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Cost Considerations and Financing Mechanisms for the Disposal of Low and Intermediate Level Radioactive Waste

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FOREWORD

Near surface disposal of low and intermediate level radioactive waste (LILW) is an option being practiced in many countries for several decades. There is a growing need in various Member States for additional information in all aspects of this disposal option, regarding both existing and planned disposal facilities. To address these needs, the Division of Nuclear Fuel Cycle and Waste Technology provides guidance in a number of technical aspects of their development, operation, and closure, and pays also attention to a broad spectrum of non-technical issues, including economical considerations.

Several types of disposal facilities have been developed up to now, intended for different waste categories, and the criteria for site selection and design have been standardized reflecting evolving safety requirements and guides. These developments have also included the establishment of adequate supporting frameworks, namely institutional, legislative and financial necessary for the implementation of the safe and sustainable long-term radioactive waste management system.

This progress has been made namely in signatory States of the Joint Convention on the Safe Management of Radioactive Waste and Spent Fuel, but a number of mostly developing Member States exist that are planning or even initiating construction of disposal facilities for LILW. The need for waste disposal has become urgent with growing accumulation of waste and disused sealed sources in these countries.

The development of a repository requires, among others, to adopt a financing system ensuring sufficient funds for its whole life cycle, i.e. over periods of many decades. This financing system should respect the national institutional and legislative environment, technical capabilities, waste origin, ownership, characteristics and inventories. When considering a wide spectrum of national specifics, this system can hardly be universally proposed. Nevertheless, countries with operating disposal facilities have experienced several approaches, which may be adopted and transferred to those countries newly establishing or revising their financing mechanisms.

The overall objective of this technical document is to provide Member States, who are currently planning or preparing new near surface repositories for LILW, guidance on cost considerations and funding mechanisms for the disposal of low and intermediate level radioactive waste. It focuses on both technical and non-technical factors affecting repository life-cycle costs. The report refrains from indicating any concrete values as they are strongly dependent on national circumstances, type and size of the disposal facility, waste categories and numbers of other factors that could be hardly traded off.

It is anticipated that this report will be of use to national planners creating financial infrastructure for long-term management of radioactive waste. Also, engineers and managers, who will be involved in the process of developing and operating near surface disposal facilities for radioactive waste, may find here relevant information.

The IAEA wishes to express its appreciation to all those who assisted to drafting and review of the report. The IAEA officers responsible for this publication were R. Dayal and L. Nachmilner of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

SUMMARY

This publication presents information on major cost elements, cost estimating approaches and alternative financing mechanisms for low and intermediate level radioactive waste disposal.

Even if the ‘polluter pays’ principle is widely accepted as a governing principle for financing radioactive waste management, the selection of suitable financing mechanisms depends on a number of aspects, such as a waste management strategy adopted in a Member State, disposal option, legislative background, institutional framework, etc. In many Member States there are typically three main types of organisations involved in radioactive waste management: (i) waste producers responsible for providing the financial resources, (ii) waste management organisation (WMO) responsible for the implementation of the final steps of waste management, and (iii) regulatory/licensing authorities who supervise the waste producers and the WMO in consistency with national legal requirements and policies.

Preparing an estimate of costs for a waste disposal facility is an important part of the planning process, usually undertaken by the WMO. The costs of a disposal facility are estimated for all the life cycle phases, including the pre-operational phase, the operational phase, the closure and post-closure phases.

Developing a cost estimate involves a number of key steps, namely: (i) forecasting waste quantities and types of wastes and defining waste acceptance criteria for disposal, (ii) establishing a base reference scenario for the cost estimate, including the timetable for the repository life cycle phases, (iii) defining the main cost categories for the disposal system, (iv) estimating the costs for each category, including contingencies to cover uncertainties; and (v) documenting the cost profile so that funding provisions and associated responsibilities can be established.

The cost of a disposal facility should be established for each life cycle phase using the relevant cost elements: some may be applied throughout more stages of the life cycle, others just for a particular phase. The cost estimate needs to consider the effect of different outcomes, including the external elements, such as: national policy requirements or changes in the legal framework; regulatory changes; environmental, economic and socio-political factors; disposal concept and plan; time schedule; etc.

The financing mechanism adopted by a Member State must be tailored to particular national circumstances; there is no ideal generally valid scheme, namely when distinguishing between countries operating and not-operating nuclear power plants. A crucial aspect in determining the requirements of financing mechanisms is the production of a baseline plan or programme, underpinned by the cost database developed through the above described approach. The programme risk assessment should also be appropriately managed by assessing the risk and sensitivities associated with each cost item. The programme plan should be revisited on a regular basis to test the assumptions, and reduce uncertainties.

