.

If spent fuel is reprocessed and the repository is intended for the disposal of the resulting HLW a storage facility for HLW may be needed (at the site or away from the repository site) before the waste is disposed of.

The disposal programme may also include treatment and conditioning facilities for ILW and LLW.

Installation of the equipment

The equipment for the underground and surface facilities will have to be purchased and installed.

3.2.1.10 Operation and maintenance

Operation and maintenance start after the completion of the construction works at the disposal site and after all permits required by legislation have been obtained (including the required positive opinion from the European Commission according to the article 37 of the Euratom Treaty for EU Member States). Operation begins with the commissioning period intended to evaluate the adequacy of the facility structures, systems, components and services, as well as functioning and operating procedures in place for the safe handling and emplacement and, if necessary, retrieval of the radioactive waste. After successful commissioning an operating licence is issued, and the regular operation of the repository begins.

The operational maintenance of all the facilities and equipment should be performed from the beginning of repository operation.

Level 2 elements:

Commissioning

During the commissioning period, the disposal facility, including all the equipment and systems, must be verified so as to ensure that it meets all the relevant safety, environmental, radiation protection and other requirements and that no prescribed limit values are being exceeded. Commissioning is also required for the encapsulation plant and other facilities at the disposal site, if they form a part of the disposal programme.

From the nuclear safety perspective, the commissioning is the main milestone in the disposal programme since at this time radioactive substances are emplaced in the facility for the first time.

After the commissioning is successfully completed an operating license is issued and the regulatory body for nuclear safety can grant the permission for the commencement of regular operation.

Operation & maintenance

The commencement of regular operation is another important milestone in the geological disposal programme. It covers a number of activities since, during the regular operation of and emplacement of radioactive waste in the repository, construction works, the excavation of new tunnels and the backfilling and sealing of already filled disposal tunnels, chambers or galleries continue. The physical protection requirements at this stage usually become stricter and require additional human and financial resources.

Regular operation may span decade, throughout which strict adherence to the maintenance programme must be ensured and certain modifications aimed at operational optimisation introduced where necessary.

Transportation of the spent fuel

The transportation of SF falls into the category of exceptional transports for which special rules for transport apply. A detailed transport plan should be prepared taking into consideration all the requirements and rules that apply for this transport category. If the transport of SF is considered as part of the disposal programme, it must be included in the cost assessment.

3.2.1.11 Closure

The **closure** cost element covers the activities following the operational period of the disposal facility, i.e. backfilling and sealing, maintenance, dismantling and decommissioning activities and, if necessary, site remediation activities. Once the emplacement of waste has been completed, the facility must be safely closed and prepared for long-term institutional control. A detailed plan for all these activities, the SAR and the documentation required for the licencing of this step are included in the previous elements.

Level 2 elements:

Closure of the disposal chambers and galleries

The closure of GD facility starts with the backfilling and closure of the disposal chambers, tunnels, galleries, vaults, underground auxiliary facilities, underground research facility (if it is part of the disposal facility) or any other underground room. In some disposal programmes (particularly in those that plan long operate periods) the partial backfilling and sealing of the emplacement areas may already be completed as part of the regular operation prior the formal closure process begins. In others no prior backfilling is considered.

After the backfilling of the disposal chambers and galleries, sealing plugs may be required to achieve and maintain the required isolation of the disposed waste. In plastic rock, the requirements for seals are milder than in hard rock.

Backfilling and sealing

After the disposal chambers and other underground rooms and galleries have been backfilled and sealed the process continues with the backfilling and sealing of the access tunnels, ramps, shafts and any other passages to the disposal facility.

Various backfill and sealing materials are in use. Depending on the required performance excavated rock, cement, sand, clay, or bitumen-based materials can be used for this purpose.

Decontamination and dismantling

Prior to starting the backfilling and closure of the underground facilities, the dismantling and removal of equipment and support systems should be considered. First, potential contamination of this equipment and systems should be checked and, if necessary, decontamination made.

All nuclear surface buildings and technological facilities, including the installed equipment and systems, must also be decontaminated and dismantled.

The non-nuclear surface facilities can either be dismantled and removed or, depending on the national disposal programme, can be intended for some other purposes.

Closure

The closure is completed once all the radioactive waste resulting from the decommissioning and closure activities has been characterised, packed and (unless an alternative solution is foreseen by the decommissioning and closure plan) removed from the disposal site. Usually, some site remediation activities are also included to allow the site to be returned to normal use.

3.2.1.12 Institutional control

Institutional control is primarily intended to increase the level of confidence in the isolation and containment functions of the disposal system and to prevent or minimise the probability of inadvertent human intrusion into the repository. The control of the disposal site is first active and after a certain period followed by a passive control. The scope and duration of the institutional control is defined in the national regulations and requirements set out by the regulatory body. However, in many countries, such requirements have not yet been fully defined and certain assumptions are needed for further consideration of institutional control and its impact.

The maintaining and preservation of records of the waste, the site and the disposal facility after the closure of the repository should also be considered.

Level 2 elements:

Active institutional control

Active institutional control comprises activities such as the maintaining of the status of restricted-use areas, the monitoring of radioactivity, and keeping of the records and archives on the waste, the disposal facility and the site. The active institutional control period may extend over several decades, depending on the national regulations and licence requirements in place.

Passive institutional control

Passive institutional control primarily consists of records keeping and preserving knowledge on the waste and the repository, and of control of the repository land use.

3.3 Cost assessment

The cost of each WBS item can be assessed once the content of the disposal programme / project has been defined, detailed hierarchical WBS developed and each activity / item specified and quantified in terms of the amount of work required, the competences and skills necessary to do the work, the investments needed, and the expenses anticipated for each activity.

The cost estimate starts with the lowest level of the WBS elements and is calculated separately for each individual WBS item. First the costs of the WBS elements are estimated by summing the costs of the relevant items. By further summation of the costs of the WBS elements the cost of the whole programme at the price level of the base year or reference year is calculated. The method selected for estimating the cost of each item depends on the level of detail available for each item. In the early stages of the disposal programme, some aspects of the programme may not be developed to the same level as others. It is, therefore, unrealistic to expect that the costs of all the WBS elements, or selected items within the individual elements can be estimated using the engineering build-up method. The lack of detail on particular activity necessitates to use another cost estimation method for such item(s). This may be either the analogy method or the expert judgement or a combination of both.

The costs of many of the WBS items that are related to different activities can be assessed on the basis of the estimated duration of the particular activity, the amount of personnel required and their qualifications and competences and man-month or man-year costs (labour costs in the energy or nuclear sector are generally used in this connection) and the relevant material and equipment costs and expenses.

The majority of the disposal programme management costs and many activities related to other cost elements can be estimated in this way. The input cost data for estimation purposes can be derived from other similar projects. Attention must, however, be devoted to ensuring that the data have been adequately understood and adjusted / normalized to the particular application (see step 5 in 3.1).

It is also important to be aware of the interconnections between the various activities: an increase / saving in one activity may affect the prices of other activities. Some activities may also include other specific costs. For example, in licencing such additional cost may be the licencing fee, which is usually prescribed by the law, or charges for the services provided by various technical support organisations (TSO) and research institutions during the licencing process. Similarly, the international cooperation may require additional resources for participation in different training activities for personnel, joint research projects or other forms of cooperation. The cost estimations of such activities should be based on legal requirements and experience obtained from other similar projects.

The cost estimation of stakeholder engagement may also include various incentives and benefits offered to local communities including financial incentives. This issue is country specific. In some countries these incentives are defined by the law, in others they are agreed directly between the WMO and the local community or communities involved.

The cost of the siting element may, in addition to the cost of the estimated work effort, required expertise or qualification and the related labour costs, include also the cost of the land for the construction of the disposal facility. The cost of land can be estimated based on the size of the land and expected price per square metre.

The cost assessment of the site investigations, RD&D activities and monitoring depends on the programme and the scope of activities required: the explorations, investigations, measurements and tests planned and their scope (quantities, duration, etc.). The input cost data can be obtained from other similar projects, from research organisations and institutions involved in this field, or from potential contractors.

The cost of the development of the safety assessment, safety case and EIA can be estimated using historical data and experience gained from other similar projects. Potential contractors may also be able to provide useful input data. The costs of such activities in the early stages of the disposal programme are sometimes estimated as a certain percentage of the disposal facility construction costs.

The design costs are dominated by the labour costs of the personnel of the WMO or other organisation responsible for the implementation of the disposal project and external design services provided by engineering companies. Such companies are able to provide certain input cost data for the estimation of the design costs of the disposal facility. In the very early stage of the disposal programme, when the disposal concept has not yet been well defined, the design costs are sometimes roughly estimated as a percentage of the construction costs of the disposal facility.

The estimation of construction costs is more challenging since many details may not yet have been defined, the boundary conditions are subject to changes and experience in this field is limited.

The construction costs of geological disposal facilities are usually divided into the construction costs of the surface facilities, the construction costs of the underground facilities and the cost of the off-site infrastructure. The cost estimation of the construction of the surface buildings can be based on local prices for industrial buildings, while the cost estimation for the underground facilities may apply representative local unit prices for the excavation and construction of underground facilities for a specific rock type.

The cost estimation of equipment is usually more challenging, particularly if the technologies are new (for example the equipment for the encapsulation plant if included in the disposal programme) and the design proposal for the repository is still in the early stage. Cost estimations from other more developed disposal programmes can be used in such cases until more detailed plans and data become available.

The cost of the on-site and off-site infrastructure is estimated on the basis of local costs for such infrastructure.

The cost of the operation of the disposal facility may, in addition to labour and maintenance costs, include also the costs of various services, supplies, insurance and so on.

Labour costs are estimated on the basis of an organisational flowchart and the expected monthly gross earnings for the planned job positions. Monthly gross labour costs usually include social security, health insurance and pension scheme contributions and overhead costs.

The cost of maintenance can be estimated as a certain percentage of the construction work and equipment costs, the cost of services as a percentage of the investment cost and labour cost and the cost of insurance as a percentage of the investment costs.

The cost estimation of the canisters for the spent fuel is particularly challenging. Either the production of canisters is assumed as part of the disposal programme or their purchase on the market is planned the cost estimation is difficult and uncertainties substantial. Often the cost estimate is based on those of advanced disposal programmes and adjusted to specific project conditions and requirements.

The cost estimate for the closure of the disposal facility is based on the costs of the sealing plugs and backfilling material per m^3 and the quantity of plugs and material needed. The labour cost for the closure activities can be considered in this element or can be included in the cost of repository operation.

In the very early stage of the disposal programme decommissioning costs can be estimated as the percentage of the investment costs. As the decommissioning plan becomes more detailed, the cost estimate is based on the amount of work and the labour costs (including contractors) and the costs of the special equipment required and cost of the waste packages.

The cost estimate of the institutional control depends on its scope and duration, and is usually defined by national regulations and requirements set by the regulatory body.

The cost estimate for each element or item should also include the contingency. Contingencies can be estimated using either the deterministic method or the probabilistic method as presented in 3.4.4.

Practical examples

Further details and practical approaches to cost assessment are provided in Appendix A which presents several examples of cost assessment from Slovenia/Croatia, Hungary and the Czech Republic. They are taken from different disposal programmes in different phases of development or implementation and concern the geological disposal of SF, an underground repository for L/ILW and a near-surface repository for LILW.

<u>Example 1</u> presents a cost estimate for the construction of underground facilities for the geological disposal of spent fuel and a labour cost estimation for the period of operation of these underground facilities. The information originates from a 2019 report that describes the concept (the reference scenario and several alternatives) for the disposal of spent fuel from the Krško NPP [15], which is co-

owned by Slovenian and Croatian state-owned companies. The Krško NPP has been in operation since 1983. The original operating lifetime of 40 years has been extended to 60 years (up to 2043).

The disposal programme is in a relatively early stage. The reference scenario for geological disposal assumes the direct disposal of spent fuel and is based on Swedish and Finnish solutions for fuel disposal in copper canisters emplaced in vertical boreholes in disposal tunnels (the KBS-3V concept).

The cost estimation for the construction of the underground facilities (tunnels, ramp and shafts) is based on estimated excavation volumes and representative Slovenian unit prices for 2018 for the excavation and construction of underground facilities. The estimation of the construction cost for the disposal tunnel is presented in more detail and accompanied by explanatory comments.

The estimation of labour costs during the operation of the underground facilities is based on the number of employees and average monthly gross earnings, multiplied by factors that correspond to similar job positions elsewhere in the energy sector.

Example 2 concerns the Bátaapáti National Radioactive Waste Repository (NRWR) for the disposal of L/ILW in Hungary. The project has been initiated in 1993. In 1997 the site at granitic rock in the vicinity of the village of Bátaapáti was selected, and its suitability for hosting a repository for L/ILW was confirmed in 2003. The underground research activities started in February 2005 and, in 2012, the first disposal of radioactive waste was made. Since then, the further construction of underground structures has continued in parallel with the final disposal of waste.

Since this repository is already in the operational phase and significant experience has been gained since the start of the project, the example presents the following:

- the actual costs of repository implementation in the early phases,
- how the boundary conditions of the cost assessment were defined,
- the strategic inter-relations of this project with other elements of the national radioactive waste management programme,
- the approach to the optimisation of the disposal system, and
- how the cost of one of the engineered barrier system elements (a concrete vault) was estimated once the detailed design was available.

The optimisation of the disposal system after the repository was already in operation, and the cost implications of this optimisation, present particularly interesting aspects of this example.

The cost estimate of the engineered barrier system element once all the design details were available is also very instructive. First, the whole facility was broken down into systems, structures and components (SSCs) at 4 levels, which were then classified into safety classes, and their costs assessed based on the detailed design.

Example 3 is taken from the Czech Reference Project for a Deep Geological Repository for SF and presents estimates of the investment and operation costs in the early stage of repository development. It also presents an analysis of working in more than one shift and its impact on the operational costs.

Example 4 presents the cost assessment of planned field investigations at one of the candidate sites for a disposal facility for LLW in Slovenia. It covers geological, hydro-geological, geochemical and geophysical investigations and explorations, geomechanical testing and drilling. A detailed list of measurements, tests and analysis with the respective cost estimates is provided for the geochemical exploration.

3.4 Cost uncertainty and risk management

Uncertainties related to, or an insufficient knowledge of, the parameters, phenomena or processes, associated with the development and implementation of any programme or project affect its cost estimate. Disposal programmes are faced with numerous uncertainties due to their complex and often not fully defined scope, the number of assumptions that have to be used in place of gaps in the information or data available, the societally sensitive nature of the programme with the large number of stakeholders involved, and long implementation periods. The probability that the estimated cost of the disposal programme will differ from the actual cost is, therefore, significant.

The uncertainties involved are of various origins. They can be related to technology, socio-political aspects, programme, personnel, organisational issues, budget etc. According to [16] we can broadly group them into three categories:

- uncertainties due to the routine variability of the environmental and/or working conditions (e.g. delays and work interruptions due to the weather, equipment breakdown, material delivery problems, pandemics, etc);
- uncertainties due to "insufficient knowledge", e.g. due to a lack of relevant experience or insufficient, inconsistent or biased data;
- uncertainties due to external events or "risks" that are unpredictable, but whose likelihood and impacts can be examined through the risk analysis.

Risk

The international standard definition of risk for common understanding in different applications is "effect of uncertainty on objectives" [17]. There are many other more specific definitions of risk adjusted to different disciplines.

In risk analysis, risk is traditionally defined as a function of probability and impact or consequence, where the probability is the likelihood of an event occurring, expressed as a qualitative and/or quantitative metric. Consequence is the outcome of an event. The outcome of an event may include cost and/or schedule impacts [18].

In more scientific language the risk is defined [13] as the mathematical mean (expectation value) of an appropriate measure of a specified (usually unwelcome – threat or welcome (positive) - opportunity) consequence:

$$R_i = \sum_i p_i.C_i$$

where p_i is the probability of occurrence of scenario or event sequence i and C_i is a measure of the consequence of that scenario or event sequence.

There are various definitions of the risks and uncertainties that vary across the fields of study or applications. They are often used interchangeably. In this guide the term "uncertainty" is used for those uncertainties that can be reasonably expected to occur within the defined scope of the programme although they cannot be predicted. Such uncertainties are known as **in-scope uncertainties**. The term "risk" is used for uncertainties due to external or risk event(s). They are also known as **out-of-scope uncertainties** as they act to alter the scope of the disposal programme. They are more complex to treat and if they occur, could result in significant cost increase.

Accounting for the programme's uncertainties and risks is necessary if we want to adequately capture the uncertainty associated with the programme's cost estimate. Due to this reason uncertainty and risk management forms an important part of the disposal programme management. It refers to the practice of identifying uncertainties and potential risks in advance, analysing them and evaluating their possible impact on the disposal programme and cost consequences and taking steps to minimize, monitor, and control the probability or impact of the uncertainty or risk or to maximize the realisation of identified opportunities for a reduction of costs.

> *Uncertainty*
>
> *Wikipedia (https://en.wikipedia.org/wiki/Uncertainty) defines uncertainty as a lack of certainty, a state of limited knowledge where it is impossible to exactly describe the existing state, a future outcome, or more than one possible outcome. Uncertainty is quantified by a probability distribution which depends upon our state of information about the likelihood of what the single, true value of the uncertain quantity is.*

Guidance on how to address the uncertainties and risks in cost estimates is available in a number of documents [7], [16], [18], [19]. In ref. [9] more specific advice is provided on how to address the uncertainties and risks in disposal programme. The following steps are recommended:

- the identification of the uncertainties and the risks in the programme,
- the performance of risk and uncertainty analyses and the evaluation of the potential consequences for the programme,
- The development of a risk and uncertainty management framework aimed at mitigating their potential impacts and
- ensuring provisions are set aside to cover the cost impacts of the uncertainties and risks.

Short summary of these steps is provided below.

3.4.1 Identification of uncertainties and risks

Uncertainties and programme risks must be identified and registered. Based on further consideration of these uncertainties and risks, some of them will be incorporated into the cost estimation, while others will be considered as not relevant and excluded. Records of this process should be documented in the register, accompanied by the reasons and justification for considering or not considering them in the cost estimate.

Uncertainties and risks may be identified in any element of the work content, and at any time during the programme or project life cycle. Since the WBS serves as a common framework for defining and organising the scope of work, the schedule, the technical data and the cost estimation, it provides a convenient base of the risk management process. The identified risks may be associated with one or more WBS elements. The WBS provides a common reference point for documenting, managing, tracking, and communicating the programme's risks [11].

A number of techniques are available for the identification of uncertainties and risks like brainstorming, workshops, interviews, diagram techniques and others. In uncertainties and risk identification process it is important to involve as many subject matter experts and knowledgeable participants as possible. It is good if the uncertainties and risks derived from interviews or workshops can be formulated with a consensus of involved experts. On the other hand, one should also be aware of the potential biases that may appear in such process and influence the information provided. Typical biases include bias toward risks and uncertainties already identified, preferring information that supports existing points of view while avoiding contradicting information, allocating a disproportionate weight to the initial information provided and an unwillingness to change the direction. Well known is also optimism bias. This is the tendency for experts to be over optimistic with respect to key project/programme parameters, which result in optimistic rather than realistic cost estimates. Therefore, it is very important that the process of identifying and assessing risks and uncertainties is consistently and comprehensively documented. More information on the identification of uncertainties and risks can be found in [7], [18] and [19].