Potential financing schemes, which could be applied separately or in an appropriate combination, consider the following approaches:

— ***State budget*** may be the only practicable financial resource available at the early stages of developing waste management systems and infrastructure, especially in the case where no dedicated resources for waste management exist and when the State assumes responsibility for waste liabilities, such as orphan and historic wastes. Instead of the

direct use of State budget resources, the provision of ***state guarantees*** may allow the WMO to obtain necessary financial resources through bank loans or through other financial instruments.

— In some cases, the initial capital to start waste management activities is provided by the State in the form of an ***endowment***. This is a lump-sum, one-off payment provided for a clearly specified purpose and without the need for reimbursement. Endowments can be considered to be appropriate for financing the early phases of repository development.

— ***Waste management fund*** is used to collect and invest contributions and revenues from nuclear utilities, other major waste producers, and possibly from the State Budget. In this way, money is made available for satisfying cash flow needs throughout the life cycle of the repository by financing future liabilities from existing resources. Financial risks need to be taken into consideration before establishing a fund to manage financial resources.

— ***Waste management organisation resources*** could be created if the WMO is allowed to make a profit and, as a result, accumulate a financial reserve which could be utilised to finance certain activities in the repository life cycle. Such a mechanism allows the WMO to act proactively and independently from the regulator, the waste producers and the State.

— A further possibility for WMO financing is directly to ***charge the waste producers*** for services rendered. Usually, the waste producers are charged 'once and for all' at the time of delivery or collection of waste, covering all past, present and future services associated with the management of their waste.

— ***Bank loan*** might be used when repository planning is at an advanced stage and where cost requirements are known with some degree of confidence.

— Financing through an ***advance payment*** applies mainly at the early phase of repository implementation (planning, construction, siting) or to finance larger capital investments such as the construction of the final cap for the repository at the time of closure.

— Income from ***charging for disposal services*** during disposal operations is an additional potential revenue stream generated from payments associated during the operational phase of the repository. Such an income stream may utilise a pricing system for selling repository space and may include: (i) proportional costs per unit volume related to the handling and disposal of the waste, (ii) the amortisation of prior financing commitments (the capital costs of infrastructures and other pre-operational costs), and (iii) contributions to funding the closure and post-closure phases of the repository.

The approach taken by the report is intended to be generic and to apply to all repository types with the specific exception of deep geological repositories for high level radioactive waste and spent fuel. It is further intended to be suitable for use in various Member States ranging from those that have nuclear power plants and multiple institutional low and intermediate level waste producers to those with small inventories of waste from a limited number of research, medical or other institutional applications.

1. INTRODUCTION

1.1. BACKGROUND

Low and intermediate level waste (LILW) derived from both nuclear power and from non-power applications such as medicine and research, is currently in storage in many countries that have no operating disposal facilities. In many Member States, the preferred option for the long-term management of LILW is disposal in near surface or subsurface facilities with varying levels of engineering and depth. It is now generally recognised that the practice of LILW disposal is likely to increase in the future and, given that most countries around the world produce some LILW, it is apparent that even those countries producing relatively small quantities of institutional waste need disposal facilities.

Repositories meet widely different requirements in terms of waste definition and the range of waste types accepted. Subject to the particular categorisation of waste in the Member State, some repositories accept only low level waste while others accept both low and intermediate level waste. The origin of waste varies from one country to another, ranging from waste from medical and research applications to nuclear fuel cycle activities, including nuclear power generation, decommissioning and fuel reprocessing. These and a number of other factors affect disposal costs considerably.

A unique feature of radioactive waste disposal is the timescale over which there is a need to ensure the availability of adequate funds for the proper and timely discharge of all activities. While operation of a facility may last several decades, its institutional control and post-closure monitoring extends till several centuries. Many countries have signed the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and have adopted basic financing principles aimed at avoiding burdens for future generations and ensuring that adequate funds are available for the proper discharge of all nuclear liabilities. Hence, an important consideration in the development and operation, as well as closure and institutional control of a waste disposal facility is the estimation of life cycle costs of the repository. Financial considerations play an important role in the decision-making process for a repository development project and therefore the provision of adequate cost estimates is essential.

Other important issues associated with the financial considerations for a repository development project include the various financing sources and mechanisms that are potentially available for the project. These schemes need to be identified and established before a repository development project is undertaken. Many Member States with nuclear power programmes have adopted a range of approaches to establishing financing mechanisms for repository development and to funding the decommissioning of nuclear installations. Experiences developed through the implementation of these schemes will be useful also to Member States without nuclear power programmes.