3.4.1.1 Uncertainty and risk register

Each identified uncertainty and risk should be deposited in a register that provides for common, uniform format for the presentation of the identified uncertainties and risks. For each uncertainty or risk a number of attributes should be recorded in the register. Some of most important are listed below:

- Each risk or uncertainty should be recorded in the register under a unique identifier so as to avoid confusion and to ensure the traceability of all the information related to this uncertainty or risk.
- It is also important to identify the type of uncertainty or risk and register whether it is an in-scope or out-of-scope uncertainty or risk and whether it represents a threat or an opportunity.
- It is useful if each uncertainty or risk is categorised according to the WBS element to which it refers together with the uncertainty or risk owner identification.
- The register should also include all the assumptions related to the individual uncertainty or risk that have been used.
- For each identified uncertainty and risk the register should also include the potential cause(s), trigger events and effect(s), probability of risk occurrence etc.
- Very important information that needs to be included in the register is about the handling strategy or how each uncertainty or risk is treated.
- The register should also record the current status of each uncertainty or risk, i.e. Whether it is open and requires further actions or closed and requires no further action.

The uncertainty and risk register should be regularly reviewed and updated. The risk and uncertainty identification process should also be repeated whenever the programme changes - either in terms of budget, schedule, or scope.

3.4.1.2 Potential uncertainties and risks in the disposal programme

Some of potential uncertainties and risks related to the individual WBS elements of the disposal programme are described below.

Programme management

In programme management, risks and uncertainties can arise in connection with the operational capacity of the WMO or other organisation responsible for the development and implementation of the GD programme. Insufficient financial resources or a lack of human resources and competences may result in delays in the implementation of the disposal programme and, consequently, increase in the cost.

Uncertainties and risks may also arise in the decision-making process related to the disposal programme which requires approval from national and local government authorities. Since the disposal of radioactive waste is a politically sensitive issue there is a risk that political decisions will be delayed or even postponed to a future date. The same risks apply to authorisation processes and procedures. Since the disposal of radioactive waste is a relatively new issue in many countries, requirements concerning licencing, the granting of permits and the relevant approval procedures may not yet be fully established. Changes to these procedures and/or introduction of new requirements may have impacts on costs. Moreover, the approval process or the granting of permits or licences may take longer than expected and be subject to the requests for additional documentation and evidence for the support of the submitted application. All these delays to the programme involve cost implications.

Human resource management may also present a source of uncertainties and risks. The development and implementation of disposal programme requires specific competences and skills that are unlikely to be covered solely by the WMO but which also require assistance from research organisations and other potential contractors. Some of the required competences and skills may not be available or be available in insufficient numbers. This may be particularly challenging for SIMS, where the responsible organisations are smaller and the resource base for recruiting staff is limited. By timely planning and support of human resources development the shortage may be avoided, however delays or other difficulties in implementing the disposal programme may reduce the options concerning the timely engagement of new experts or reduce their interest to engage in this field.

Stakeholder engagement

Cost uncertainties related to stakeholder engagement concern the estimation of the effort required to establish and maintain a high level of communication and dialogue with the public and, particularly, with the involved local communities and the number of stakeholders that need to be engaged.

More serious cost uncertainties and implications are related to the question of whether a sufficient level of stakeholder support has or will be achieved so as to be able to successfully complete the siting process and to implement the disposal programme. Potential public opposition, insufficient stakeholder support or the withdrawal of support may result in significant delays to the programme and may lead to changes and modifications to, or even the cancellation of, the disposal programme.

Some delays and cost uncertainties may also arise during the consultation process with neighbouring countries due to potential cross-boundary effects and the environmental impact of the disposal facility.

Siting

In siting stage, following the development of the overall site selection plan and before any research has been performed or information obtained on site suitability, the uncertainties involve primarily the amount of effort needed in each of the site selection phases and the time required to complete each stage. In conceptual and planning stage it is also proposed how the selection among candidate sites will be conducted. This is a particularly sensitive decision, and the associated risks may have high cost impacts not only on the siting process itself but on the design of the repository and the EBS.

Site investigations and RD&D

The site investigation process involves the risk that the research activities planned for the site characterisation and site confirmation are insufficient and that the time allocated to the research has been underestimated. The expansion of the research plan and the extension of the research period may exert significant cost impacts.

The risk is also present that the site characterisation process will fail to confirm the suitability of the candidate site and that the process has to be repeated at another site.

Monitoring

Uncertainties in monitoring can be related to the poorly-defined requirements and the scope of measurements and investigations required or under-estimated time periods for monitoring in different phases of the programme. Delays in the implementation of the programme will also result in extended periods and, consequently, increased costs for monitoring. The results and findings of the monitoring may also have impact on other elements of the programme with cost implications. Any need to abandon the preferred site and transfer the exploration to another candidate site means also additional cost for monitoring.

Safety assessment, safety case and EIA

A certain degree of uncertainty applies as to whether the safety assessment and safety case are able to confirm that the facility will provide for the required safe isolation and containment of radioactive waste over the long-term. Should this not be confirmed, it may be necessary to re-design the facility or even select an alternative site. In both cases, the cost implications could be significant.

Design

Uncertainties in the design of the disposal facility may be related to the inaccurately estimated quantities of waste to be disposed of, new types of waste that may need to be included in later stage, packaging of the waste may be changed with time or some equipment or technologies might be replaced with the new one. Such changes may require the modification of the facility design and a new safety assessment and may have cost impacts also on the construction, operation and closure of the disposal facility.

Design modifications may also be needed due to the emergence of new site-specific data obtained during the detailed research in site characterisation or underground research facility.

Other plans/document

Any change in safety and security legislation and regulations triggers the need to update and adjust the protection and rescue plan and the physical protection plan. Sometimes additional investments may also be needed resulting in increased cost estimates.

Construction

Uncertainties related to construction may arise due to the unexpected and unfavourable underground research results, which may require certain design modifications and/or changes to the construction techniques. In addition to delays to the programme, this may also require additional investments and, consequently, increase in the disposal cost.

The construction of the off-site infrastructure is also exposed to a number of uncertainties such as delays in obtaining approval and permits from the relevant authorities or the realisation that more work than planned is necessary due to unexpected field conditions, both of which will have cost implications.

Uncertainties should also be considered concerning the costs of materials, the equipment and technologies that need to be installed in the disposal facility and other construction-related expenses. The cost of materials and equipment may change over time or new technologies may become available which may affect the cost estimate.

The occurrence of accidents during construction may also have significant cost implications as they may require remedial actions and cause delays in the implementation of the programme.

Operation and maintenance

During the commissioning period there is a risk that the disposal facility with its installations and technological systems will fail to meet all the safety, environmental, radiation protection and other relevant requirements, and that certain prescribed limit values will be exceeded. This could result in the need for remedial actions and/or new investments with the consequent impacts on the cost estimate.

Uncertainties during the operation that may affect the cost are related to the plan of waste emplacement. The emplacement plan usually consists of disposal campaigns separated by so-called downtimes. The duration of each disposal campaign is estimated on the basis of the assumed disposal rate. Any departure from this disposal rate will result in the modified duration of the disposal campaign and in the revised cost estimate.

The need for the maintenance and modification of the various disposal facility systems and technologies is often underestimated. With time, some spare parts, software updates etc. may no longer be available and in case of failure the replacement of whole systems may be required with the consequent cost implications.

The risk of accidents during the operational phase should also be considered along with the potential impacts on the cost estimates.

Closure

The final act of the closure is the removal from the site of all the radioactive waste resulting from the decommissioning and closure activities. There is a risk that no other site will be available for this waste and, thus, the removal will not be possible. Other solutions will therefore have to be found with further cost implications for the disposal programme.

Institutional control

Uncertainties may arise from non-regulated or insufficiently regulated long-term institutional control. Whereas both active and passive institutional control is usually required, it is possible that the time periods and content of these controls are not specified or may depend on the safety analysis results. Institutional control may also change due to the requirements of other stakeholders (local communities, the regulatory body or other authorities).

3.4.2 Uncertainty and risk analysis and evaluation

Once the uncertainties and risks have been identified an analysis should be performed with the assessment of the probabilities and consequences of the uncertainties and risks. By analysing the impact versus the probability, the various uncertainties and risks can be categorised and prioritised as some of them may have a severe impact on the programme and its cost but only happen rarely, while others may have a moderate impact but occur more frequently. The identification of potential uncertainties and risks, and the analysis of their potential cost impacts is important to be able to assess how realistically the cost of the programme is estimated and to select and implement options for addressing these uncertainties and risks.

3.4.2.1 Qualitative uncertainty and risk analysis

The uncertainty and risk analysis is usually performed as a two-stage process. First, qualitative methods are applied to examine and categorise or rank the identified uncertainties and risks. Qualitative methods usually use descriptive scales like low, moderate and high, to determine the level of uncertainty or risk and to rank them in terms of probability and impact. Among various qualitative techniques the most commonly used tool to assign uncertainty and risk ratings is the qualitative uncertainty and risk analysis matrix, also referred to as the probability impact diagram or matrix. Uncertainty and risk ratings are also often referred to as uncertainty and risk impact scores. They are usually classified as low, moderate and high or numerical values could also be assigned to each. Based on these ratings, key uncertainties and risks are identified and treatment strategies developed. More details on this method can be found in [18].

An example of a qualitative risk and uncertainty matrix is given in Figure 2. The matrix may be adjusted to the needs of individual project or organisation, or a new matrix may be created and tailored according to the specific requirements.

Probability or likelihood \ Impact or consequences	Negligible	Marginal	Significant	Critical	Crisis
Very high	Low	Moderate	High	High	High
High	Low	Moderate	Moderate	High	High
Moderate	Low	Low	Moderate	Moderate	High
Low	Low	Low	Low	Moderate	Moderate
Very low	Low	Low	Low	Low	Moderate

Figure 2 – Qualitative risk and uncertainty analysis matrix

For small and less complex projects, the qualitative uncertainty and risk analysis may be sufficient for managing the uncertainties and risks. For large, multi/year and complex programmes or projects, a quantitative uncertainty and risk analysis should also be performed. It usually focuses on the main uncertainties and risks (for example: those uncertainties and risks that are ranked higher than low) indicated by the qualitative analysis process.

3.4.2.2 Quantitative uncertainty and risk analysis

The quantitative risk and uncertainty analysis is a numerical analysis of the probability and consequence of individual risk or uncertainty that also addresses the extent of the overall project risk and uncertainty by using sensitivity simulations, statistical modelling techniques such as the Monte Carlo, and other stochastic methodologies.

The simulation produces a probability distribution function for a range of possible project outcomes and a cumulative distribution function that represents the likelihood that, with a given probability the project cost or duration will be at or below a given value.

Sensitivity method

The sensitivity analysis of the cost estimate is recommended to explore the sensitivity of the point estimate to a change in a certain parameter or assumption (cost driver[2]) and to develop a range of potential costs for a particular baseline document. For example, the analysis may consider an increase in the waste inventory, a delay in the site confirmation, additional RD&D activities required during the site characterisation etc., and the overall effect of such change on the cost examined.

In sensitivity analysis usually only one parameter or assumption is varied at a time. It is important to choose those parameters/assumptions that are inaccurate and likely to change. The variations to these parameters should be both reasonable and justified. The result provides an indication of the parameters and assumptions that have the strongest impact on the cost estimate. As the best practice, the sensitivity method is recommended to be included in all cost estimates for identifying those factors that yield a

[2] Cost driver is any factor which causes a change in the cost of any activity.

large change in the overall cost estimate and for assisting the decision-makers to make a decision based on a range of potential costs that surround a point estimate and to understand what drives that range [7].

Monte Carlo simulations

The Monte Carlo simulation is a computerised mathematical technique for the conducting of risk and uncertainty analyses by building models of possible results by substituting a range of values with a probability distribution for any factor with inherent uncertainty. These distributions can be of different shapes: the normal distribution or bell curve, lognormal, uniform, triangular, discrete and others [7], [18]. In Monte Carlo simulation the results are then calculated again and again, each time using a different set of random values from the probability functions. Depending on the number and ranges of uncertainties, the Monte Carlo simulation may involve thousands or tens of thousands of recalculations before it is completed. As a result, the Monte Carlo simulation produces distributions of possible outcome values.

The Monte Carlo simulation provides a range of possible outcomes and the probabilities that they will occur for any choice of action of decision-makers.

3.4.3 Uncertainty and risk treatment

Uncertainty and risk treatment refers to the practice of selecting and implementing options or strategies for addressing them. Such strategies should be selected based on the outcome of the uncertainty and risk analysis and the expected cost of implementing and benefiting from these options. The most common strategies are acceptance, avoidance, mitigation, and the transfer of the risk [18].

The acceptance strategy assumes that the risk or uncertainty has been accepted, the corresponding cost of acceptance estimated, and the financial provisions provided and included in the project or programme cost estimate.

The avoidance strategy focuses on measures aimed at avoiding or eliminating the potential threat. Generally, this is considered the most desirable strategy provided the cost/benefit to the programme or project remains within the financial boundaries of the programme or project.

The aim of the mitigation treatment strategy is to reduce the risk or uncertainty to an acceptable level. A mitigation plan must be developed and analysed so as to ensure its feasibility and to confirm that sufficient resources are available to implement the mitigation measures. The cost of the risk mitigating measures should be included in the overall cost estimate and only the remaining residual risk[3] should be recorded in the risk register for further consideration.

The transferring or sharing risk strategy is more common in the private sector. It usually involves the purchase of insurance or bonds as the means of transferring the risk. The risk is passed to the insurance company that accepts the risk for a fee.

3.4.4 Provisions for uncertainties and risks

Once the risk and uncertainty treatment strategy has been decided the cost of the risk and uncertainty mitigating measures should be included in the overall cost estimate. For the remaining risks that cannot be avoided, shared or mitigated, some provisions are required to allow for the compensation of the cost of such risks should they occur.

[3] Residual risk is a risk that remains after risk and uncertainty treatment strategies have been implemented.

The disposal programme is exposed to many uncertainties and risks and its cost estimate is very challenging. It is highly likely that the actual cost will exceed the estimate. To account for this cost uncertainty and to prevent cost overrun, a reserve fund should be included in the base cost estimate.

The reserve amount included in the base cost estimation to compensate for additional costs incurred due to uncertainties within the existing scope of the baseline document (so-called in-scope uncertainties) is known as a contingency.

In addition to in-scope uncertainties, the disposal programme is exposed also to other risks that are related to uncertainties beyond the scope of the programme or project (so-called out-of-scope uncertainties). These uncertainties, if they materialise, affect the scope of the programme and could result in significant cost increases. Examples of such risks include changes to the national policy on waste disposal, the unsuccessful siting of the disposal facility due to local community opposition or changes in regulations that directly affect the disposal programme.

The risks related to the out-of-scope uncertainties can be either funded or unfunded. It means that the provisions can be set aside also for the out-of-scope uncertainties or at least for some of them. While the contingencies are expected to be fully spent during the execution of the programme or project the provisions for the funded risks may or may not be spent. The contingencies are therefore considered as an integral part of the programme or project baseline cost estimate while the provisions for the funded risks are not part of the baseline cost estimate as may be seen from the Figure 3.

Figure 3 schematically presents the overall cost estimate of the disposal programme consisting of several parts or contributions. The main part is the estimated overnight cost of the baseline disposal programme that includes also the allowances and the cost of risk and uncertainty mitigation measures. Allowances are a provision for items which are at the time the estimate is calculated uncertain but are expected to be known with greater precision at a later date (e.g. quality and reliability of pricing level of given components, [16]). To this overnight cost estimate (together with the allowances and the cost of risk and uncertainty mitigation measures) a contingency reserve fund is added aimed at compensating for cost increases due to in-scope uncertainties, the provisions for funded risks related to the out-of-scope uncertainties and the excluded cost impact of unfunded risks related to the out-of-scope uncertainties.

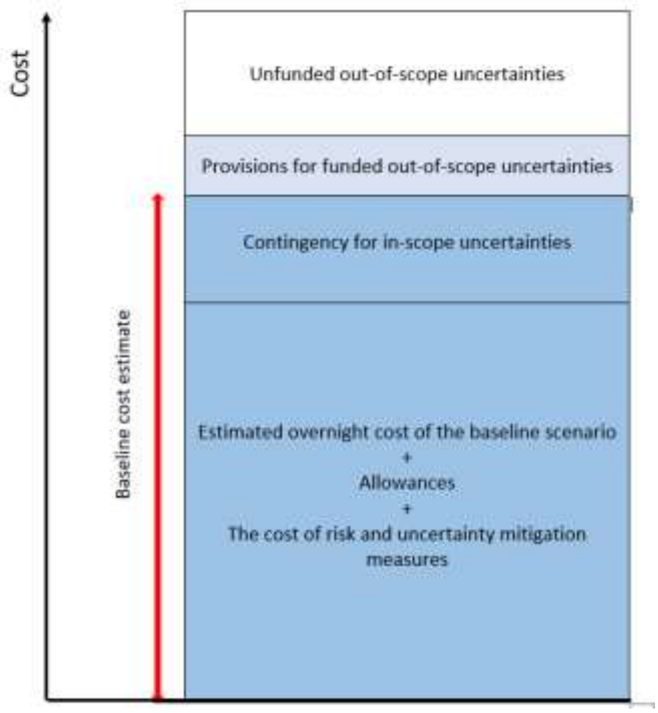

Figure 3 – Main components of cost estimate ([9], [16])

3.4.4.1 Contingency

Based on the previous risk and uncertainty analysis, the contingency level is calculated either by applying "deterministic methods", using a predetermined percentage of the total cost, or "probabilistic approaches", that are based on complex mathematical and statistical methods.

Deterministic method

The deterministic methods estimate a contingency reserve fund as a percentage of the base cost depending on the maturity of the project (Contingency= % x Base Cost Estimate).

In practice, contingencies are determined for each element of the WBS and then added up to obtain the total contingency amount for the project.

The percentage of the contingency for each element is determined either by applying expert judgement or special guidelines that set out predetermined contingency values and ranges such as the cost contingency practices and standards for construction projects issued by the Association of Advancement for Cost Engineering AACE International, the American National Standards Institute ANSI, and the Electric Power Research Institute EPRI.

Some of these methods distinguish between project and technology contingencies. Project contingencies are specified for the various project phases (e.g. conceptual screening, the feasibility study, the detailed planning or budgeting stage, the final planning or tendering stage) to reflect uncertainties relating to the maturity of the project and can range from + 50 % or even higher for the screening phase to 3 % - 10 % in the final planning phase. Technology contingencies are focused on uncertainties related to the maturity and complexity of the technology used. For new complex technologies that have been subjected to preliminary design analysis only, contingencies may be as high as 70 %, and even for modifications to already commonly used technology can range from 5 – 20 %.

Since this method estimates the overall contingency reserve fund for the project from contingencies calculated for the individual WBS elements, it is more suitable for addressing in-scope uncertainties.

Out-of-scope uncertainties usually affect the scope of the project itself and, consequently, lead to changes in the WBS. In such cases, the probabilistic approach is more appropriate.

Probabilistic method

For the calculation of contingencies for large and more complex projects probabilistic risk assessment methods are more appropriate. The application of such methods and, particularly, the compilation and development of the necessary input information, involve higher time and budget requirements than the deterministic methods since they are based on Monte Carlo or similar simulation routines.

The use of the probabilistic method requires the development of the probability distribution for each cost item and each uncertainty. The probability distribution represents the risk shape and the bounds (the tails) of the distribution represent the best and the worst outcome for particular item.

The selection of the probability distributions may be quite challenging, particularly for those cost items for which not much data and experience are available and for which the probability distribution must be "invented". In such cases, the opinions of a group of experts from different fields relevant for this particular estimation might be helpful. Typically, the distribution is determined using 3-point estimates of the high, most likely and low values followed by the selection of the function that best matches the uncertainty variation. A number of probability distribution shapes are available for the modelling of cost risk. The triangular, lognormal, beta, uniform and normal distributions are most commonly applied when performing the uncertainty analysis.

The appropriate levels of attention and consideration should also be given to the potential correlation between those cost items whose cost deviations originate from the same 'trigger' and their potential impact on the total cost probability distribution. The correlated elements or items should be identified and properly addressed. For example: if one cost item is high within its own probability distribution, the correlated item will also feature a high cost in its own probability distribution. It means that the correlated cost items should rise and fall together. Without correlating these two items, inconsistent simulations with one item high and the other low could occur, resulting in false outcome.

Monte Carlo simulations are then performed by randomly choosing the values of individual cost items from their probability distributions to calculate the overall cost of the disposal programme. By repeating this calculation a great number of times, a range of cost estimates is generated. By plotting them against the number of their occurrences the cumulative probability distribution of the overall cost of the disposal programme, also known as the S-curve, is provided.

By using the information from the S curve, the contingency reserves required to attain a specified level of confidence can be defined. The difference in the cost between the point estimate and the desired confidence level determines the required contingency reserve, as shown in Figure 4.

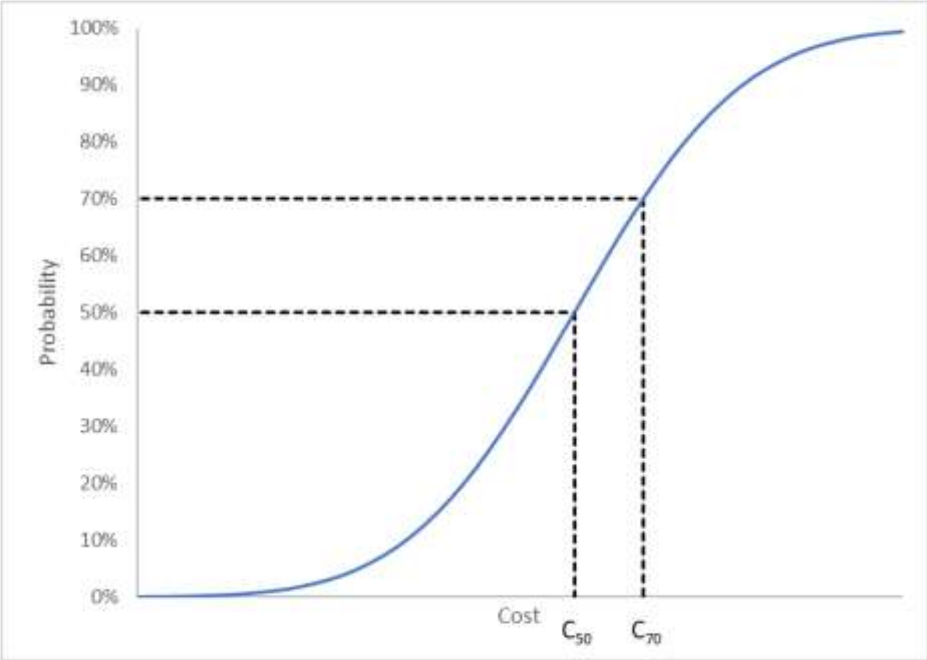

Figure 4 – Cumulative probability distribution of the overall cost of a programme or project, or the S curve

No set rules have been defined as to what level of contingency is sufficient. The contingency budget is determined according to the desired level of confidence for the project. Confidence level of 70 % to 90 % is recommended for more risky programmes of projects [18]. However, in reality the contingency level depends on the financing options and the financial power of the organisations that have to cover the cost.

3.4.4.2 Provisions for risks

Provisions for covering such risks may or may not be considered by the organisation responsible for the waste disposal programme. While contingency reserve fund is recognized as necessary and is considered an integral part of the cost estimate, the arrangements for the funding of risks are the responsibility of the implementing organisation and depend on its decision whether to make such provisions or not. The implementing organisation may decide to fund only certain (accepted) risks and leave others unfunded.

Risk provisions are often provided in the form of guarantees such as parent-company guarantees and surety bonds or letters of credit issued by those that have to cover the cost.

3.5 Time distribution of the cost elements

The overnight cost of the disposal programme estimates how much money will be needed to implement the entire programme today. In reality, disposal programmes span over several decades or even more than a hundred years and the financial resources needed for their implementation are distributed over the entire lifetime of the programme.

An example of the time distribution of estimated costs for the geological disposal facility development and implementation is illustrated in Figure 5 below. In addition to the yearly cost distribution the main milestones in the disposal programme implementation that have strong influence of the cost are also indicated in the figure.

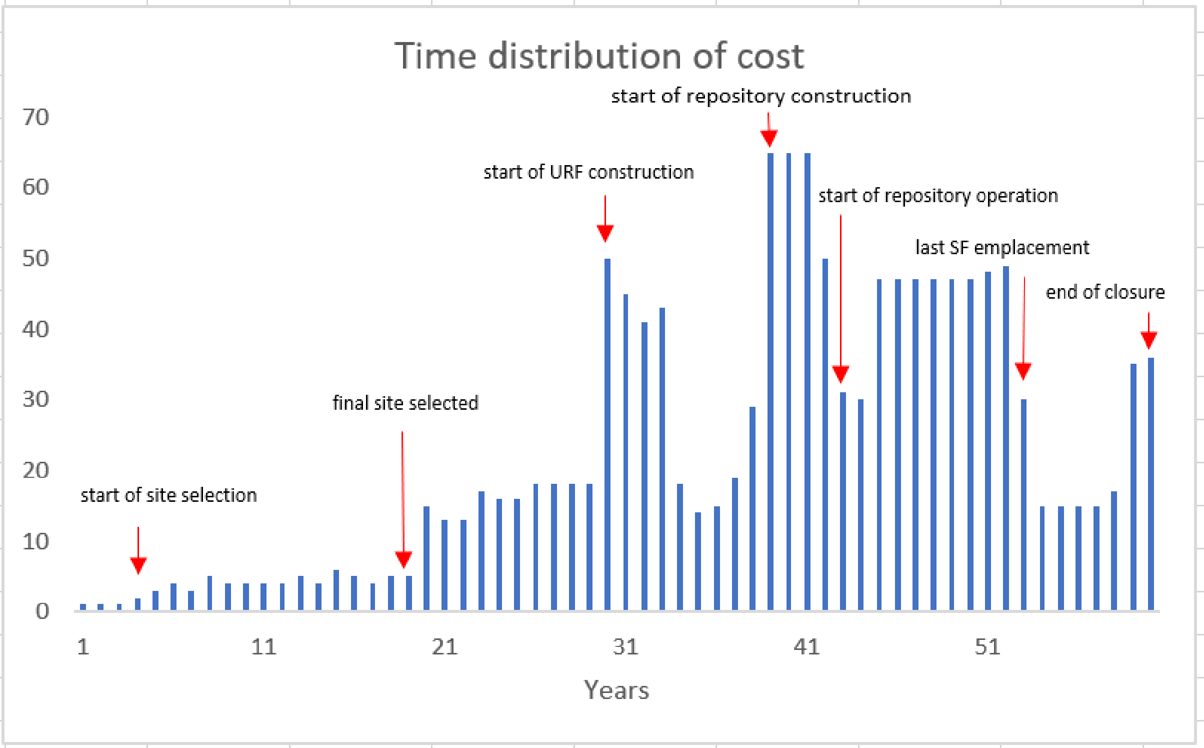

Figure 5 – Illustrative yearly costs distribution for geological disposal programme with indicated major milestones

For estimating the financial provisions that are needed today to finance the future disposal programme we need to consider both, the time distribution of the WBS costs and any anticipated economic changes such as inflation or capital growth (interest rates) during this period. The costs of the WBS items that occur over the lifetime of the disposal programme are discounted to today's prices using the appropriate discount rate. The sum of the discounted WBS items thus provides an estimate of the provisions required today for funding of the disposal programme. This aspect is discussed further in chapter 4.

3.6 Reassessment process

The estimated cost of the disposal programme forms the basis for determining provisions for its funding. It is therefore important that the estimated cost is as accurate as possible. Reviews and updates of cost estimates should therefore be performed on a regular basis. This may be determined by specific national regulations and regulatory requirements.

In practice, waste management project cost estimations should be updated regularly (ideally every year), or each time when major changes are made to the programme. Major revisions and/or updates should be undertaken every 3 to 5 years.

Some items of the WBS may be affected by technical or strategic changes, which will require the recalculation of the costs of these items (a new or updated disposal concept, changes in the waste inventory etc.). For those items for which a cost estimation is available (but for a past base year) and where no strategical or technological changes have occurred, a cost escalation rate (inflation) can be used as the basis for the update. The importance of using nuclear-specific cost escalation rates when adjusting price levels (changing the base year) has been emphasized in [20]. The study draws a conclusion, that: *"Setting an assumption for future cost escalation requires an understanding of general* *long-term inflation expectations and nuclear specific cost considerations."* Further details can be found in the document.

4. Financing scheme

Every country that has nuclear energy or radioactive sources from other than the nuclear industry must ensure its own financial resources to cover the national RWM programme, including the assessment of the necessary provisions and the development of financial schemes which provide for the sustainable funding of the related activities.

One of the fundamental prerequisites for the financing of RWM activities is the creation of a robust, reviewed and approved cost estimation for all the activities necessary for the management of RW and SF as part of the national RWM programme. Guidance on how to estimate the overnight cost profile for all these activities can be found in earlier chapters of this document, in particular in chapter 3.

The adequate allocation of financial resources is required by international agreements, e.g. the Council Directive [1] as referred to in chapter 1, or the Join Convention, Article 22 [12].

The generally accepted "polluter pays" principle requires that the costs of managing radioactive waste, from generation to final disposal are borne by those organisations whose activities produce the waste. This principle allows for the consideration of national specificities and the consequent implementation of differing financing schemes for RWM activities, all of which potentially satisfy the relevant principles. Taking into account the wide variety of workable financing solutions, this chapter introduces a list of potential schemes without suggesting the best methodology to be implemented.

4.1 Financing mechanisms

The financing mechanism refers to the approach to the payment of the costs of RWM-related long-term liabilities. It can be described at the national RWM programme level, and the financing solution for geological disposal – which this guide primarily addresses – can be derived from the overall system. The national RWM programme contains all those activities that must be conducted for the management of RW and SF from generation to disposal, covering all the waste and spent fuel streams within the scope of the programme. The responsible organisations are defined for all these activities based on the national legislative and organisational framework; this forms the basis for the determination of the source of financing of all the related activities.

When the financing mechanism is being developed for RWM activities, it should be taken into account that most of these tasks are implemented over much longer timescales than those over which the waste itself is generated and – in the case of commercial NPPs and nuclear applications – revenues are realized. This usually results in the decision to collect the necessary financing for long-term liabilities in a fund during the period in which waste generators earn income.

An alternative mechanism involves the direct annual financing of RWM from the state budget (non-segregated government liabilities). This option is usually selected for the financing of activities related to the RW and SF generated by state-owned research reactors, other small-scale nuclear applications or legacy waste management[4] (including orphan sources); however, in certain cases, this approach may also be applied for the financing of the RWM and the decommissioning of commercial NPPs.

According to national specificities, some predisposal activities may be directly financed by the respective utilities or waste generators (e.g. treatment, conditioning, characterisation, storage) and only those RWM activities from the transfer of the final waste packages to the disposal site are financed from the

[4] The financing considerations of legacy waste management are discussed briefly in Chapter 2.3 of this guide.

accumulated fund. This could also be the case for RWM activities during the transient or post operational period following the shutting down of the NPP when it is necessary to allow for the cooling down of the SF from the last cores in the pools. Since no revenue is earned by the operator in this period, the owner of the NPP must reserve funding (provisions on the balance sheet) for this period if it is not already covered by the fund.

Details on the various financial mechanisms available can be found in a number of documents (e.g. [9], [21] and [22]); this guide describes only the financing of RWM activities from a pre-collected fund.

4.2 Financing of RWM activities through a fund

One of the most important prerequisites of this kind of financing mechanism is to collect enough money in the fund at least until the end of the operating (revenue generating) lifetime of the waste generator to cover all the long-term liabilities which must be financed from the fund. More conservative approaches may also be developed where adequate funding has to be collected earlier than at the end of the revenue generation period of the utility [23].

It is important to set up a fund contribution scheme that takes into account the planned lifetime of the waste generator. Several options have been implemented to date that rely on:

- a levy on electricity generation (EUR/kWh),
- a tariff based on the characteristics of the waste (e.g. volume, activity) (EUR/m^3),
- annual lump sum payments (or fees)[5] (EUR/yr).

Based on the ‘polluter pays’ principle, the distribution of cost elements - and the calculation of the contribution based on this factor - between the different waste generators should be transparently demonstrated.

Member States have implemented funding structures which best suit their legislative environment and which are in line with the ownership structures of the main entities (waste generators and their owners, waste management organisation). Based on [22] and [24] – where more information can be found on the details of the various implemented funding schemes – funds can generally be grouped into three main categories:

- Segregated external fund: the fund is external to the NPP owner (utility). In this case the fund can be incorporated into the state budget or external to it.
- Segregated internal fund: the fund is maintained by the NPP operator and segregated so that the assets from the fund can be used only for RWM and decommissioning purposes.
- Non-segregated internal funds: directly managed by operators in one general budget, where power companies are required by law or other regulations to build up reserves in their balance sheets for back-end operations.

It is essential for any funding system that the amount accumulated in such funds should be ring-fenced by legislation (secured) to be used exclusively for RWM and decommissioning purposes. The responsibilities and governance (decision-making) on fund management have to be transparent for the key stakeholders.

The reserve accumulated in the fund is invested in assets according to the investment strategy of the given fund; the investment approach must be balanced between the potential yield of the investment and the associated financial risks. A detailed analysis can be found in section 4 of [22] on the risk profiles

[5] Based on the national financing scheme policy of the given country, the lumpsum payments may be equal annual contributions or may differ year to year.

and investment strategies of funds allocated to the back-end activities of the nuclear fuel cycle in various EU Member States.

4.3 Calculating the contributions to the fund

Several technical and financial inputs are needed to calculate contributions to the fund. The basis of these calculations is the overnight cost (for the calculation base year) of implementing the national RW disposal programme and its time distribution (cost or expenditure profile). Guidance on how to conduct the cost assessment, which results in the overnight cost profile of activities, can be found in chapter 3 of this guide.

There are several methodologies for calculating the necessary contributions to the fund. One of the most popular approaches is the net present value (NPV) calculation. With respect to this method – supplementary to the overnight cost profile – some additional information and parameters are needed. It is important to know what the assumption is for the payment schedule (fund contribution schedule) into the fund and the nature of the contribution mechanism (levy, tariff, fee etc.) to the fund. It is also essential to assume a well-selected and justified cost escalation rate (inflation) and expected rate of return on the investment over the long-term. The latter may form the basis for defining the nominal interest rates or nominal discount rates in the calculations. Detailed analyses of the assumptions made on cost escalation rates and discount rates have been performed in [22]. The two main findings of this reference are listed below:

- "*Discounting reflects the time value of money – i.e. the fact that investments are expected to generate investment returns over time. **The discount rate should therefore reflect the expected future returns from the fund's investment strategy**.*
- *There is a need to analyse the underlying drivers of inflation for the main decommissioning and waste management activities and to **set an assumption for future cost inflation that reflects these nuclear specific cost inflation drivers to the maximum extent possibl**e. Such an assumption should also be a long-term assumption, reflecting the likely timeframes over which decommissioning and waste management will be carried out*."

Cost escalation is the change in the cost of specific goods or services over time. It includes the effects of inflation, but it also takes account of cost changes due to changes in work productivity, technology or supply, as well as market demand, which can be significantly influenced by the worldwide political and economic situation and energy strategy changes. In most countries, forecasting services are available that publish predictive escalation indices. These are typically prepared for a basket of goods for a particular market.

A fund contribution plan needs to be defined, the aim of which is to ensure that the fund will be sufficient to cover all the disposal costs. The two components of the contribution plan comprise its target value (i.e. specifying how much funding will be needed) and the contribution schedule of the fund. The specification of these two components requires several assumptions; moreover, significant uncertainties surrounding the specified value and schedule have to be considered. Thus, it is necessary to revise the funding scheme periodically. This revision often depends on the MS legal framework, in particular the economic rules and financial policy.

The discounted cost has to take account of the effects of future price increases and the future value of money. The discounted cost of the complete disposal programme is the sum of the discounted costs of the programme's activities and items. This requires that these costs are distributed over the lifetime plan of the disposal programme. The lifetime plan indicates when costs will occur and when resources for cost expenditures are needed. The discounted cost depends on the discount rate and the timing of the occurrence of the final cost.

The difficulty of determining suitable discount rates for such long timescales, which apply to RWM, is explained and discussed in [25]. This reference also provides a state-of-the-art summary on the costing and financing practices implemented in several OECD Member States.

The net present value calculation can be performed in nominal terms, in which case the cost escalation rate and the nominal discount rate are considered separately. In this case, long-term assumptions are needed for the cost escalation rate and the nominal discount rate separately, and the discounted cost can be calculated as follows, where the time is given in years:

$$discounted\ cost = overnight\ cost * \left(\frac{(1 + annual\ cost\ escalation\ rate)}{(1 + annual\ nominal\ discount\ rate)}\right)^{time}$$

There is also the option of defining the real discount rate, which is the real term interest over inflation (in other words the nominal discount rate adjusted to inflation). In this calculation, the overnight costs are given in real terms – without an explicit inflation assumption – and the cost escalation rate is considered through the real term discount rate, which is used to convert the overnight costs into a present value. "*Whilst this is a reasonable approach, it does not diminish the need to keep the real discount rate under review and ensure it remains appropriate. This is because future returns from all investments are not perfectly correlated with future inflation expectations*". [22] The real term discount rate can be calculated by using the equation below.

$$real\ discount\ rate = \frac{(1 + annual\ nominal\ discount\ rate)}{(1 + annual\ cost\ escalation\ rate)} - 1$$

The net present value calculation for implementing an RWM programme can be made for example by using the following formula in real terms:

$$NPV = F_0 + \sum_{i=0}^{n} \frac{P_i}{(1+rd)^i} - \sum_{i=0}^{m} \frac{E_i}{(1+rd)^i}$$

Where: *NPV*: is the net present value

F_0: is the accumulated amount of money in the fund at the calculation base year (year “0”)

n: is the duration of payments into the fund from year “0” to “n”

P_i: is payment into the fund in year “i”

rd: is the real discount rate

m: is the duration of expenditures from the fund from year “0” to “m”

E_i: is the expenditure from the fund in year “i” (overnight cost of the programme in year “i”)

If the NPV is zero, and assuming that all the technical and financial assumptions are correct, it means the accumulated amount of money in the fund with future payments and the yields of the investments (which are considered through the real discount rate) will be enough to cover all the long-term liabilities related to RWM activities.