1.2. OBJECTIVE

The objective of this report is to provide guidance to Member States concerning the financing of disposal facilities for low and intermediate level waste. 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.

1.3. SCOPE

The scope of this TECDOC includes economic considerations regarding disposal of low and intermediate radioactive waste in near surface repositories, cavern-based repositories, borehole disposal and deep geologic repositories used for low and intermediate level wastes. Geological repositories designed for high level waste and/or spent nuclear fuel are outside the scope of this report. Costs incurred for waste treatment, conditioning, packaging, interim storage and transportation of waste are not addressed in this report. However, these factors may be considered by individual Member States when evaluating the full spectrum of life cycle costs, particularly if the waste management organization bears the responsibility for such activities.

The report considers the major cost elements that comprise a cost evaluation for a disposal facility for low and intermediate level wastes and identifies those factors which may result in major uncertainties in an overall cost estimate. The report differentiates between those cost elements that are largely independent of the quantity of waste for disposal (fixed costs) and those that are largely proportional to the quantity or specific type of waste (variable costs). The report considers the relative importance of the different cost elements and, taking account of the factors that govern these costs, discusses the impact on costs of different design options, including co-location with other nuclear facilities.

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 (medical, research and non-power related industry applications). 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 Member States during the pre-operational, operational and post-closure institutional control phases. The publication recognises, however, that individual Member State decisions reflect domestic policies and circumstances.

1.4. STRUCTURE

Section 2 lists the basic disposal options and summarises the legal bases and infrastructure needs for establishing an effective financing system. Section 3 includes the cost estimation methodology, considers the major cost categories and discusses factors to be considered when planning the financing mechanism. Section 4 is concerned with relevant financing schemes. The conclusions are presented in Section 5.

2. TECHNICAL OPTIONS, LEGAL FACTORS AND RESPONSIBLE ORGANIZATIONS

2.1. INTRODUCTION

The management of radioactive waste entails a range of activities including its collection, treatment, conditioning, storage, transportation and disposal in a manner that protects human health and the environment, without imposing undue burdens on future generations. This objective is reflected in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [1] ('the Joint Convention') and is also a requirement of the fundamental safety principles for waste disposal developed by the IAEA [2].

National policy in many Member States is that LILW should be disposed of by emplacement in repositories located in suitable geological environments.

The strategy for disposal of radioactive wastes in a manner that adequately protects the environment and humans, takes into account a number of aspects, such as [3, 4]:

- existence of a national policy, technical and institutional infrastructure, and legislation relevant for the safe management of radioactive waste;
- available financing schemes and financial resources;
- classification and quantification of waste according to its radiotoxicity, environmental mobility, waste form durability and longevity of its potential radiological impact;
- availability of technologies used for waste treatment and conditioning for disposal;
- availability of disposal site and its characteristics; etc.

Near-surface disposal facilities are usually built on the surface or at a depth up to several tens of metres. A variant of this concept takes advantage of rock voids (caverns) and boreholes (drilled to depths of tens of metres).

Disposal in deep geological formations is commonly envisaged for high level wastes and spent nuclear fuel which contain significant quantities of long-lived and heat generating radionuclides. However, deep geological repositories may be also employed for the disposal of LILW, an example being Morsleben in Germany. Variants of deep geological repository concept may include boreholes (drilled to depths of hundreds of metres) or caverns at similar depths. Brief descriptions of the different disposal options are presented in Section 2.2.

Member States with nuclear power programmes and/or nuclear fuel cycle activities typically manage significantly larger quantities of radioactive wastes than those with just institutional waste. As a result, disposal facilities for low and intermediate level wastes may exist and/or are currently planned in these countries. In certain cases, separate disposal arrangements are made for fuel cycle wastes and for wastes from industry, medicine and research, though the reasons for this are usually institutional rather than technical, e.g. nuclear utility companies may have developed disposal facilities solely for disposal of wastes from the nuclear fuel cycle. In other cases, waste from nuclear power plants and institutional sources are disposed of in the same facility.

A variety of financing mechanisms is employed by Member States to provide the resources required during each repository life cycle phase, including the post-closure period. In Member States with nuclear fuel cycle wastes, there may also be separate financing arrangements for disposal of fuel cycle wastes and wastes from institutional sources. This may result, in part, from the significant differences in quantities of these wastes. Also, responsibility for disposal of institutional wastes may lie directly with the State, in which case financing may be provided as needed from State budgets. In the case of nuclear fuel cycle wastes, Member States need greater assurance that funding provisions are in place during the period while income is generated from the activities that produce these wastes.