5. Conclusions

The estimation of costs is indispensable when assessing the financial provisions needed for radioactive waste management. It is important to identify solutions that are safe and that can be implemented in a manner that are also economically feasible. As part of the national framework, each Member State defines the roles and responsibilities in the area of cost assessment and the financing of RWM activities, including the geological disposal of RW.

Despite the existence of several good examples of cost assessments internationally, there is no ‘one size fits all’ methodology for assessing costs. It is essential to identify the national boundary conditions, which can seriously influence programme planning and the cost assessment. The cost of a disposal programme is affected by many factors, some of the most significant of which are the waste inventory, the timing of waste arisings, the timing and duration of each phase of implementation, the geology at the site of the disposal facility, the design of the disposal facility itself and, in some cases, political decisions and public acceptance.

Good planning (programme plan, inventory) is fundamental to the cost estimation. Various methods exist for estimating the cost of a project, of which the analogy method, the engineering build-up method and the parametric method are the most commonly used.

One of the prerequisites for launching a cost estimation is to specify a baseline document that defines the purpose of the cost estimation and describes the scope of work with all the major activities and deliverables that are needed for the implementation of the disposal programme. This should also include a time schedule of all the activities, and present and justify all the assumptions that are used in the assessment (e.g. the timing and duration of the main activities, assumptions on the site and the geological settings, selected decisions or technical solutions that are not well defined in the disposal programme).

In the early (planning) stage, uncertainties concerning several factors are inevitable; therefore, in most cases, a reference case is developed that comprises a reasonable set of assumptions for a reference disposal concept as the planning basis for the implementation programme. The WBS should be developed once the disposal programme work content has been defined. The WBS should be broken down into sufficiently small items to make the cost assessment feasible and practical. Cost estimations are made for each individual WBS item and, subsequently, these partial results are summated so as to determine the cost of the entire programme at the price level of the calculation year (base year or reference year).

Based on various disposal programmes and their WBSs, an attempt was made in this guide to develop a generic WBS for geological disposal that could be useful for countries and organisations that have just started or plan to start the cost estimation process in the near future. Although the WBS presented in this guide was made for a geological disposal programme, with certain adaptations it can also be applied to near-surface or borehole disposal programmes. The scope of the geological disposal programme is broken down into just two levels in this guide so as to ensure that the WBS is relatively simple and understandable.

One of the fundamental prerequisites for an accurate cost assessment is the development of a cost database in which all the quantities and durations and the estimated unit costs of the items in the WBS are included. The database forms the foundation of the estimate, and its quality determines that of the overall cost estimate. It is crucial to record and keep track of the sources for the cost data and to document how the cost data is adapted, scaled or indexed, and which assumptions might be made when using or adapting the cost data. Future cost estimations will benefit from such records.

The results of the cost calculations are dependent on the input parameters, either based on technical boundary conditions or on economic and financial assumptions. Once the cost estimation is completed, it is important that the whole process with all the input data, assumptions, databases, methods used, and results is well documented so as to provide for traceability, and that it is available for review and audit purposes, as well as for future iterations of the cost estimations.

A wide range of sources of uncertainty should be considered in the cost calculation: society, economics, implementation, organisation, human, technology, calculation and others, each of which may affect the cost calculation in different ways: societal uncertainty may take the form of local community opposition to the construction/operation of a storage/disposal facility for radioactive waste; technological uncertainty (future innovative technologies, for example) can lead to uncertainties in terms of costs and project planning. Most countries apply contingencies in the cost calculation for such uncertainties in various ways. Since the uncertainties may be higher in the early stage of programme implementation, higher contingency values could be justified in the cost assessment.

Cost estimations are performed based on the WBS for the disposal programme, the calculation of the overnight cost of all the WBS elements and the evaluation of the potential consequences of the uncertainties and risks. This guide includes a description of possible approaches to estimations supported by national examples of various disposal types and implementation phases. Four examples have been chosen to share experience and provide information on potential processes for addressing the cost estimation: (i) an estimation of the construction costs of underground facilities for the geological disposal of SF and an estimation of labour costs during the operation of underground facilities (Krško, Slovenia), (ii) an underground repository for L/ILW from NPPs (Bátaapáti National Radioactive Waste Repository, Hungary), (iii) a cost estimation for a deep geological repository without knowing the final disposal site (Deep Geological Repository programme, Czech Republic) and, (iv) the cost assessment of field investigations at one of the candidate sites for a disposal facility for LLW of the near-surface silo type (Vrbina, Slovenia); all these examples are described in Appendix A.

The financing mechanism is the approach to the payment of the costs of the long-term liabilities connected with RWM. Depending on national specificities, different countries may implement different financing schemes for RWM activities. The most commonly used method is the financing of RWM activities from a pre-collected fund.

One of the most important prerequisites of this kind of financing mechanism is to collect enough money in the fund at least up to the end of the operating (revenue generating) lifetime of the waste generator so as to cover all the long-term liabilities which have to be financed from the fund. More conservative approaches can also be developed that involve the collection of adequate funding earlier than the time at which the revenue generation of the utility ends.

Member States have implemented different funding structures which best suit their legislative environments and which are in line with the ownership structures of the main entities (waste generators and their owners, waste management organisation). Each of these will work well provided there is a clear and transparent process in place concerning how the contributions are calculated and paid, how the accumulated funding is managed and stored and how the various expenditures can be financed from the fund.

The net present value calculation is one of the most widely-used methods for the calculation of payments into the fund. It can be performed in nominal terms and in real terms. It is essential for both calculation types to assume a well-chosen and justified cost escalation rate (inflation) and expected rate of return on investment over the long-term, which requires detailed economic considerations.

The main purpose of this guide was to provide information on the cost estimation in relation to the establishment, development, implementation and improvement of a waste disposal programme and to provide insight into the implementation of a financial scheme that ensures the efficient and sustainable financing of the programme.

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Appendix A. Examples of cost estimations

Example 1: Geological disposal of SF from the Krško NPP

This example presents an estimation of the construction costs of underground facilities for the geological disposal of spent fuel and an estimation of the labour costs during the operation of the underground facilities. It originates from a report that describes the disposal concept (the reference scenario and several alternatives) for the disposal of spent fuel from the Krško NPP [15], co-owned by Slovenian and Croatian state-owned companies. The Krško NPP has been in operation since 1983. The original operating lifetime of 40 years has been extended to 60 years (up to 2043).

The disposal concept for spent fuel is based on a disposal programme [26] developed jointly by the two countries with the intention of estimating the relevant radioactive waste and spent fuel disposal costs and to provide the basis for the determination of annual contributions by the Krško NPP to designated decommissioning and radioactive waste management funds in Slovenia and Croatia. The first estimation of costs for the geological disposal of spent fuel was made in 2004, and then revised and updated in 2009 and 2019. The first cost estimation was based on the analogy method. The tendency concerning revised cost calculations is to estimate, where possible, selected cost elements applying the engineering build-up method.

The reference scenario

The reference geological disposal scenario that was developed as part of this disposal programme assumes the direct disposal of spent fuel in a repository constructed at a depth of 500 m in hard rock. The repository will commence operation in 2093 and will be closed after 10 years of operation. The disposal concept follows the Swedish and Finnish solutions for fuel disposal in copper canisters emplaced in vertical boreholes in disposal tunnels (the KBS-3V concept). It is planned that an underground research facility will be constructed in the first stage of repository development.

The repository is small and is intended for the disposal of 2282 elements of spent fuel encapsulated in 571 canisters, as well as small amounts of HLW, ILW and LLW from the decommissioning of the surface facilities at the end of the operation of the repository. Repository operation is planned for 10 years.

The generic site of the shared repository is in a hard rock formation in Slovenia or Croatia. Since no specific data on the rock properties is yet available, generic data on the geological, hydro-geological and thermal properties for igneous (magmatic) and metamorphic hard rock was applied. Where possible, data from existing databases and the archives of the Geological Survey of Slovenia and the Slovenian National Building and Civil Engineering Institute were used. Concerning many of the other parameters, reference data for the Swiss Kristallin-I and Swedish Äspö hard rock geological conditions was assumed to be sufficiently representative for the current phase of the programme.

Construction of the geological repository

The example focuses on one item from the WBS of the geological disposal project - the construction of the underground facilities – and presents the approach to the cost estimation for this item.

The construction of the geological repository, according to the WBS, comprises the following activities:

- Coordination of health and safety at work in the project implementation stage
- Supervision of the construction work
- Construction of an underground testing facility
- Construction of the above-ground facilities
- Construction of an encapsulation plant
- Construction of the underground facilities
- Technical inspection

The cost was estimated for each of these activities separately by further breaking down into smaller units as presented below for the underground facilities. The construction of the underground facilities consists of:

- Access ramp,
- Service shaft,
- Ventilation shaft,
- Service area,
- Access tunnel in the disposal area,
- Disposal tunnels,
- Deposition boreholes,
- Vehicles and equipment.

The cost estimation for the construction of the underground facilities with the necessary equipment is presented in Table 1.1. For each of the underground facilities it shows: the construction costs per unit of volume (EUR/m^3), the number of m^3 that need to be excavated or backfilled and the total cost per item (EUR). The cost estimation for the construction of the tunnels, ramp and shafts is based on the estimated excavation volumes and representative Slovenian unit prices for 2018 for the excavation and construction of underground facilities.

Table 1.1: Costs of underground facilities for the reference scenario.

Underground facilities & equipment	**Unit price (EUR/m^3, EUR/pc)**	**Quantity (m^3, pcs)**	**Cost (EUR)**
Ramp	153	240,000	36,749,580
Service shaft	274	13,250	3,633,005
Ventilation shaft	335	4,500	1,506,872
Service area	136	74,660	10,143,373
Access tunnel	138	106,674	14,667,323
Disposal tunnels	151	180,576	27,258,981
Deposition boreholes	756	11,037	8,347,703
Vehicles and equipment	23,017,048	1	23,017,048
TOTAL			**125,323,885**

Table 1.1 presents the summary results of the construction costs for the underground facilities. The cost of each item was estimated by using the more detailed work breakdown as presented for the disposal tunnel in Table 1.2 below.

Table 1.2: Construction costs for the disposal tunnel.

Item No.	**Structure/item**	**Unit**	**Quantity per unit [1/m']**	**Unit price [€]**	**Amount [€]**
1	***Disposal tunnel –*** ***Length 27 x 207 m + 1 x 54 m*** **Dimension: 5.5 m x 5.5 m**				
1.1	Underground excavation				
1.1.1	- cat. A1, A2 (hard rock) by ÖNORM	m3	32	90	2,880

1.2	Supports: approx. 10% of total length				
1.2.1	- shotcrete 10-15 cm	m2	17	63	1,040
1.2.2	- mesh/fixing anchors (5kg/m2)	kg	95	2.4	228
1.2.3	- anchors (self-drilling), length of 4 m	pcs	6	240	1,440
	Sum of 1.2				2,707
	10% of 1.2				271
1.3	Transport of the excavated material	m3	32	4.8	154
1.4	Bottom lining (30 cm)				
1.4.1	- concrete	m3	2	160	264
1.4.2	- reinforcement	kg	99	1.8	178
1.4.3	- panelling	m2	3	36	119
1.5	Backfilling (clay block product., transp., filling)	m3	32	181	5,787
1.6	Preparation work; 10% of the sum of 1.1 - 1.5				965
1.7	Total amount per 1 m' without contingency				10,618
	Length/total price without contingencies	m	5,643		59,916,783
	Excavation	m^3	180,576		
	Construction & backfilling price	EUR/m^3 excav.			331.81
	Backfilling price	EUR/m^3 excav.			180.85
	Construction price	EUR/m^3 excav.			150.96

Table 1.2 presents the cost estimation for the construction of 28 disposal tunnels with a total length of 5643 m (27 of the tunnels are 207 m long and 1 tunnel is 54 m long), 5.5 m high and 5.5 m wide as set out in the repository design proposal. The estimation is broken down into the underground excavation activities (1.1), the construction of supports (1.2), the transport of excavated material (1.3), the bottom lining (1.4), the backfilling (1.5) and the preparatory work (1.6). The excavation of the deposition boreholes is not included in this cost estimate. The costs of the deposition boreholes were estimated as a separate item.

1.1 The excavation cross-sections of the underground openings corresponded to anticipated clear cross-sections of 32 m^2 considering the assumed rock properties (category A1 or A2 hard rock using Austrian ÖNORM standards, which are normally used in Slovenia for excavation work). The excavated volume per 1 m of disposal tunnel is therefore 32 m^3. The unit price (€/m^3) for excavation is based on representative Slovenian unit prices for 2018 for the excavation and construction of underground facilities.

1.2 Since the quality of the rock is assumed to be good or very good (A1 or A2), support in the tunnels is expected to be needed for only approx. 10% of the total length of the disposal tunnels. The required activities and materials concerning the tunnel supports (shotcrete, mesh, anchors) and the unit prices were estimated based on similar underground facility construction projects.

1.3 Similarly, the cost of the transport of the excavated materials was estimated based on experience from similar underground facility construction projects.

1.4 The cost of 30 cm of the bottom lining, including the necessary reinforcement, panelling and concrete, was calculated using representative Slovenian unit prices for 2018.

1.5 Clay blocks were assumed for the backfilling. The revalorised cost of a bentonite/rock crush mixture was used for the clay costs and included: bentonite clay with a montmorillonite content of 50–60%, clay block production, transport and backfilling. The bentonite costs were estimated based on expert recommendations[6], and were revalorised with the Construction costs index (EUROSTAT, EU28).

1.6 Based on experience from other similar projects, the cost of the necessary preparatory work was estimated at 10% of the total cost of the construction of the tunnels.

The sum of all the costs from 1.1 to 1.6 in Table 1.2 provides the total disposal tunnel construction cost per unit length of tunnel. The total disposal tunnel construction cost was estimated by multiplying the unit cost with the disposal tunnel length.

For further cost estimates it is useful also to calculate costs per m^3 of excavation: construction cost/m^3, backfilling cost/m^3 and construction & backfilling cost/m^3, as presented in Table 1.2. Note that no VAT or contingencies are included in these cost estimates; they are estimated in a separate calculation.

The equipment costs were estimated based on underground facility equipment costs for geological disposal in Finland [27] and the Czech Republic [28], and adapted to the Slovenian disposal capacity, and Slovenian experience from the cost estimation of an LILW disposal project [29]. A list of equipment and prices is presented in Table 1.3. These prices are based on cost estimates from 2009 and revalorised using the Producer prices in industry (Capital goods) index (EUROSTAT, EU28) which, for the period 1.1.2009 – 31.5.2018 registered a 7.73% rise in costs.

Table 1.3: *Underground equipment and systems costs.*

Item	**EUR**
Lifts	
Service shaft; main lift 20t-3m/s	517,116
Service shaft; emergency lift 0.75t-3m/s	517,116
Ventilation shaft; emergency lift 0.75t-3m/s	517,116
Cranes	-
Workshop vault crane 20t/12m-60m	323,197
Storage vault crane 20t/12m-60m	323,197
Vehicle/trolleys	-
Truck for bentonite - surface/underground	323,197
Truck - service - surface/underground	323,197
Canister transfer and installation vehicle	1,615,987
Bentonite blocks transfer/installation	646,395
Dynamic roller compactor (floor levelling)	64,639
Forklift truck (bentonite blocks)	48,480
Block placing equipment	150,825
Pellet placing equipment	150,825
Service systems	-

[6] Workshop on "Disposal of spent fuel", Ljubljana, July 2009

Mechanical systems	7,799,833
Electrical system	8,187,670
Telecommunication systems	1,508,255
TOTAL	**23,017,048**

Operation of the underground disposal facility

Operation costs for the disposal facility include:

- Labour costs (for the surface and underground facilities),
- Costs of maintenance and service, utilities and supplies,
- Costs of insurance,
- Canister purchase costs,
- Bentonite costs,
- Costs of plugs.

The labour cost estimation is presented in more detail below.

Labour costs are estimated separately for the operation of the surface and underground facilities (Table 1.4). The estimation of personnel requirements is based on other geological disposal projects. Data from the POSIVA project [27] was considered to be most relevant according to the size of the disposal project and the disposal rate (60 canisters per year). Based on this data and adjusted to the project needs, the total number of employees in the underground facilities was estimated at 34 workers of various profiles: engineers and managers (responsible for underground facility operation and disposal, for systems and construction and mine measurements), technicians and foremen (disposal preparation activities, transport, deposition hole preparation, canister emplacement, safeguarding) and craftsmen (maintenance activities, bentonite block handling, tunnel filling etc.).

The estimation of labour costs was based on average monthly gross earnings as published by the Statistical Office of the Republic of Slovenia[7], and factors which correspond to similar job positions[8] in the energy sector. The monthly gross labour costs include contributions to social security, health insurance and pension schemes and overhead costs.

Table 1.4: Labour costs – underground facilities, reference scenario.

Job position	**No. of employees**	**Monthly labour costs per employee (gross, EUR)**	**Yearly costs (in EUR)**
Type A (Engineer, Manager)	6	6,896	496,514
Type B (Technician, Foreman)	20	3,941	945,741
Type C (Craftsman)	8	1,576	151,319
TOTAL	**34**		**1,593,574**

[7] Average monthly gross earnings for June 2018 were EUR 1,654 + 16.1% tax + other costs (transport costs and meals), in total EUR 1970.

[8] Type A = 3.5 x average monthly gross earnings, type B = 2 x average monthly gross earnings, type C = 0.8 x average monthly gross earnings.

Example 2: Disposal of L/ILW in Hungary

Aim of this example

The Bátaapáti National Radioactive Waste Repository (NRWR) is an underground repository in Hungary, which provides the final disposal route for L/ILW of NPP origin. The aim of this example is to provide a practical illustration of:

- the actual costs of repository implementation in the early phases,
- how the boundary conditions of the cost assessment were defined,
- the strategical interrelations of this project to other elements of the national radioactive waste management programme,
- how the disposal system was optimised and
- how the detailed build-up of the total cost of one engineered barrier system element (concrete vault) was developed.

The prices in this example are given in Hungarian forints at 2021 price levels (HUF_{2021}). For the first eleven months in 2021 the average exchange rate between the EUR and the HUF was 358 HUF/EUR. Detailed analyses can be found in [10] of how the cost assessments of different countries can be benchmarked provided the technical content and scope are more or less comparable. It was found that: *"Purchasing Power Parities (PPP) are the rates of currency conversion that equalise the purchasing power of different countries by eliminating differences in price levels between countries. PPP's are supposed to give a more realistic view than the currency exchange rates between countries".*

Summary of the implementation of the project

The national project to find a site for the final disposal of nuclear power plant (NPP) origin low- and intermediate-level radioactive waste (L/ILW) was initiated in 1993 by the Paks NPP[9].

Following the country-wide screening process, a granitic site at the vicinity of the village of Bátaapáti was selected for detailed site investigation work in 1997. The surface-based site characterisation was carried out between 1998 and 2003. The Hungarian Geological Survey as the regulatory body confirmed that the selected granitic-type rock was suitable from the geological point of view to host the L/ILW repository.

The underground geological research activities carried out in the granite formation declared to be suitable were aimed at defining the exact location of the repository. After the authorities issued all the required licences, the underground research activities started in February 2005.

Two inclined tunnels (exploration tunnels) with a slope of 10% and length of around 1700 m were excavated. The two tunnels are connected at each 250 m length section.

The first phase of the construction of the repository comprised the completion of the surface facilities in 2008, which enabled the temporary storage of a part of the solid waste from the Paks NPP. The commissioning licence was granted to NRWR on 25 September 2008, the scope of which covered the operation of the surface facilities, where only the temporary storage of RW was underway (the underground disposal chambers were constructed in parallel with the operation of the surface facilities).

The first two disposal chambers were completed by the end of 2011 (I-K1, I-K2); the licencing authority granted an operating licence for the surface facilities and the I-K1 chamber. The licence became legally binding on 10 September 2012. Since this time, the further construction of underground structures has

[9] Public Limited Company for Radioactive Waste Management (PURAM) the waste management organization of Hungary was established in 1998 and took over the responsibility for this task since then

been underway along with the final disposal of waste in chamber I-K1. Currently in the first chamber section (see Fig. 2.1), chamber I-K1 has been filled with waste packages and chamber I-K2 forms a part of the operational (radiation controlled) area and is ready to receive waste packages. Chambers I-K3 and I-K4 are currently being excavated; the inner engineered barrier system has not yet been constructed. PURAM has a valid construction licence for the I-N1 and I-N2 chambers, which will be excavated at a future date.

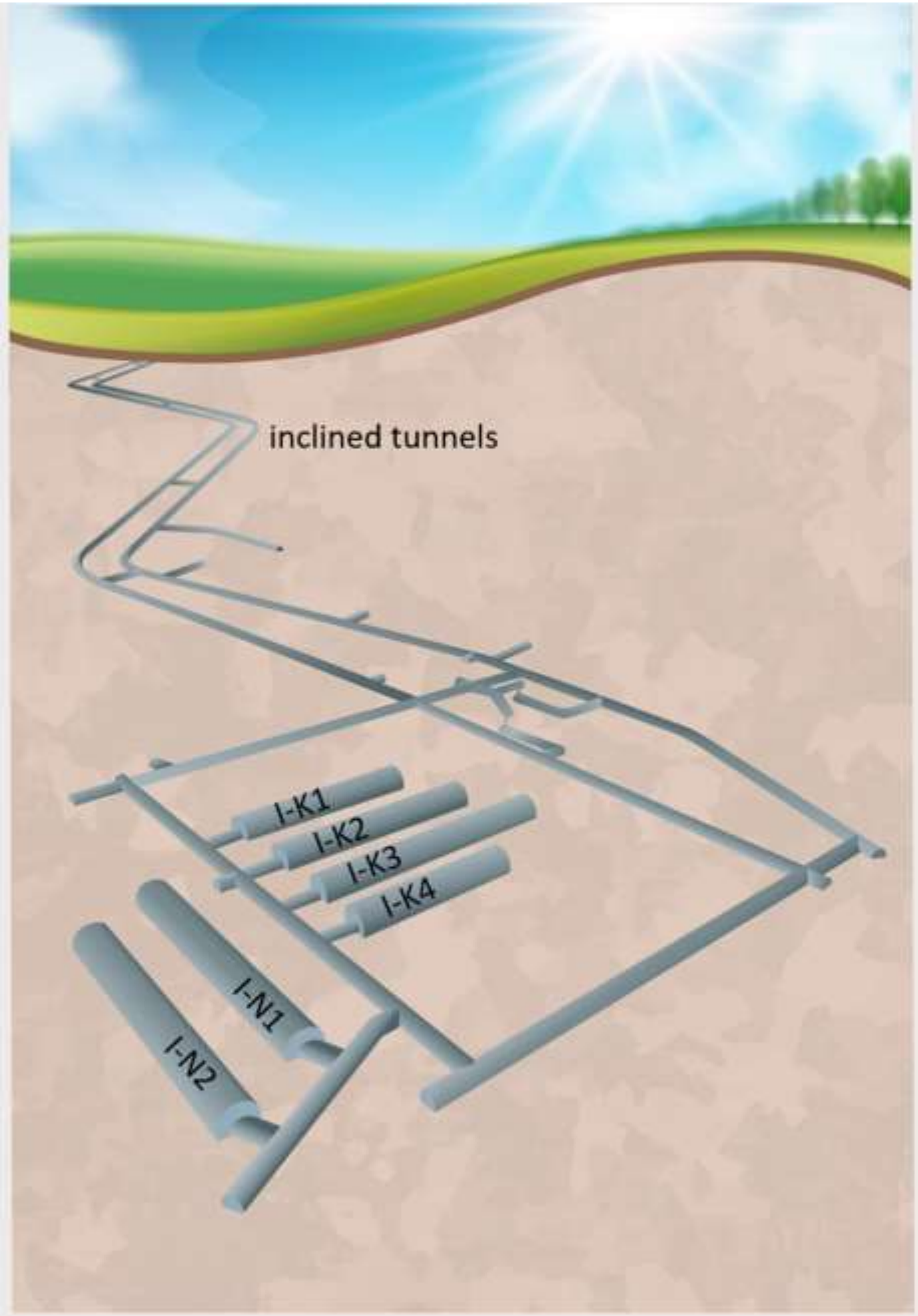

Figure 2.1 - Underground layout of the National Radioactive Waste Repository in Bátaapáti.

Cost breakdown for the early implementation phases

From 1993 until 1998, the disposal project was coordinated by the Paks NPP. During this period all the costs were directly covered by the utility since no fund (Central Nuclear Financial Fund) had been established at this time. Based on the modification of the Act on Atomic Energy, the national radioactive waste management organisation PURAM and a fund – covering all activities in relation to radioactive waste and spent fuel management, as well as decommissioning – were established in 1998. A summary of the relevant activities and the annual realised expenditures for project implementation adjusted with inflation rates to the 2021 price levels (excluding VAT) is presented in the Table 2.1 below in Hungarian forints (HUF). The programme management cost is included in the operational cost of PURAM and is not included in Table 2.1.

*Table 2.1: Cost breakdown for the NRWR implementation phases at the 2021 price levels (VAT excluded)**

Year	Expenditure (million HUF/y)	Phase	Expenditure (million HUF /phase)	Relevant activities
1998	1 459	Site selection and evaluation	21 682	drilling of boreholes, hydrogeological, geotechnical, geophysical investigations; excavation of investigation trenches; geophysical surveys; preparing the final report on the surface-based investigations; environmental baseline survey; preparing the preliminary environmental impact study; preparing and updating the conceptual design of the repository (comparison of alternatives); compiling and updating preliminary safety assessments (derivation of preliminary WAC);
1999	1 010			
2000	635			
2001	1 037			
2002	5 917			
2003	7 475			
2004	4 149			
2005	5 376	Site characterisation (underground)	15 809	Excavation of a pair of inclined exploration tunnels, which later became access tunnels; rock characterisation from underground; preparing the environmental impact assessment; preparing the detailed design of the surface installations and the underground facilities; preparing the construction licence application; constructing and commissioning of the surface facilities and technologies; preparing the operating licence application for the surface facilities
2006	10 433			
2007	9 292	Site characterisation (underground) / Facility construction (surface)	21 286	
2008	11 994			
2009	7 821		29 189	

Year	Expenditure (million HUF/y)	Phase	Expenditure (million HUF /phase)	Relevant activities
2010	6 179	Facility construction (underground)		constructing the repository (excavation of tunnels, sumps and two disposal chambers (IK1 and I-K2), construction of the portal buildings, underground road construction); installation of technologies (ventilation, water collection and management, radiation protection, electrical etc.) preparing the operating licence application for the repository (surface facilities + I-K1 chamber)
2011	8 998			
2012	6 191			

* Programme management costs are not included

Consideration of the boundary conditions

This chapter provides practical examples of how the national circumstances were taken into account during project planning, implementation and cost assessment via the boundary conditions.

National policy and programme

Initially the strategic target of the project was formulated as: "the final disposal of NPP origin L/ILW – also including the waste originating from the decommissioning of the NPP – will take place in a new facility that satisfies all the relevant technical and safety requirements". With this aim in mind, the site selection process for a new repository was initiated.

In the late 1980s the Hungarian site selection programme failed due to opposition from the host community, namely concerning socio-political reasons. The lesson learnt; the new project involved a technically-led[10] selection strategy that seriously considered the existence of the support of local municipalities. Once a granitic formation was selected from the four candidate sites and the strategic decision on the geological disposal of L/ILW had been made, it was concluded that the public potentially more easily accept an underground disposal option than a near-surface alternative. (Note: in other countries, contrary arguments have been raised such as: the waste has been buried so it cannot be controlled. This is a clear indication of the need to carefully consider the national boundary conditions.)

At the national radioactive waste management programme level, the NPP-origin L/ILW project has several interrelationships with other programme elements such as:

- The NRWR is the target end point of the decommissioning of L/ILW elements of the Paks NPP. The currently-approved decommissioning strategy is for deferred dismantling; this means that the primary circuit of the NPP will be dismantled after a 20-year safe enclosure period.
- Some L/ILW will also be generated from the decommissioning of the interim spent fuel storage facility. According to the current plans, this facility is to be dismantled together with the Paks NPP but, in any case, not earlier than the time of the final transfer of spent fuel to the future deep geological disposal facility.

[10] A technically-led approach via which potentially suitable areas are selected through a documented process based on the defined technical characteristics of a site, followed by seeking the approval of the local communities to proceed with examining these potentially suitable areas.

These interrelationships have to be taken into account when planning the operational time schedule of the NRWR.

Time horizon of the facility

The national nuclear programme may seriously influence the time horizon of RWM facilities: this is also the case for the NRWR. The originally planned lifetime of the Paks NPP was 30 years. In 2005, the Hungarian Parliament made a decision on the 20-year lifetime prolongation of the four NPP units. This decision had to be taken into account during the planning of the various implementation milestones of the NRWR.

Recently, the Hungarian electricity policy was changed to include a decision on building a new NPP at the Paks site with two VVER-1200 units. The designed operational timeline of these units is 60 years. The national RWM policy states that the existing repository has to be considered for the disposal of L/ILW generated from the operation and decommissioning of the two new units. Taking into account the immediate decommissioning strategy for the new units, this means that the NRWR should be in operation at least until the end of the century. The planned two new units will significantly increase the waste inventory, as well as the total revenues allocated to the disposal fund, which will reduce the unit NPV cost of future disposal, i.e. a lot of the fixed costs have now been covered. Based on the polluter pays principle, a separate cost estimation is needed to calculate those cost items that have to be financed by the new operator.

Concerning the post-closure period, a legal requirement is in place that the length of the active institutional control period is a minimum of 50 years; however, it can be extended based on a decision from the licencing authority. Due to the fact that the NRWR is a geological repository for L/ILW, a minimum of 50 years of active institutional control is considered in the cost assessments.

National regulatory and organisational framework

A dispersed regulatory framework existed in Hungary before 2014. In 2014, the nuclear safety, radiation protection, security (physical protection) and safeguard regulatory functions were merged into one licencing authority, i.e. the Hungarian Atomic Energy Authority (HAEA). A completely new legislative framework was created. This change influenced the technical and organisational requirements, as well as the licencing procedures, both of which had to be taken into account in the cost calculations.

Taking into account the above-mentioned changes in the regulatory system, the Act on Atomic Energy was modified and a regulatory fee was introduced that has to be paid by the licensee annually. The fee differs for near-surface and underground repositories and is in the range of 12-20% of the direct operational costs of the repositories. This cost element should be taken into account during the operation of the repositories.

Inventory

The radioactive waste inventory (volume, isotope specific activity, chemical, etc.) together with the waste package types (geometry, mass, composition etc.) form basic inputs for the design of the repository and, consequently, for the cost assessment. The access tunnels, disposal cells or chambers, internal roads, transfer vehicles and lifting devices have to be specified in terms of providing for the suitable handling of the waste.

At the beginning of the NRWR project, the volumetric inventory, estimated isotopic composition of the waste and the waste package geometry all influenced the design of the repository. The design target was to dispose of all the operational and decommissioning L/ILW of Paks NPP-origin in reinforced concrete containers. The waste package contains 9 drums of 200 l and the empty space in the package is filled with inactive mortar at the repository site.

During the NRWR project implementation stage, a number of significant design changes were introduced, which influenced the waste inventory.

- As mentioned earlier, the operational lifetime of the Paks NPP was prolonged, which increased the volumetric inventory of the waste to be disposed of.
- During the last review of the preliminary decommissioning plan, the estimated amount of L/ILW waste from the dismantling activities was increased.
- The Paks NPP introduced a new liquid waste management technology which, on the one hand reduced the amount of waste but, on the other, led to the necessity to consider new waste streams.
- A new waste category (very low level waste, VLLW) was recently introduced into Hungarian legislation on waste classification. While the final decision has not yet been made, most probably this waste type will not be disposed of in the NRWR but in a newly-built landfill type repository. This may act to significantly decrease the volume of waste to be disposed of in the NRWR.

All these examples demonstrate that flexibility is essential in the design of any repository. Flexibility allows for reacting to changes in the waste inventory. Such changes require the reviewing and updating of the relevant parts of the cost assessment.

In 2003, an incident occurred at the Paks NPP in which 30 spent fuel assemblies were damaged. This served to increase the waste volume; however, more importantly, a number of L/ILW waste streams were found to have higher levels of alpha contamination. Based on the results of the safety assessment and the derived waste acceptance criteria (WAC), it was decided that most of these waste streams could be safely disposed of in the NRWR. Because Hungary opted for a geological L/ILW repository, this NPP incident did not require a completely new waste management route (potentially with a new repository) and the disposal of the waste from the incident in the NRWR had no significant impact on the cost assessment of the NRWR. At the beginning of any repository implementation project, it is worthwhile and justified to consider a cost contingency to cover the effects of an unforeseen event that may seriously influence the waste inventory.

Stakeholder relations

In Hungary, municipal associations have been established around all the country's operational radioactive waste and spent fuel storage and disposal facilities. Associations were also established around the investigation areas for the selection of the site for the future deep geological repository. The main aims of these associations are to monitor the activities of PURAM in their vicinity and to forward the relevant information to local people.

In 1997, six municipalities located in the immediate vicinity of the (at the time) potential site of Bátaapáti established the Social Oversight and Information Association. Currently, the association has eight member municipalities.

Based on the provisions of the Act on Atomic Energy, the association is entitled to receive financial incentives from the Fund. The specific rules on how such incentives can be distributed between the four existing associations in Hungary are set out by government decree.

Operational cost distribution

Since the NRWR is in operation, experience has been gained on the main cost elements in relation to the operation of the facility. These cost elements can be grouped into four categories:

- direct operational costs,
- indirect operational costs (programme management),
- financial incentive provided to the Social Oversight and Information Association,
- regulatory fee.

The breakdown of the yearly operational costs is illustrated in Figure 2.2, which can be regarded as the usual distribution for an average year.

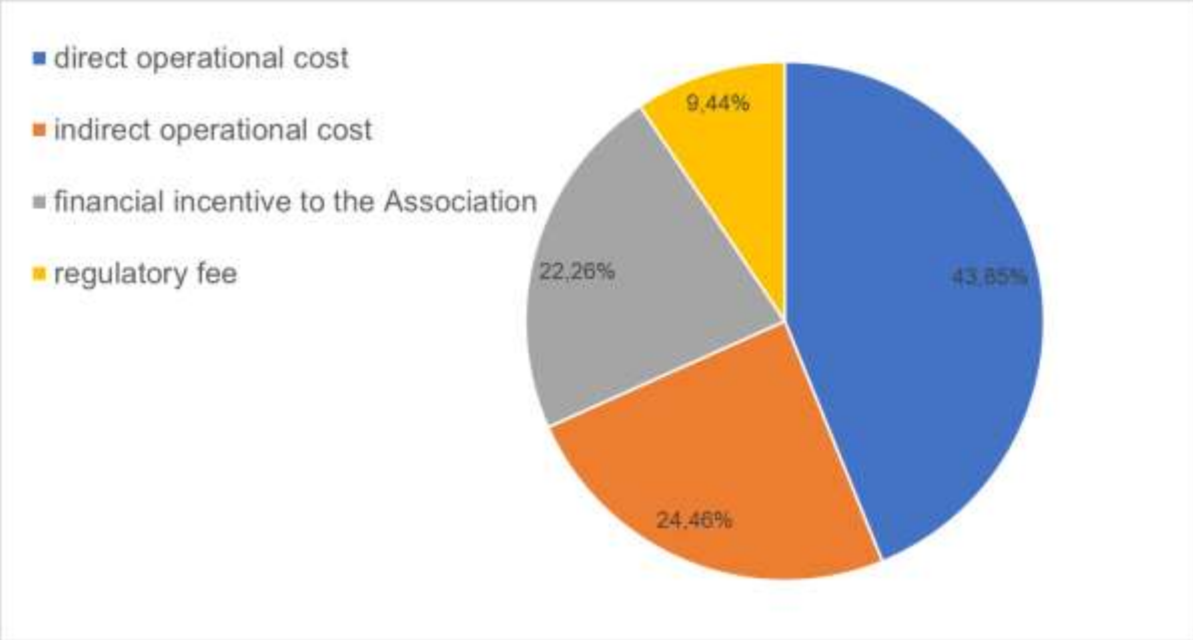

Figure 2.2 - Relative breakdown of cost elements in relation to NRWR operation

Direct operational costs cover: operation, maintenance and surveillance; transport costs, public utility services (electricity, water, gas etc.), radiological, environmental and geotechnical monitoring; security (physical protection); engineering services and licencing.

Indirect operational costs include: IT services, communication, financial and HR services, accounting, quality management, legal services, knowledge management and training. These cost elements are dominated by the labour costs of employees, the running costs of offices and overhead costs.

The above-mentioned operational costs do not include the treatment and conditioning of radioactive waste and the cost of preparing the final waste packages since these activities are performed and directly paid for by the Paks NPP. The cost of the extension of the facility (excavation of chambers, construction of engineered barrier system elements etc.) and modifications to the buildings and technologies are not included in the operational costs, i.e. they are regarded as investment costs in the Hungarian case. Similarly, the costs of the partial backfilling of the disposal chambers are also regarded as investment costs.