In some Member States there exist large quantities of historic wastes, where the owner may no longer exist and for which the State is now responsible, for which no (or very limited) financial provisions have been made for their long-term management. In addition, there may be orphan wastes for which the owner is unknown. Both these wastes may present particular difficulties in the context of financing their disposal, especially where the waste characteristics are not known, or the waste is not suitably packaged or the packages have deteriorated.

A fundamental component of any system for management of radioactive waste is the legislative and regulatory framework. This framework should include a clear allocation of responsibilities for different aspects of the management process, particularly the establishment of an independent regulatory authority and the implementation of a system of licensing whereby the operator of a nuclear installation is fully responsible for the safety of that installation [3]. Section 2.3 describes the main legal basis and financing principles.

Many Member States have established a national agency or waste management organisation with responsibility to ensure proper long-term management of radioactive waste. This arrangement also provides a clear separation of responsibilities between the regulatory authority, the waste producer — whose primary interest is the activity that results in production of the waste and related safety issues — and the organisation that manages the waste in the long term in accordance with national policy. Section 2.4 gives an overview of the responsibilities of the main actors in waste management.

2.2. DISPOSAL OPTIONS

This section presents an overview of disposal facilities that are now in use or planned to be used in different Member States for disposal of low and intermediate level radioactive waste. This discussion is not intended to cover all possible disposal options or the varying levels of engineering and technology involved. The choice of disposal option depends on many aspects, mainly safety related, but others such as national and international guidance, local socio-economic factors and resource availability may also apply. Consideration of these and other factors in selecting a preferred disposal option is outside the scope of this publication.

2.2.1. Trenches

Near surface disposal of wastes in trenches is generally applied to wastes that contain mainly short-lived radionuclides and, potentially, long-lived radionuclides with very low specific activity. The use of trenches may especially be cost effective when disposing of large volumes of low activity wastes and/or large items of decommissioning waste [5]. Long-term safety may be largely provided by a combination of natural site conditions, the engineered disposal system and the waste form. This option may be particularly suitable for arid regions with low rainfall and deep groundwater. Where appropriate, engineered barriers, including designs to minimise plant and animal intrusion, may also be employed. Typically, trenches are located above the groundwater level, although they may occasionally be located within the saturated zone and utilising low permeability materials. Ensuring the safety of such facilities typically requires that the post-closure institutional control period be sufficiently long that the potential risk to inadvertent intrusion is reduced to acceptable levels. The cost of this disposal option is generally lower than other approaches, though this is case specific.

2.2.2. Vaults

Vaults are a common type of near surface disposal facility employing engineered barriers. Vaults may be either above ground or below ground reinforced concrete structures, typically containing an array of storage chambers for emplacing one or more waste packages. The disposal units are normally located above the groundwater level, though vaults may be constructed within the saturated zone. Vaults typically incorporate multiple engineered barriers to limit or delay radionuclide migration from the repository, and may also incorporate drainage systems to collect and control water ingress. The disposal vaults are lined with concrete or other materials to provide a robust structure and improve isolation of wastes. Following emplacement of the waste, the space between the packages is generally backfilled with soil, clay or concrete grout. A low permeability capping system is placed over the backfilled disposal units to minimise the ingress of surface water and to prevent intrusion by plants and animals. The integrity of these covers is maintained during the institutional control period. Generally, this disposal option is more expensive than trenches and requires more pre-operational resources, but may be suitable for a broader spectrum of wastes than is the case for trench disposal.

2.2.3. Disposal facility in caverns at intermediate depth

Specially excavated cavities or disused mine caverns at depths (usually) of tens of metres are examples of this option. The primary distinguishing feature of this option compared to typical near surface concepts is that the distance below the ground surface is usually adequate to eliminate potential intrusion by plants, animals and humans [6]. The disposal caverns may be unlined or lined with concrete, and may incorporate a number of engineered barriers to limit or delay radionuclide migration from the disposal facility based on site-specific geological conditions and the waste characteristics. Such facilities may accept a broader spectrum of radioactive wastes including higher proportions of long-lived waste. These facilities are generally more secure against intrusion but may require more extensive barrier systems to prevent water ingress if located below the water table. In comparison with typical near surface disposal facilities, less reliance may be placed on institutional controls.