The main cost elements of the above-mentioned four categories that contribute to direct operational costs are illustrated in Table 2.2 at 2021 price levels. The boundary conditions, which are relevant for understanding the background to the significant cost drivers of direct operational costs, are as follows:

- The staff that performs regular operational activities consists of 16 persons. They transport waste packages from the NPP and handle them at the repository site (driving vehicles, operating lifting devices e.g. cranes and forklifts), check the compliance of the WAC, provide the necessary radiation protection services, compile regular reports for the authorities, coordinate surveillance, maintenance and ageing-management activities. Their wages and the related taxes and fees are included in the operational labour costs item (1.1).
- Most of the maintenance activities are outsourced, so they fall into the cost of outsourced services (1.3) for the support of operational activities.
- The number of security guards at a facility can be determined based on the design basis threat defined for the repository by the relevant authorities. The labour costs of security personnel (2.1) contain the wages and the related taxes and fees of the security guards and other staff that provide physical protection and other administrative or property protection services.

- Most of the maintenance of the physical protection systems is also outsourced (2.3).
- Some basic laboratory measurements are taken by the operational staff of the repository and are included in cost items 1.1 and 1.2; in addition, some of these services are provided internally from other directorates (these are included in the indirect operational cost category, see Figure 2.2). Most of the monitoring services are outsourced and included in cost item 3.

Table 2.2: The average yearly direct operational cost elements of the NRWR at 2021 prices

Cost element	Cost (million HUF)
1. operation, maintenance and surveillance	**414**
1.1. labour cost	210
1.2. material cost	16
1.3. cost of outsourced services	188
2. security (physical protection)	**346**
2.1. labour cost	297
2.2. material cost	7
2.3. cost of outsourced services	42
3. outsourced monitoring services (radiological, environmental and geotechnical)	**72**
4. public utility services (electricity, water, gas etc.)	**71**
5. outsourced engineering services and licencing	**16**
6. transportation of waste	**10**
Sum	**929**

It is useful to compare the average yearly operational cost (including direct operational costs, indirect operational costs, financial incentives provided to the Association and the regulatory fee) with the total cost of facility implementation, which was described earlier and summarised in Table 2.1. Because the operational costs include VAT, where relevant, gross expenditures are compared. Thus, the yearly operational costs of the NRWR are ~2% of the total investment costs of the repository incurred from 1998 to 2012[11]. The conclusion can, therefore, be drawn that taking into account the length of the operational period of the repository – which can last for several decades, or almost a century – the total operational costs for this time span are comparable to the total investment costs. This is useful information for optimisation planning at the national RWM programme level.

Optimisation of the disposal system

In parallel with the implementation of the originally planned disposal concept in 2010, the Paks NPP (the waste generator) and PURAM (the WMO) initiated a joint project aimed at the optimisation of the disposal system. It was essential to start the operation of the facility with the original concept since it formed the basis for all the relevant licences, and the NPP had run out of free storage capacity.

[11] Note: additional investment costs will be incurred for the continuous extension of the repository in parallel with normal operation

At the beginning of the project, it was discovered that the optimum could only be found for the whole waste management process from generation to disposal (or 'cradle to grave'). The value engineering process[12] was used for optimisation purposes. The first step of this methodology was the functional analysis. Each function of the system was identified. Subsequently, the approach to fulfilling the given functions by the system elements was investigated. Various alternatives were developed for the same functions and, finally, the costs of the various alternatives were evaluated. Subsequently, the solution for which the fulfilment of all the functions can be implemented at the lowest price was identified as the optimum.

Original waste package: reinforced concrete container with nine 200 l drums, the empty space between the drums is filled with inactive mortar.

New waste package: containing four 200 l drums, the empty space between the drums is filled with mortar produced from active liquid waste.

Figure 2.3 - Comparison of the original and new waste package design

As a result of the project, a new waste package type and, in parallel, a new engineered barrier system was developed. As mentioned earlier, the original waste package comprised a reinforced concrete container with 9 drums, while the new waste package is a thin-walled cast iron container containing 4 drums. The two package types are illustrated in Figure 2.3. A new engineered barrier system element was developed to replace the functions of the reinforced concrete container. A reinforced concrete vault was constructed in chamber I-K2, in which the new waste packages, as well as some low activity drummed waste, can be disposed of. The new waste disposal concept is illustrated in Figure 2.4. In subsequent stages, the cross-section of the disposal chambers (from chamber I-K3) was optimised in line with the new package geometry.

[12] https://en.wikipedia.org/wiki/Value_engineering

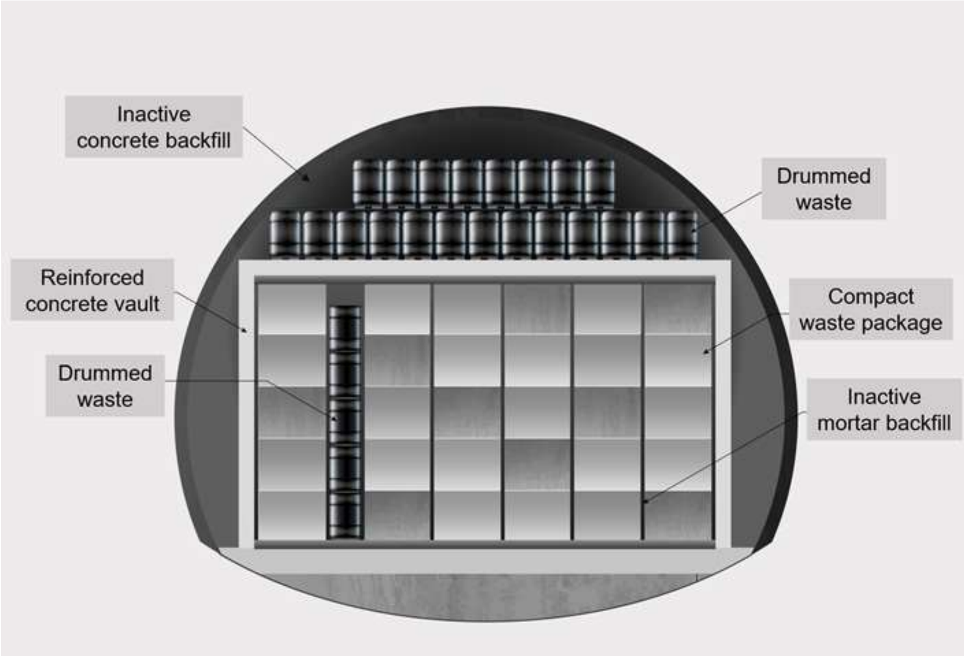

Figure 2.4 - The new (optimised) disposal system of the NRWR (chamber I-K2).

The feasibility of the new concept was demonstrated, and the updated safety case proved that the safety level of the repository remained the same. Based on the required supporting documentation, the necessary licences (environmental protection, construction) for the repository were modified and chamber I-K2 now has a valid operational licence for the new disposal concept.

The comparison of the two disposal concepts revealed that as a result of the optimisation process, 3-3.3 times more radioactive waste can be disposed of in the chambers than previously, i.e. significantly fewer chambers have to be excavated, thus reducing the variable costs of disposal.

Table 2.3: Cost comparison of the original and optimised disposal concepts of the NRWR (100% is the total gross investment cost from 1998 to 2012)

	Relevant cost items	New concept	Original concept
1.	Excavation cost	13.22%	37.75%
2.	Cost of the 200 l drums (for cemented waste)	-	13.31%
3.	Cost of the reinforced concrete containers	1.11%	17.59%
4.	Cost of filling the reinforced concrete containers with inactive mortar	0.03%	0.53%
5.	Cost of backfilling the chambers containing reinforced containers	1.03%	16.44%
6.	Cost of implementing the cost of new cementation technology at the Paks NPP (estimated)	4.62%	-
7.	Cost of the design and safety assessment of the new disposal technology	0.92%	-
8.	Cost of the new cast iron containers	14.37%	-
9.	Cost of constructing the reinforced concrete vaults	5.47%	-
10.	Cost of backfilling the chambers containing the new package types	6.88%	-
11.	Cost of purchasing new handling equipment and modifying existing equipment	0.55%	-
	Sum	**48.22%**	**85.62%**

The reduction in costs is illustrated with the respective numbers in Table 2.3, which indicates the relevant cost items in percentages of the total gross investment cost from 1998 to 2012 calculated at 2021 price levels (see Table 2.1). The comparison shows that the future construction and chamber backfilling cost – required to dispose of all the L/ILW generated during the 50 years of operation of the Paks NPP – has been reduced by almost one half (85.62% => 48.22%), while the safety level of the repository remains the same. Two of the key elements of the success of the project concerned the joint approach of the waste generator and the WMO, and the determination of the optimum approach for the whole of the process from generation to disposal.

Cost assessment based on a detailed design

The first conceptual plans were developed during the initiation of the disposal project, and they evolved continuously as more information was collected. Firstly, the functions of the planned facility and the main activities to be performed were identified:

- reception of waste packages and their unloading;
- quality control of the waste packages;
- buffer storage of the waste packages;
- emplacement of the drums in the reinforced concrete containers;
- filling the containers with inactive mortar and closure of the containers;
- emplacement of the containers in the disposal chambers;
- backfilling of the chambers.

In order to successfully accomplish these basic radioactive waste management functions, additional supporting activities were necessary such as:

- providing radiation protection and environmental monitoring;
- enabling the identification of the waste packages and the keeping of records of the waste properties;
- providing the necessary level of security (physical protection);
- providing the necessary infrastructure (electricity, water, gas, heating, cooling) for the systems.

Based on the identified functions and activities, a conceptual reference design was developed with selected alternatives where possible. Once the alternatives had been evaluated, the cost of their implementation was taken into account. Finally, following a number of interim stages and iterations (in which the safety assessment also played an important role), the detailed design of the NRWR was developed.

The whole of the facility was broken down into systems, structures and components (SSCs) to 4 levels and classified into safety classes based on their safety functions. The first two levels are illustrated in Table 2.4.

Table 2.4: Systems, structures and components of the NRWR to level 2

1. Radioactive waste management systems
1.1. Transfer and lifting equipments
1.2. Holding equipments
1.3. Transport vehicles
1.4. Collection system for the liquids with potential contamination
2. Radioactive waste disposal systems
2.1. Waste packages
2.2. Engineered barrier system
2.2.1. Reinforced concrete vault in chamber I-K2
2.3. Complementary disposal subsystems
3. Buildings and underground cavities
3.1. Technological building
3.2. Main office building
3.3. Underground inclined access tunnels
3.4.Underground disposal chambers
3.5. Other complementary tunnels
4. Radiation protection systems
4.1. On-site operational radiation protection system
4.2. Dosimetrical system
4.3. Monitoring system for potential radioactive releases and discharges
4.4. Environmental radioactive monitoring system
5. Water management systems
5.1. Underground drainwater collection system
5.2. Underground drainwater management and pumping system
5.3. Surface drainwater management system
6. Other mechanical systems
6.1. Surface ventillation system
6.2. Underground ventillation system
6.3. Heating and cooling systems
6.4. Water- and gas supplying systems
7. Electrical systems
7.1. Electricity supply system
7.2. Lightning protection system
7.3. Electrical grounding system
8. Fire protection system
8.1. Fire alarm system
8.2. Firefighting water system
8.3. Other fire protection systems
9. Non radiological monitoring systems
9.1. Geotechnical monitoring system
9.2. Environmental and meterological monitoring system
9.3. Hydrogeological monitoring system
10. Rainwater collection and management system
11. Industrial ethernet network system
12.Low current system
13. Automatization system (PLCs)
14. Data collection and record keeping systems
14.1. Long-term record keeping system
14.2. Radiation protection data collection and alarm system
14.3. Central data collection system
14.4. Radioactive waste record keeping system

One of the elements of the engineered barrier system (a reinforced concrete vault) was selected as an example to illustrate the creation of an SSC cost assessment once the detailed design has been determined. Table 2.5 shows the main cost elements of constructing the reinforced concrete vault and the extension and connection of the necessary technological systems that serve the I-K2 chamber to the main repository systems.

Table 2. 5: Selected indicative cost elements of the construction of a reinforced concrete vault in the I-K2 disposal chamber of the NRWR at 2016 price levels (VAT excluded)

Main cost components of construction	**amount**	**unit**	**material unit cost**	**labour unit cost**	**material cost**	**labour cost**
			[HUF/unit]	[HUF/unit]	[HUF]	[HUF]
Construction of the concrete structures						
Preparatory works					29 588 406	6 367 524
Subgrade concrete structure (concrete quality: C30/37)	570,57	m3	34 882	7 305	19 902 848	4 167 831
Subgrade concrete structure (fiber reinforced concrete quality: C30/37)	253,54	m3	38 201	7 908	9 685 558	2 005 024
Assembly of reinforcing iron bars for bottom plate side walls and end wall of the vault					71 228 484	35 616 306
diameter 10 mm	2,13	t	309 698	336 621	659 656	717 003
diameter 12 mm	2,92	t	303 428	221 274	886 011	646 119
diameter 16 mm	21,04	t	303 428	221 274	6 384 133	4 655 598
diameter 20 mm	8,23	t	303 428	221 274	2 497 216	1 821 082
diameter 25 mm	98,79	t	306 892	140 200	30 317 873	13 850 398
diameter 32 mm	99,33	t	306 892	140 200	30 483 595	13 926 106
Formwork and falsework					2 473 517	26 846 080
One side formwork of vertical wall, height 5.67 (backfilling structure)	806,85	m2	1 413	15 460	1 140 003	12 473 670
One side formwork of vertical wall, height 5.77 (end wall)	81,65	m2	1 413	15 460	115 364	1 262 286
One side formwork of vertical wall, height 5.77 (side wall of the vault)	821,08	m2	1 413	15 460	1 160 109	12 693 662
Concreting the structures					142 518 732	33 646 282
Concreting the side backfilling structure (concrete quality: C30/37-XC4-XV3-24-F3)	923,80	m3	40 249	8 437	37 181 949	7 793 648
Concreting the side walls and end wall of the vault (concrete quality: C35/45-XC4-XV3-24-F3)	268,94	m3	42 672	13 465	11 476 280	3 621 368
Concreting the bottom plate (concrete quality: C35/45-XC4-XV3-24-F3)	407,71	m3	42 672	16 221	17 397 559	6 613 517
On-site qualification (control) of the concrete composition and properties						43 687 982
Compressive strength examination on cured concrete samples	99	pieces		5 029		497 835
Water penetration tests on cured concrete samples	99	pieces		20 115		1 991 341
Extension of operating technological systems					78 174 414	49 299 735
Water manegement system					8 220 067	1 980 742
Partial ventillation system					3 915 329	8 283 980
Underground road construction					9 698 604	6 047 677
Electrical technology system					33 650 370	11 037 788
Fire alarm system					9 411 480	12 205 714
Lowcurrent system (telephone and telecommunication)					327 013	78 966
Radiation protection system					7 081 316	475 860
Industrial ethernet network					2 705 776	2 235 914
Automatization system (PLCs)					3 164 459	4 453 094
IT systems					0	2 500 000
				Sum	**323 983 553**	**195 463 909**

Example 3: Czech Reference Project for a Deep Geological Repository for SF

This example illustrates how, in the early stage, the cost of the Czech Deep Geological Repository (DGR) programme was estimated without knowing the final disposal site. The cost was determined on the basis of the Reference project for a DGR at a hypothetical site in hard rock [30] taking into account the existing and expected future SF and HLW inventories.

The selected reference scenario assumes the direct disposal of SF from currently-operational Czech NPPs (4x500 MW_e and 2x1000 MW_e) and potential new sources of radioactive waste that cannot be disposed of in current repositories. Together, this means 5880 disposal canisters with SF and 2290 concrete containers with other radioactive waste. Horizontal disposal at a depth of 500m is considered with the railway transportation of the waste to the site. According to the various options, the duration of DGR operation is planned between 2065 and 2163 or 2175 and closure in 2168 or 2180 [31].

The Updated Reference Project for a Deep Geological Repository at a Hypothetical Locality consists of several parts that deal with the conceptual solution, technical variants, safety analysis, environmental impacts, uncertainties, time schedule and, finally, the cost evaluation of the economic demands of DGR construction and operation [32]. The data used in this example originates from the 2011 versions of these documents. A new update is presently under preparation.

The financial costs estimation consists of two basic parts – investment costs for DGR construction and its operation costs.

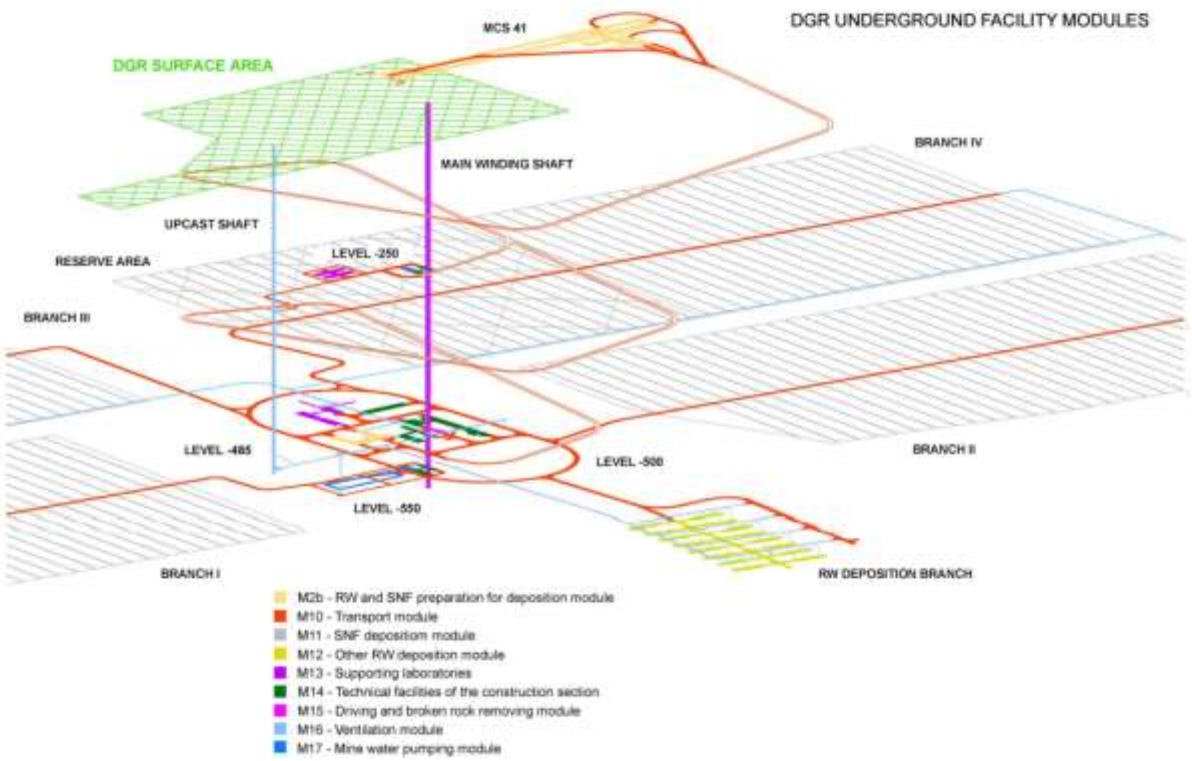

Figure 3.1 - Scheme of the Czech DGR [31]

Investment costs for DGR construction

The investment costs calculation was performed on the basis of the conceptual design.