2.2.4. Borehole disposal facility

The borehole disposal concept entails emplacement of radioactive waste in an engineered facility of relatively narrow diameter, bored and operated directly from the surface. It aims to achieve safety by a combination of natural and engineered barriers together with institutional control. Borehole disposal facilities cover a range of design concepts with depths ranging from a few metres up to several hundred metres. Borehole diameters may vary from a few tens of centimetres up to a few metres. The borehole may have a casing and the packaged waste would typically be surrounded by backfill material. A common characteristic of borehole facilities is the small relative size of the footprint at the surface, which may reduce the likelihood of human intrusion. Even if siting a borehole facility requires the same procedures as applied to facilities, the investment and operational costs may be significantly reduced, which is a consideration when disposing of small waste volumes [7, 8].

2.2.5. Deep geological disposal facility

Deep geological disposal of radioactive waste (at depths of several hundred metres) is generally considered the most appropriate approach for high-level waste and spent nuclear fuel where it is necessary to isolate them from the biosphere for tens of thousands years. This disposal option is generally much more expensive to develop in comparison with the previously discussed options, but may require less institutional control after closure, namely, if used for low and intermediate level waste. Therefore for LILW the overall life cycle cost for deep disposal may be comparable to other disposal options. Furthermore, for some countries this is the only accepted solution due to the legislative restrictions on surface disposal of radioactive waste

2.2.6. General financial impact of disposal option choice

The disposal options presented above may have different site investigation requirements, different waste acceptance criteria, different operational and post-closure monitoring requirements, and different time periods for post closure institutional control. All these aspects impact upon waste management and disposal costs and may be further influenced by socio-political consideration in Member States.

The length of the institutional control period varies among Member States, ranging from a minimum 50 years to several hundred years. Many countries have plans to apply institutional controls after the closure of near surface disposal facilities ranging in duration from 100 to 300 years [9]. Some countries have plans to apply institutional control for 200 to 300 years after the closure even for cavern type facilities (due to the waste characteristics) while other countries may not consider active institutional control necessary for such repositories.

The length of the institutional control period may also be extended in the future according to changes in national regulations, results of continuing monitoring or safety assessment. This uncertainty is addressed in Section 3. The duration of the institutional control is not the only factor influencing post closure costs, however. Near surface, intermediate depth and deep geological disposal facilities may require different post closure maintenance needs and monitoring systems with different implementation costs.

2.3. LEGAL BASIS AND BASIC PRINCIPLES OF FINANCING SCHEMES

2.3.1. Requirements of the Joint Convention

The Joint Convention is a binding international treaty [1]. It came into force on 18 June 2001. Most Member States with nuclear power wastes are signatories to the Convention, although the process of ratification is still proceeding in many of these.

Article 3 of the Convention includes a requirement on Contracting Parties '*to aim to avoid imposing undue burdens on future generations*'. In addition, Article 22 requires Contracting Parties to take appropriate steps to ensure that:

— *'adequate financial resources are available to support the safety of facilities for spent fuel management and radioactive waste management during their operating lifetime and for decommissioning'; and*

— *'financial provision is made which will enable the appropriate institutional controls and monitoring arrangements to be continued for the period deemed necessary following the closure of a facility'.*

Article 19 (1) requires Contracting Parties to *'establish and maintain a legislative and regulatory framework to govern the safety of spent fuel and radioactive waste management'*. The legislative and regulatory framework should provide for *'a clear allocation of responsibilities of the bodies involved in the different steps of spent fuel and of radioactive waste management'* (Article 19 (2)).

Taken together, these articles establish a requirement on Contracting Parties to the Convention to ensure that sufficient funds are made available, in a way that they cannot be diverted to other uses, to cover the costs associated with long-term management of all existing radioactive wastes, including their disposal. In some Member States, particularly those with nuclear power programmes, segregated funds have been established with the aim of providing sufficient financial means to address all expected management costs of fuel cycle wastes. Additional guarantees may be required to ensure that financing is available when needed. These funds are also used for management of wastes from medical, industrial and research applications.

2.3.2. Principles governing the financing of disposal of radioactive waste

The 'polluter pays' principle is widely accepted as a governing principle for the establishment of mechanisms for financing radioactive waste management. This principle is reflected in the environmental protection legislation of many Member States, as well as in international agreements, such as the European Community Treaty [10]. In this case the principle is included in Article 174 (2):

'Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of then Community. It shall be based on the precautionary principle and on the principles that preventative action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay.'

The establishment of financing schemes should normally also aim to achieve the following objectives [11]:

— to ensure the long-term adequacy of funds,

— to allocate the costs fairly; and

— to optimise value for money.

These objectives may not to be mutually achievable, e.g. a special levy on the price of electricity produced from nuclear power plants may help to ensure the long-term adequacy of funds for managing nuclear fuel cycle wastes, but may not mean that waste producers pay the costs exactly in proportion to their specific waste producing activity.

The type of financing scheme used will influence the behaviour of waste producers through the price signals it creates. It is a requirement of the Joint Convention that

Contracting Parties should take appropriate steps *'to ensure that the generation of radioactive waste is kept to the minimum practicable'* (Article 11). Financing schemes that incorporate charging mechanisms that are related to the volume of waste produced are likely therefore to result in smaller volumes of waste being produced. Financing schemes are explored further in Chapter 4 of this report.

Special provisions may need to be made for wastes whose ownership is unknown (orphan wastes) or where the owner no longer exists (historic wastes). Where such wastes are present, the financial responsibility for their management falls to the government of the Member State, though it may make arrangements for the waste management organisation ('WMO') to deal with them.

2.4. RESPONSIBLE ORGANIZATIONS

In many Member States there are typically three main types of organisation involved in radioactive waste management [8]:

— the waste producers (e.g. nuclear power plant, institutional waste producer, others);

— the regulatory / licensing authorities;

— the waste management organisation which may be State owned, utility owned or a private company.

This institutional arrangement is often referred to as the 'classical triangle'. Generally, the three organisations have different assignments and are independent. In some cases there are strong organisational linkages between them, such as where the WMO is owned by the waste producer. The roles and responsibilities of each are briefly described below.

2.4.1. Waste producers

The use of radioactive material in nuclear power production, other industry, medical applications, research and other areas produces radioactive waste which requires safe long-term management. Any organisation which owns radioactive materials which no longer have a use is considered to be a waste producer. The responsibility of the waste producers is to provide the financial resources necessary for the safe long-term management of the waste they generate under the 'polluter pays' principle. In cases of unknown waste ownership, or where the owner no longer exists, this responsibility falls to the State.

2.4.2. Regulatory body

In most Member States one or more Regulatory Bodies supervise the waste producers and WMO consistent with their legal requirements and policies. According to the definition in the IAEA Glossary the Regulatory Body is defined as follows: '*A regulatory body is an authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorisations and thereby for regulating the siting, design, construction, commissioning, operation, closure, decommissioning and, if required, subsequent institutional control of the nuclear facilities (e.g. near surface facilities) or specific aspects thereof. This authority could be a body (existing or to be established) in the field of nuclear related health and safety, mining safety or environmental protection vested and empowered with such legal authority*' [12].

2.4.3. Waste management organisation

Many Member States have founded a national WMO or entrusted this function to an existing institution. Some are government owned and others are owned by the major waste producers. In some countries, for example the USA, private companies have been established and operate on a commercial basis. The range of tasks undertaken by WMOs varies between Member States. In most cases the WMO is responsible for the development of disposal facilities - where these are envisaged - including research and development, siting, construction, operation, repository closure and post-closure monitoring. In some Member States, a national WMO may also have broader pre-disposal management responsibilities, particularly for institutional wastes. This may include providing facilities for treatment, conditioning, storage and transportation. Examples also exist where the WMO is responsible for the decommissioning of nuclear facilities.

It is normally also the responsibility of national WMOs to develop cost estimates for the long-term management of radioactive wastes, including the costs associated with each life cycle phase of the repository. These estimates provide the basis for determining appropriate financing mechanisms, as discussed in Chapter 4. In some Member States the WMO is also responsible for administration of the funds collected, with appropriate oversight arrangements.

Responsibility for long-term waste management in Member States with radioactive wastes resulting only from medical and research applications is generally undertaken directly by an agency within a government department, such as a national research centre for atomic energy. In some Member States the safe management of orphan or historic waste is entrusted to the WMO.

Table I shows the WMOs for some Member states, their legal status and responsibility for the waste, and the types of funding mechanism in place.