The construction cost estimation is structured according to the functional modules. Concerning the more detailed structure, the civil part covers the civil structures and the technological part the functional units.

The pricing of the functional units was performed on the basis of consultations with potential suppliers, by searching of catalogue prices on the websites of relevant manufacturers and the use of the professional estimations of engineers with references and experience in designing and constructing nuclear installations. For financially significant functional units (laboratories, radiation monitoring, SNF disposal/storage handling), pricing was performed by means of calculations.

The investment costs for the technological and building parts include costs related to preparatory activities for construction and commissioning activities.

Table 3.1: Costs of the research activities before commissioning.

Activity	Cost [thousands CZK]				
	Total	2011-2018	2019-2033	2033-2045	2045-2062
Geological survey and research	1 056 000	484 400	231 500	180 000	160 100
Research and development of disposal canister	415 800	60 000	196 000	88 400	71 400
Research and development of buffer, backfill and construction materials	340 400	60 000	102 000	90 000	88 400
Technological research	444 150	28 800	104 250	111 100	200 000
Research focused on safety issues	307 200	57 800	106 500	73 200	69 700

Other costs not included in the technological or construction parts:

- Surveys, geodetic and design work
  - Geological surveys: the costs are calculated on the basis of professional estimations performed by engineers. They include the basic geological survey of the site and geological surveys performed during DGR construction.
  - Design work: the costs are calculated according to the “Price list for the setting of bid prices of design and engineering work - UNIKA” – including the addenda and the factual realisation of the construction, category Energy industry, zone V.
  - Research work and tests of materials: the costs are set via professional estimations performed by engineers (long-term research activities).
  - Geodetic survey activities: the costs were set according to the Geodetic work price list.
  - Site preparation – the costs cover preservation work and the removal of materials and structures – e.g. the securing of archaeological findings, as well as natural values, exhumation, the grubbing up of vegetation, demolition of buildings, etc. The relevant costs are only estimated due to the lack of the definition of a site.
- On-site facilities – the costs include the related design activities and ground work, site equipment (lease, temporary roads, storage, site barracks, on-site operation and maintenance costs), site safeguarding (lighting, fencing, traffic signs, guards), as well as on-site facility liquidation (dismantling, demolishing, the required transport of materials, grading). The costs are estimated at 5% of the investment cost.
- Engineering activities – the costs include supervision, expert opinions, tests and measurements, monitoring, coordination activities and other engineering activities (the relevant methodological guide was applied – see the above-mentioned UNIKA document). Accordingly, the price of the

engineering activities was set at 40% and other costs were estimated at 2.5% of the investment costs.

- Financial costs – insurance, state fees, financial reserve, fines, interest expenses. Concerning the mine construction, the financial reserve is recommended to be up to 30% of the investment costs. This project applied 20%. 2% was estimated for the above-mentioned state fees.
- Compensation for difficult working conditions (underground work), work in health-hazardous conditions, remote workplaces and long travel distances to and from the workplace etc. Based on experience from similar construction projects in the energy sector, the contribution for the transport of employees was set at 1.5% and the cost of off-site transport at 2.5% of investment costs.
- Other costs – this item includes securing activities in the case of the interruption of construction, trial operation costs, spare parts, consumables, equipment for offices etc. Based on the experience of project design engineers, spare parts were estimated at 2.5% of the technological part costs, fixed assets in reserve at 5% for pre-commissioning tests, furniture and consumed materials for approx. 20 offices at CZK 1600 thousand.

DGR operating cost

Initially, model scenarios with the hypothetical deployment of work shifts for selected disposal activities were developed and analysed for estimating the DGR operating costs. One, two and three-shift operations were analysed. The results showed that the three-shift operation is compatible with the planned time-schedule for the disposal of SNF and is also the most cost-effective option.

Since the operational costs directly affect the overall DGR costs, the aim is to minimise the operational costs and, thus, the overall costs. Operational costs can be effectively reduced by reducing the DGR operating time, which can be achieved by adopting the three-shift operation of the DGR. Hence, only the three-shift scenario was further considered for the operating cost estimation.

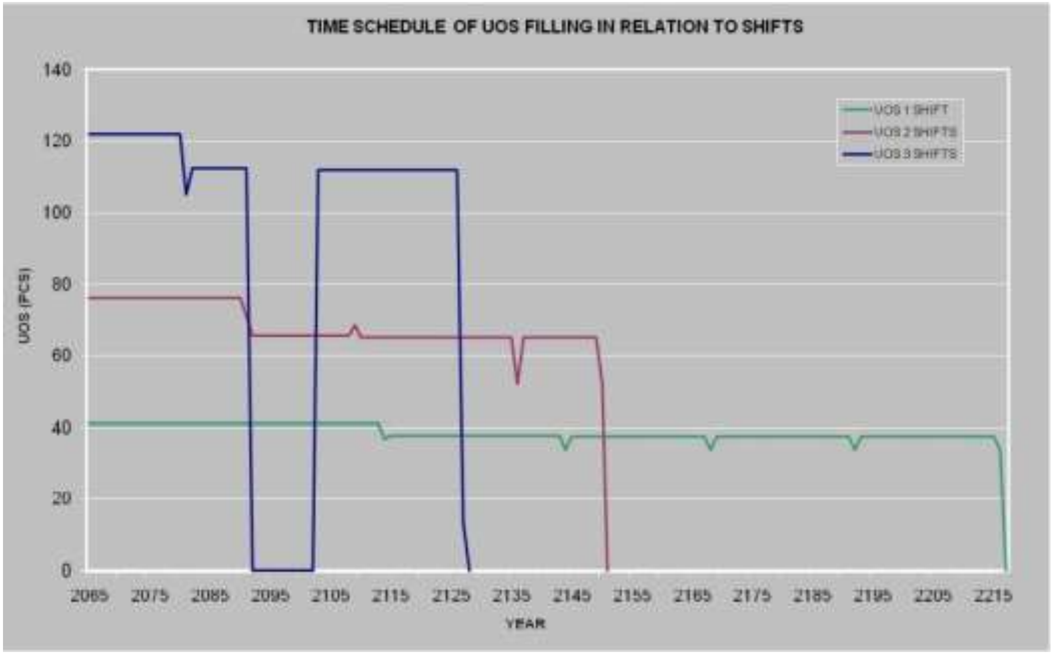

Figure 3.2 - Number of disposed of canisters (UOS) for the one, two and three-shift operation of the repository [32].

Table 3.2: Operating costs of the DGR for selected items.

	Cost without VAT [CZK]
DGR - operation costs	
DGR - labour costs/year	
Single shift operation variant	324 000 000
Two-shift operation variant	348 000 000
Three-shift operation variant	372 000 000
DGR - operation costs of the disposal process	**9 034 833 405**
DGR - closure of the DGR	**2 336 283 150**
Maintenance, overhaul, replacement of equipment	
Overhaul of the equipment - after 5 years	52 815 000
Overhaul of the equipment - after 10 years	662 965 000
Overhaul of the equipment - after 20 years	985 075 000
Overhaul of the equipment - after 40 years	1 115 530 000
DGR - disposal canisters	**26 940 000 000**

Concerning the determination of the DGR operation costs, only the following items of higher importance were considered (i.e. items which will significantly influence the total operation costs):

- Costs related to the disposal container – this item includes the construction materials for, and the costs of activities related to, the manufacturing and assembly of the disposal container. The costs were set on the basis of the professional experience of the design engineer; for the disposal container for SNF from the NPP Dukovany – estimation of approx. CZK 3.8 million, for SNF from the NPP Temelín and New Nuclear Units - approx. CZK 5 million.
- DGR operation – these costs include the costs of energy, water, sewage and similar, the cost of the handling of the disposal containers, bentonite for the super-containers, the closure/sealing of the deposition drifts, etc. Based on the professional experience of engineers, these operation costs were estimated at 30% of the relevant super-container price.
- Costs of repairs, maintenance, and the modernisation of equipment – only those that are critical to DGR operation and may, in terms of the costs incurred, have a major impact on the overall operating costs, are included. These operating costs were assessed over time horizons of 5, 10, 20, 40 and 70 years based on the professional experience of the design engineer and according to the expected maintenance of, and upgrades to, the various facilities.
- Labour costs – pricing was performed for three operation variants: for one-, two- and three-shifts for the loading of the disposal canisters with spent nuclear fuel. In line with the technical solution [32], around 40 workers are needed for one-shift operation, 50 workers for two-shift and 60 workers for three-shift operation. Together with the staff that provide for radiation control, fire protection, monitoring and surveillance, and administrative staff, the total number of workers for the one-shift operation variant is approx. 135 persons, for the two-shift option approx. 145 and for the three-shift option approx. 155.
  Per capita costs consist of direct wages and extra payments due to the hazardous work environment, other direct costs (the operating cost of machines, cars, computers, etc.), other costs (business trip reimbursement, transport allowances, etc.), to which the costs of heating, energy, water, protective clothing and tools, etc. are added. The total cost is on average estimated to be CZK 217,400/month per worker for the entire duration of DGR operation.

Example 4: Near-surface disposal facility for LLW in Slovenia

This example presents the cost assessment of field investigation work at one of the candidate sites for a disposal facility for LLW in Slovenia

The planned disposal facility for LLW will be of the near-surface type, with a disposal unit in the form of a silo. The site of the repository was selected in 2009, i.e. Vrbina in the vicinity of the Krško NPP in the Municipality of Krško. The repository is intended for the disposal of LLW from the operation and decommissioning of the Krško NPP and for institutional radioactive waste from medicine, research and industrial activities in Slovenia. The planned disposal capacity is 9400 m^3 [26]. The application for the construction licence for the repository has been submitted. Construction is planned to commence following the granting of approval.

Figure 4.1 - Concept of the disposal facility for LLW in Slovenia

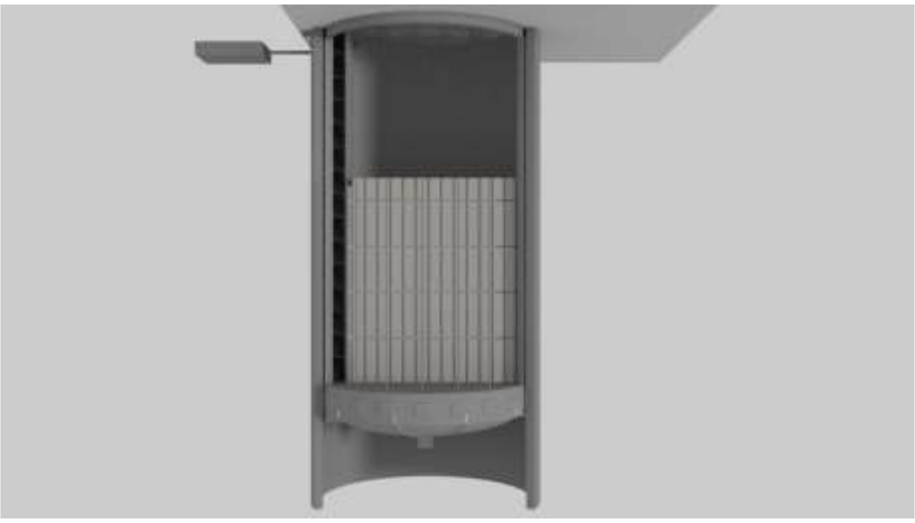

Figure 4.2 - Detail of the LLW repository in Slovenia: the disposal silo

The site is located on gravelly lowland in the vicinity of the Sava River. During the site evaluation phase, numerous research and field investigations were conducted at the site to assess its suitability. This example presents the cost estimation for the geological, hydro-geological, geochemical and geophysical investigations and explorations, geomechanical testing and drilling at the site. A detailed list of measurements, tests and analysis with cost estimations is provided for the geochemical exploration. The cost estimate is from 2007.

Table 4.1: Summary cost assessment of field investigations at one of the candidate sites for the disposal facility for LLW in Slovenia (uninflated 2007 values)

Segment	**Amount, no VAT (€)**	**VAT (€)**	**Amount with VAT (€)**
Geological and hydro-geological prospecting and investigations	192645	38529	231174
Geochemical explorations	111605	22321	133925
Surface geophysical prospecting	65338	13068	78406
Geophysical borehole explorations	15980	3196	19176
Geomechanical in –situ and laboratory testing	19900	3980	23880
Drilling	143951	28790	172742
Sum of all the segments	**549419**	**109884**	**659303**

Table 4.2: Cost assessment of the field investigations at one of the candidate sites for the disposal facility for LLW in Slovenia with a detailed list of measurements, tests and analysis for the geochemical exploration (uninflated 2007 values)

	Activity	Unit	Quantity	Price (€)	Amount (€)
1.	Segment 1 - Geological and hydro-geological prospecting and investigations				192,644
2.	Segment 2 - Geochemical exploration				111,605
2.1.	Analysis and measurements				
2.1.1.	Chemical analysis of soils and rocks	analysis	20	1,834 €	36,679 €
2.1.2.	Analysis of gas content	analysis	2	763 €	1,525 €
2.1.3.	Rock, soil and groundwater radiological analysis				
2.1.3.1.	VLG spectrometry	analysis	22	321 €	7,070 €
2.1.3.2.	Analysis of Sr-89/90	analysis	13	257 €	3,335 €
2.1.3.3.	Analysis of H-3	analysis	6	239 €	1,436 €

2.1.4.	Determination of organic material in rocks and soils	analysis	4	52 €	209 €
2.1.5.	Analysis of water rock/soil interaction (analysis of solubility)	analysis	5	272 €	1,359 €
2.1.6.	Hydrogeochemical characterisation of groundwaters	analysis	22	1,233 €	27,130 €
2.1.7.	Hydrogeochemical characterisation of surface waters	analysis	5	1,051 €	5,255 €
2.1.8.	Analysis of groundwater impact on concrete	analysis	3	360 €	1,080 €
2.1.10.	Sorption testing (extraction experiments, column tests determination of distribution coefficients)	analysis	5	3,141 €	15,705 €
2.1.9.	Synthesis and interpretation of results	flat rate	1	10,822 €	10,822 €
3.	Segment 3 - Surface geophysical prospecting				65,338
4.	Segment 4 - Geophysical testing in boreholes				15,980
5.	Segment 5 - Geomechanical rock and soil investigations				19,900
6.	Segment 6 - Drilling				143,951
	TOTAL				**549,419 €**

Appendix B. Glossary

Contingencies

The value of all contingencies, expressed as a fraction (%) of the total undiscounted cost.

Cost assessment

An assessment of the National Programme costs and the underlying basis and hypotheses for that assessment, which must include a profile over time.

Discount rate

The discount rate is used to calculate the net present value of future cash flows. The 'real' discount rate equals the nominal discount rate minus the assumed inflation rate.

Financial liabilities

The costs that will need to be covered in the future that result from past, current and future activities.

Financing scheme

Definition of the mechanism and responsibilities for ensuring that adequate financial resources are available when needed for all the decommissioning activities of nuclear installations and for the management of spent fuel and radioactive waste

Fixed cost

A cost which is not proportional to variations in key parameters. The fixed costs (of a GDF) include the site selection and investigation programme and the construction of the surface facilities, access shafts and access drift. These are considered to be predominantly fixed costs as they are largely unrelated to the volume of waste being emplaced.

Variable cost

A cost which is proportional to variations in key parameters, such as the capacity.

Inflation

Inflation is the decline in purchasing power of a given currency over time. A quantitative estimate of the rate at which the decline in purchasing power occurs can be reflected in the increase in the average price level of a basket of selected goods and services in an economy over a certain period of time. The rise in the general level of prices, often expressed as a percentage, means that a unit of currency effectively buys less than it did in prior periods. Inflation can be contrasted with deflation, which occurs when the purchasing power of money increases and prices decline

Discounting

Discounting is the process of determining the present value of a payment or a stream of payments that is to be received in the future. Given the time value of money, the valid currency (EUR) is worth more today than it will be worth tomorrow. Discounting is the primary factor used in pricing a stream of tomorrow's cash flows.

Even though discounting is widely applied in the financial schemes of disposal programmes, it is not considered or present in all such schemes.

Discount rate

Refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. DCF is a valuation method used to estimate the value of an investment based on its expected future cash flows. DCF analysis attempts to determine the value of an investment today based on projections of how much money it will generate in the future.

Nominal discount rates are not adjusted for inflation, while real rates are.

Interest rate

The interest rate is either the cost of borrowing money or the reward for saving it. It is calculated as a percentage of the amount borrowed or saved. The interest rate may be nominal or variable. The nominal interest rate refers to the interest rate before taking inflation into account. Nominal may also refer to the advertised or stated interest rate on a loan, without taking into account any fees or compounding of the interest.

Overnight cost

By definition the overnight cost comprises cost estimates prepared at a given calculation date without allowance for future cost inflation or discounting. Where "overnight" cost estimates are prepared without an explicit inflation assumption, it is common to subsequently use a real discount rate to convert these into a present value. That is, the discount rate is defined as the additional expected investment return over (implicitly) assumed future inflation.

Present Value (PV)

Present value is the current value of a future sum of money or stream of cash flows given a specified rate of return. Future cash flows are discounted at the discount rate, and the higher the discount rate, the lower the present value of the future cash flows. Determining the appropriate discount rate is the key to properly valuing future cash flows, whether they be earnings or debt obligations. Present value is the concept that states an amount of money today is worth more than that same amount in the future, i.e. money received in the future is not worth as much as an equal amount received today.

Net Present Value (NPV)

The net present value is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The net present value is used to calculate the current total value of a future stream of payments. The NPV looks to assess the profitability of a given investment on the basis that a dollar/Euro in the future is not worth the same as a dollar/Euro today. Money loses value over time due to inflation. However, a dollar today can be invested and earn a return, making its future value possibly higher than a dollar/Euro received at the same point in the future.

NPV Formula: $NPV = TVECF - TVIC$

Where: TVECF=Today's value of the expected cash flows, TVIC=Today's value of invested cash

The time value of money refers to the concept that money available today is worth more than in future due to the capacity of money to earn money via interest or investments.

Total undiscounted cost

The total cost estimation of the disposal, according to the list of cost elements, without discounting or contingencies.

VAT

Value added tax: indirect tax, which is imposed on goods and services

Appendix C. Challenges and lessons learnt from past practices, based on the screening of key references

A preliminary screening (gap analyses) was performed on the references available in the field of cost assessment and financing [33]. The references are listed at the end of this Appendix with brief summaries of the main points raised. Based on this screening analysis and taking into account the experiences of the WP12 team, selected important challenges and lessons learnt are summarised here.

Challenges and lessons learnt from past practices

The **roles and responsibilities** of the various official entities should be **clearly defined** in the national framework and in legislation. The main functions that might be allocated to the respective entities of Member States are:

- development of a baseline document and performance of the cost calculation;
- determination of the necessary contributions to the fund or other types of payments based on the financing scheme of the given country;
- independent review of the cost calculation and determination of the financing needs;
- management of the fund (if it exists).