TABLE I. NATIONAL ARRANGEMENTS FOR LOW LEVEL WASTE MANAGEMENT

Country	Institution Responsible for Radioactive Waste Management	Type	Type of Funding Provision	Waste Ownership*	Disposal Options
Argentina	CNEA	Gov	Segregated fund	State	Near surface
Australia	DEST (Commonwealth waste)	Gov	State Budget, fees	State	Near surface
Austria	Nuclear Engineering Seibersdorf	Gov	State Budget, fees	State	Not decided
Belgium	NIRAS/ONDRAF	Gov	Segregated Fund	WMO	Near surface
Bulgaria	SE RAW – NPP waste	Gov	Segregated fund RAW	State	Not decided
	INRNE – institutional waste	Gov	Governmental provisions	State	Near surface
Canada	LLRWMO - AECL	Gov	Fees	Producer	Deep geological
Czech Republic	RAWRA	Gov	Segregated Fund	State	Near surface, near surface caverns
Denmark	Riso Research Centre	Gov	Commercial contracts	State	Not decided yet
Finland	POSIVA Oy	Ind	Segregated Fund	State	Near surface caverns
France	ANDRA	Gov	Contracts ANDRA/producers	WMO	Near surface
Germany	BfS (DBE – contracted operator)	Gov	Advanced payment ordinance	State (after closure)	Deep geological
Hungary	PURAM	Gov	Segregated Fund	WMO	Near surface, near surface cavern
India	NPP's, BARC	Ind	Financial provisions	Producer	Near surface
I. R. of Iran	AEOI – WMD	Gov	Budget, fees	State	Near surface

Country	**Institution Responsible for Radioactive Waste Management**	**Type**	**Type of Funding Provision**	**Waste Ownership***	**Disposal Options**
Japan	JNFL (NPP LILW)	Ind	Financial provisions)	Producer	Near surface, near surface cavern
Lithuania	RATA	Gov	Segregated Fund,	WMO	Near surface
Netherlands	COVRA	Gov	Segregated Fund	WMO	Not decided yet
Norway	IFE Kjeller	Gov	Financial provisions	State	Near surface cavern
Poland	RWMP Swierk	Gov	Financial Provisions	WMO	Near surface
Romania	ANDRAD	Gov	Financial Provisions	WMO	Near surface
Russia	RADON (institutional waste only)	Gov	Financial Provisions	State	Near surface
Slovakia	VYZ	Ind	Segregated Fund	WMO	Near surface
Slovenia	ARAO	Gov	Segregated Fund	State	Near surface
South Korea	KHNP	Ind	Segregated Fund	Producer	Near surface/ near surface cavern
Spain	ENRESA	Ind	Segregated Fund	WMO	Near surface
Sweden	SKB	Ind	Segregated Fund	WMO	Near surface cavern – short lived
Switzerland	NAGRA	Ind	Segregated Fund	WMO	Not decided yet
United Kingdom	Nuclear Decommissioning Authority	Gov	Financial Provisions	WMO	Near surface
United States of America	Multiple private companies Federal Government facilities	Priv Gov	Segregated Funds Budget	State Government Federal Government	Near surface Near surface

Organisation type: Gov – owned by the government; Ind – owned by utilities; Priv – private commercial company; WMO –waste management organisation

3. COST ESTIMATION

3.1. INTRODUCTION

Preparing an estimate of costs for a waste disposal facility is an important part of the planning process, particularly in view of the long duration of such projects in comparison to most conventional projects. The estimation is usually undertaken by the WMO and provides input to:

- policy makers and regulators who need to be satisfied that adequate funds are in place when needed;
- waste producers, who will need to make provision for payment of the costs; and
- the WMO itself which may need to take this into account when planning its future programme, e.g. in deciding the feasibility of a specific project proposal and to know which design aspects will have significant cost impacts.

This chapter provides a general description of how the costs of a planned waste disposal facility may be estimated. The main cost categories are discussed in the context of different project phases. Finally, some key factors that may affect the cost estimate, and therefore result in uncertainty about future costs, are described and some illustrative examples are given.

The chapter does not seek to present a recommended method for cost estimation; rather it describes different approaches that may be useful for planners, depending on specific circumstances.

The life cycle of a disposal facility may be divided into phases, i.e. pre-operational phase, operational phase, closure and post-closure phase, as shown in Figure 1. The costs of a disposal facility are estimated for all the life cycle phases. Closure is typically regarded as part of the operational phase, but for the purposes of this publication they have been treated separately.

(1) Pre-operational phase

This includes:

- site screening and evaluation, including all costs associated with the siting programme;
- design and construction, including detailed design work and construction of the disposal facility and related infrastructure on- and off-site (e.g. roads, service buildings and drainage systems, visitor and public information facilities);
- licensing, including safety assessment and environmental impact assessment required by the regulatory and planning authorities;
- research and development activity necessary to permit the definition of a repository concept; and
- environmental monitoring to set baseline conditions.