The main players to whom these roles and responsibilities could be allocated are: the waste management organisation, the waste generator (or owner), the regulatory body and the government. Several well-functioning systems have been implemented in Member States, the key to the success of all of which is a transparent and clear decision-making mechanism.

Several costing approaches published internationally can be **adapted within the boundary conditions** of a given country provided the appropriate adjustments are made. At the start of a programme, empirical relationships (analogies with other similar and comparable disposal programmes) may help, but they must eventually be replaced by more specific methods as the boundary conditions and data become better defined and more specific.

There are several **pillars to an accurate cost assessment**, e.g.:

- **programme planning**: Planning the radioactive waste disposal programme (deliverables and/or phases plus milestones) forms the starting point of the assessment.
- **justified assumptions**: The baseline document is the starting point of any cost assessment. It identifies and describes the scope of work included in the cost assessment with all the activities, tasks, deliverables, other relevant items and the time schedule of these activities/tasks. Whenever the disposal programme has not been well developed, and not all the details have yet been defined, the baseline document should make justified assumptions and predictions. Such assumptions must be traceable and well-understood so as to ensure consistency and to provide transparency. The assumptions should be reviewed and should respond to new information.
- **methodology**: Several well-developed cost estimation methodologies are available. For more mature disposal programmes with better-defined scopes and time schedules, more detailed (reliable) and accurate cost estimations are needed. For this purpose, the engineering build-up method, also called the bottom-up method, is applied. The work breakdown structure (WBS) should be developed once the work content of the disposal programme has been defined. The WBS should be broken down into sufficiently small items so as to ensure that the cost assessment is both feasible and practical. A good WBS is fundamental to the cost estimation.

- **data acquisition**: Concerning the cost estimation of the various WBS items, it is essential to have data available on the quantities and duration of these items and their estimated unit costs. The quality of the collected data is of high importance in terms of the credibility of the cost estimation. Poor quality data cannot result in a good cost estimation. Obtaining suitable high-quality data is often the most challenging, time-consuming and costly activity in the cost estimation process.

Disposal programmes are faced with numerous **uncertainties and risks** of various origin due to their complex and often not fully-defined scope, number of assumptions that have to be used because of missing information or data, the societally-sensitive nature of the programme with the involvement of many stakeholders and long implementation periods. The suitable management of uncertainties and risks is important in order to avoid the underestimation of the implementation costs of the disposal programme. Several methodologies are available for this purpose; however, following the development of the risk and uncertainty treatment strategy, concerning those remaining risks that cannot be avoided, shared or mitigated, certain provisions are needed to compensate for the cost of these risks in case of their occurrence.

If additional costs arise because of uncertainties within the existing scope of the baseline document (in-scope uncertainties), the reserve amount is known as a **contingency**. The treatment of uncertainties and the resulting contingencies varies widely and they may represent a large proportion of total costs. With respect to early costing exercises, it is suggested that caution be exercised by building in contingencies. The technologies to be applied will influence the contingencies; moreover, proven technologies will require smaller, and non-proven technologies larger, contingencies.

The result of the cost assessment comprises the yearly expenditure required to carry out all the necessary RWM activities, as defined within the scope of the programme. Such yearly expenditure estimations are usually calculated for the base year (price level), i.e. as "**overnight costs**" (or "overnight cost profiles" since costs are given for each year in the future). Poor cost estimates (or lack of such estimates) may result in the underfunding of the future liabilities of the nuclear facility, the poor public perception of the operating organisation or government authority, and non-compliance with regulatory requirements and/or expectations.

There is a constant need to ensure both the reliability and effectiveness of the chosen methodology. Methodologies need to be regularly back-tested. The conducting of an **independent review** of the methodology and the cost estimation is good practice in terms of back-testing, and has the potential to crucially contribute to establishing confidence in the assessment. When compiling and/or reviewing the costing "exercise", regulatory input should be acquired.

The analysis of, and comparison with, the cost estimations of other countries (**benchmarking**) is challenging due to differing national specificities, boundary conditions and methods applied to arriving at the estimation, as well as differences in the underlying basis of the analyses and hypotheses applied. In addition, many cost components will be affected not only by the inventory but also by the duration of the phases of the programme; moreover, the costs of smaller programmes are often dominated by fixed costs (economies of scale), all of which complicate the comparison process. Experience shows that national cost studies include differing cost elements, e.g. it is not always obvious whether the costs for project management, R&D, regulatory interaction, public information, incentives provided to host communities are included or not (it is important to define a common scope when comparing costs). EDRAM has developed a methodology [10] on how the cost assessments of different countries can be benchmarked provided that the technical content and scope are more or less comparable. It was found that: "*Purchasing Power Parities (PPP) are the rates of currency conversion that equalise the purchasing power of different countries by eliminating differences in price levels between countries. PPPs are intended to give a more realistic view than currency exchange rates of variations between countries*".

Based on Council Directive 2011/70/Euratom [1], each Member State is responsible for developing a national programme for the management of SF and RW. The national programme contains all the management routes up to the end-point for all the SF and RW management routes generated in the respective country. A suitably implemented cost assessment methodology provides a useful tool for **optimisation** at the national disposal programme level (between disposal routes), as well as at the disposal facility level. Concerning the latter, a practical example is provided in Appendix A of this guide. The key to successful optimisation is an understanding of the main cost drivers and the identification of how the various functions of the disposal system can be fulfilled by implementing more cost-effective solutions.

The implemented **financing scheme** for RWM activities comprises a further important part of the national framework. While several good practices are being applied by Member States, in most cases, the collection of provisions for long-term liabilities in a fund is the preferred option.

A **fund contribution plan** has to be determined that considers all the phases of the disposal programme and which is in line with the lifetime of the waste generators.

Various methodologies are available for calculating contributions to the fund, of which the **net present value (NPV) calculation** is most widely applied. The NPV calculation can be performed in both nominal-terms and real-terms; however, in both cases it is essential to adopt a well-chosen and justified cost escalation rate (inflation) and expected rate of return on the investment over the long-term (nominal discount rate), which requires detailed economic considerations.

It is necessary to analyse the underlying drivers of inflation for the main RWM activities and to set an assumption for future cost inflation that reflects **nuclear specific cost inflation** drivers to the maximum extent possible. Such an assumption should be a long-term assumption that reflects the likely timeframes over which RWM activities will be conducted [22].

The **discount rate** is a key parameter since it establishes a connection between the cost calculation and the fund contributions necessary for RW and SF management. The discount rate should reflect the expected future returns from the investment strategy of the fund.

Careful considerations are needed for these parameters since underestimating the cost escalation rate and/or overestimating the discount rate could result in the amount of money collected in the fund being insufficient to cover all the long-term liabilities connected to RW and SF management. The fund contribution calculations (e.g. NPV) are extremely sensitive to these two parameter values.

List of screened references:

ID	Title	Publishing org.	Brief description	Link to internet page
IAEA1	Costing methods and Funding schemes for Radioactive waste disposal Programmes NES No. NW-T-1.25	IAEA 2020	A methodology is presented on how to estimate the cost of a disposal programme, either surface or geological, and what mechanisms can be used to fund the programme.	https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1900_Web.pdf
IAEA2	Cost Considerations and Financing Mechanisms for Disposal of Low and Intermediate Level Radioactive Waste TECDOC 1552	IAEA 2007	The objective of this report is to provide guidance to MSs concerning the financing of disposal facilities for LILW. This guidance addresses both cost estimation and financing methodologies to meet those cost requirements. While the report's main focus is on new repository planning, the information presented may also be relevant to existing repositories. This publication presents information on major cost elements, cost estimating approaches and alternative financing mechanisms for LILW disposal. As regards financing, the report identifies various schemes and discusses their relative merits depending on a number of factors. As well as addressing financing schemes for disposal of waste from fuel cycle activities, the report considers particular issues that may arise in the case of wastes from institutional sources. These wastes may be much smaller in quantity, arise from a variety of producers, or disposed of in separate facilities, therefore different management and financing may need to be considered. The primary focus of the publication is to provide guidance for all life cycle activities based on experience gained in a number of MSs during the pre-operational, operational and post-closure institutional control phases.	https://www-pub.iaea.org/MTCD/Publications/PDF/te_1552_web.pdf

ID	Title	Publishing org.	Brief description	Link to internet page
NEA1	The Economics of the Back End of the Nuclear Fuel Cycle NEA No. 7061	OECD NEA 2013	Since no comprehensive overview of the overall state of knowledge on the costs of back-end solutions across NEA countries has been made available recently, this study was included in the programme of work of the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle. The goal was to develop a more in-depth understanding of economic issues and methodologies for the management of SF and HLW from commercial power reactors. This report offers a review of general principles and frameworks, as well as available and prospective back-end options, appraising current policies and practices in different countries and focusing on the costs of the various solutions adopted. Estimates of the final costs are generally used to define and verify the status of the financial provisions required to meet such costs. Mechanisms adopted by countries for the accrual and control of these provisions, fund features and management approaches are also considered in the report, together with additional measures set out in some national systems to protect against residual risks. A quantitative analysis of economic factors is performed in the report, encompassing a comparative appraisal of existing economic models.	https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/7061-ebenfc.pdf
NEA2	Low-level radioactive waste repositories An Analysis of Costs	OECD NEA 1999	The scope of the analysis includes LLW repositories in operation or planned in NEA Member Countries. The primary focus of the study is near-surface repositories. The cost elements considered in the study are: planning and licencing costs; design and construction costs; operation costs; decommissioning and closure costs; and the costs of post-closure activities. Costs that are typically incurred outside repositories such as waste treatment, conditioning, packaging and interim storage are not included. Economic incentives related to repository siting are mentioned in some cases where available. It is intended to show effective means of managing LLW repositories and ways of reducing their costs while ensuring the highest level of safety.	https://www.oecd-nea.org/upload/docs/application/pdf/2019-12/low-level-waste-repository-costs.pdf

ID	Title	Publishing org.	Brief description	Link to internet page
NEA3	The cost of high-level waste disposal in geological repositories An analysis of factors affecting cost estimates	OECD NEA 1993	Many different estimates for the cost of radioactive waste disposal in geological repositories have been published. This study, aimed at the general reader, illustrates why the published cost estimates for the packaging and geological disposal of spent fuel or reprocessing of waste vary so widely, and examines to what extent various political, institutional, technical and economic factors could explain the variation. The study shows that despite the differences in the various systems being considered, there is surprisingly good agreement between the estimates when compared to total electricity production costs.	https://oecd-nea.org/jcms/pl_13006/cost-of-high-level-waste-disposal-in-geological-repositories-the?details=true
EU1	Methodologies of cost assessment for radioactive waste and spent fuel management. An overview of the practices adopted in the EU Ref: ENER/D2/2017-160	EC 2020	This study assesses the methodologies in use for cost assessment, the financing schemes in place and the relationship between them. It is based on the data available and the results of surveying MSs. It identifies common trends, good practices and challenges for all MSs. It then defines possible tools that can contribute to building common ground among MSs in the analysis of the cost assessment in the field of radioactive waste and spent fuel management. This includes a comprehensive structure of activities and cost items, and relevant Cost Assessment Indicators. The aim of this study is to present an in-depth qualitative and quantitative analysis of the methodologies for cost assessment and financing mechanisms in use in the EU in the management of SF and RW. The main specific objectives of this study were to identify common trends, best practices and challenges for MSs; foster knowledge sharing among MSs; and identify a set of tools that can contribute to building common ground between MSs.	https://op.europa.eu/en/publication-detail/-/publication/415a97ef-3b5f-11eb-b27b-01aa75ed71a1/language-en
EU2	Communication from the Commission to the European Parliament and the Council on the use of financial resources earmarked for the decommissioning of nuclear installations, spent fuel and radioactive waste COM (2013) 121 final	EC 2013	This document aims to present a comprehensive overview of the situation in the Ms. In particular, it looks at the advances in the alignment of the national decommissioning and waste management financing regimes with the Commission Recommendation.	https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0121:FIN:EN:PDF

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EU3	Schemes for Financing Radioactive Waste Storage and Disposal EUR 18185, Office for Official Publications of the European Communities	EC 1999	This document comprises the final report for the European Commission on "Schemes for Financing Radioactive Waste Storage and Disposal". The study focused on the application of the "polluter pays" principle to the management of RW generated both by major generators and by small generators. Information was collected on the financing of radioactive waste management from ten Member States of the European Union and from the USA and Canada, as well as from several schemes in non-nuclear sectors that comprise financial analogies with the nuclear sector.	http://www.europa.eu.int/comm/energy/en/nuclearsafety/reports.htm
EU4	Study on the risk profile of the funds allocated to finance the back-end activities of the nuclear fuel cycle in the EU; Mercer Limited;	EC 2018	Many of the expenditure items associated with the nuclear back-end arise once the nuclear facility has ceased revenue generation. This creates a need to ensure that adequate finances are available to meet these costs as and when required, usually through an advance funding arrangement during the operation of the facility. Arguably, the ability to demonstrate that these costs can be met effectively, without placing an undue financial burden on public finances or future generations, is crucial to the future of nuclear power generation. This study considers the various funding arrangements that have been set up across the EU for the purpose of meeting these back-end costs. It includes a detailed analysis of the risk profile of these funds that considers the key features of current funding and investment arrangements, as well as the risks attached to both the investments held and the future liabilities these investments are intended to meet. The study also investigates best practices as concerns prevailing funding arrangements and investment and governance approaches, and identifies key emerging trends and challenges.	https://op.europa.eu/en/publication-detail/-/publication/3a94a52a-ec36-11e9-9c4e-01aa75ed71a1/language-en
ED	Guidelines for comparing cost assessments for geological repository projects Summary of the report of the EDRAM working group International Association for Environmentally Safe Disposal of Radioactive Materials	EDRAM 2013	The objective of the working group was to compare cost assessment methods for geological repositories. The initial working programme aimed to establish a standardised list of cost items for disposal projects and related financing mechanisms and the setting up of a reciprocal peer review system for costs and provisions. The study includes selected general guidelines for the high-level comparison of cost assessments for geological repository projects.	http://www.edram.info/fileadmin/user_upload/_imported/guidelines_comparative_analysis_cost_assessments.pdf

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SW1	Plan 2016: Costs from and including 2018 for the Radioactive Residual Products from Nuclear Power, Basis for Fees and Guarantees for the Period 2018–2020, Technical Report TR-17-02	SKB 2017	The present report provides an updated compilation of the requisite costs. As in the reports submitted in previous years, estimates are reported for two scenarios, according to the planning premises for SKB's activities and according to the conditions given by legislation. This report also includes a calculation based on an operating time of 50 years, since it has been suggested by SSM in their proposal to the Government on changes in the financing legislation.	http://www.skb.com/publication/2487964/TR-17-02.pdf
SW2	Plan 2013: Costs from and including 2015 for the radioactive residual products from nuclear power, Basis for fees and guarantees for the period 2015–2017 Technical Report TR-14-16	SKB 2014	This report, which is the twenty-ninth plan report since the first edition published in 1982, provides an updated compilation of the requisite costs. As with the reports submitted in previous years, costs are reported both for the system for managing radioactive waste as a whole, including the management and disposal of radioactive operational waste and certain waste that derives from facilities other than those belonging to SKB owners, and for systems with the restrictions that follow from the regulatory framework. The report is divided into three parts. Chapters 1 and 2 provide background information on the financing system and SKB's calculation model. Chapter 3 provides information on the underlying calculation and is based on plans for reactor operation and SKB's activities. Chapter 4 concerns the cost calculations; this theme comprises the primary purpose of the report.	http://www.skb.com/publication/2478337/TR-14-16.pdf
UK1	Geological Disposal, Review of Alternative Radioactive, Waste Management Options NDA Report no. NDA/RWM/146	RWM Ltd. 2017	The review is limited to alternatives to geological disposal that have been short-listed. Two main types of alternative management options were reviewed, i.e. alternative approaches to the long-term radioactive waste management process, which could alter the nature, and/or lead to reductions in the quantity, of waste requiring geological disposal. Such options include long-term interim storage and waste treatment techniques, including thermal treatment, enhanced encapsulation and partitioning and transmutation (P&T). Alternatives to geological disposal are considered for selected waste categories, which could remove the need to manage certain components of the HAW inventory (and/or certain nuclear materials not yet declared as waste) through geological disposal. Such options include near-surface and deep borehole disposal. The cost implications are not the main focus of the study, rather they make up one of the aspects to be considered in the comparison of alternatives.	https://rwm.nda.gov.uk/publication/geological-disposal-review-of-alternative-radioactive-waste-management-options/

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US1	Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Program Costs [-20-195G	US GAO 2020	For the purposes of this Guide, a cost estimate is the summation of individual cost elements, using established methods and valid data, to estimate the future costs of a program, based on what is known today. The management of a cost estimate involves updating the estimate with actual data as they become available, revising the estimate to reflect program changes, and analyzing differences between estimated and actual costs. The methodology outlined in this Guide is a compilation of best practices that federal cost estimating organizations, the public sector, and industry use to develop and maintain reliable cost estimates throughout the life of a government program. The ability to generate reliable cost estimates is a critical function for federal agencies and is necessary to support the Office of Management and Budget's capital programming process.	https://www.gao.gov/assets/710/706933.pdf
US2	Cost estimating guide DOE G 413.3-21A	U.S. DOE 2018	The Guide is applicable to all phases of the Department's acquisition of capital asset life-cycle management activities and may be used by all DOE elements, programs and projects. When considering unique attributes, technology, and complexity, DOE personnel are advised to carefully compare alternate methods or tailored approaches against this uniform, comprehensive cost estimating guidance. Guides provide non-mandatory supplemental information and additional guidance regarding executing the Department's Policies, Orders, Notices, and regulatory standards. Guides may also provide acceptable methods for implementing these requirements. practices and procedures for implementing requirements.	https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-21A/@@images/file

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US3	Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs GAO-09-3SP, US General Accounting Office	GAO 2009	The basic information in the Cost Guide includes the purpose, scope, and schedule of a cost estimate; a technical baseline description; a work breakdown structure (WBS); ground rules and assumptions; how to collect data; estimation methodologies; software cost estimating; sensitivity and risk analysis; validating a cost estimate; documenting and briefing results; updating estimates with actual costs; The guide discusses pitfalls associated with cost estimating that can lead government agencies to accept unrealistic budget requests—as when risks are embedded in an otherwise logical approach to estimating costs. The Cost Guide discuss the importance of cost estimating and best practices associated with creating credible cost estimates. They describe how cost estimates predict, analyse, and evaluate a program's cost and schedule and serve as a critical program control planning tool.	https://www.gao.gov/assets/80/77175.pdf
CAN	Lifecycle Cost Estimate Update Summary Report APM-REP-00440-0202	NWMO 2016	The purpose of this report is to provide an updated lifecycle cost estimate and schedule for the Adaptive Phased Management (APM) deep geological repository (DGR) for used nuclear fuel. This update replaces the previous APM reference lifecycle cost that was prepared in 2011.	https://www.nwmo.ca/~/media/Site/Reports/2016/06/28/12/12/APM_REP_00440_0202_R000.ashx?la=en