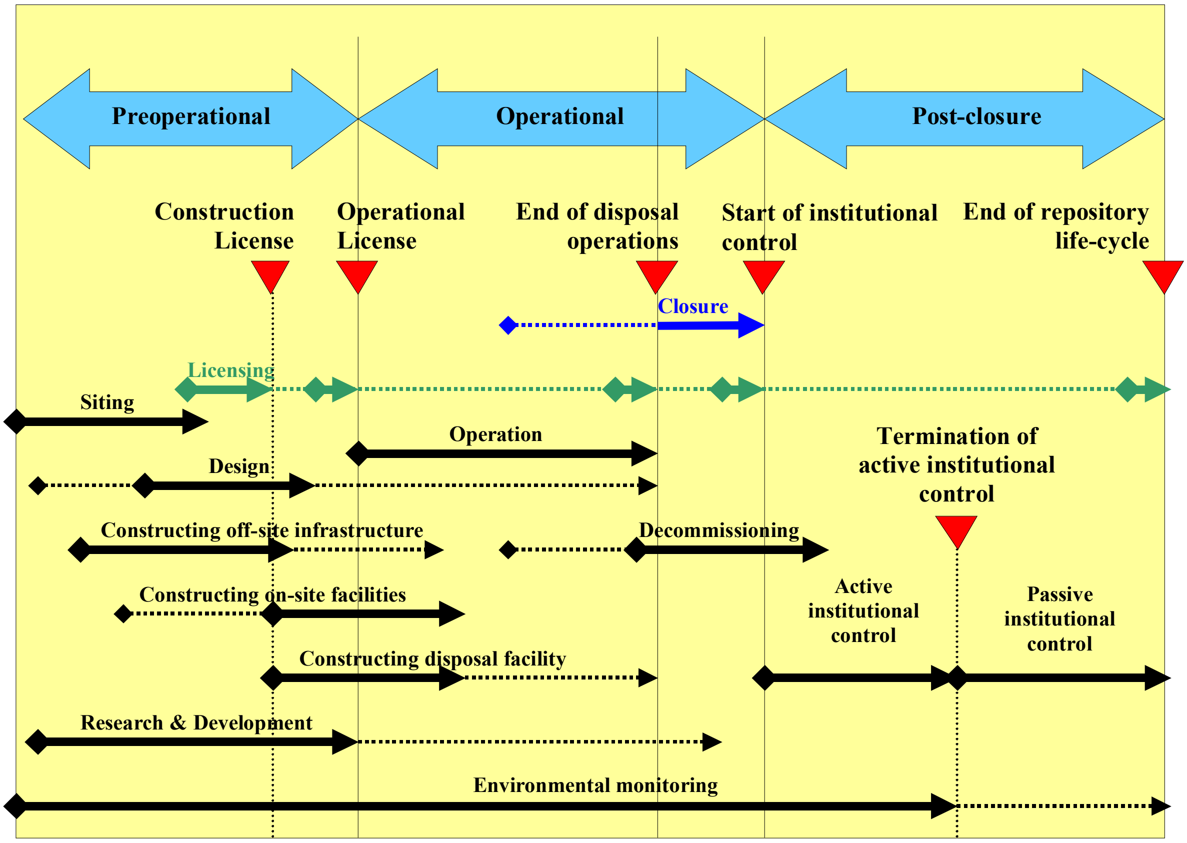

FIG. 1. Life cycle of a disposal facility.

(2) Operational phase

This includes:

— physical handling of the waste packages and their emplacement in the disposal areas on an ongoing basis;

— backfilling between emplaced containers;

— vault closure including provision of interim caps including any necessary R&D;

— environmental and repository monitoring;

— construction, if repository is developed in phases.

(3) Closure

This includes:

— safety and other assessments to permit regulatory approval to commence closure;

— emplacement of a final cap to provide long-term protection of the waste (near surface facilities); this may start in the operational phase if the repository is developed in phases;

— establishment of drainage systems (near surface facilities) if required;

— decommissioning and removal of redundant operational facilities; this may start in the operational phase if the repository is developed in phases;
— environmental and repository monitoring to provide a basis for future assessment of repository conditions; and
— provision for site maintenance and security.

(4) Post-closure phase

This includes:

— environmental and repository monitoring;
— site surveillance, maintenance and security; and
— ongoing maintenance of capping system (near surface facility).

3.2. METHODOLOGY FOR ESTIMATING COSTS

The cost estimate for developing a waste disposal facility is necessarily based on a variety of technical and socio-political assumptions. The government of each Member State establishes the national strategy for management of all categories of waste. This provides the initial assumptions needed to be able to decide on the type of facility for that category of waste.

Developing a cost estimate involves a number of key steps:

— forecasting waste quantities and types of wastes;
— defining waste acceptance criteria for disposal;
— establishing a base programme (or reference scenario) for the purposes of the cost estimate, including the timetable for the repository life cycle phases;
— defining the main cost categories for the disposal system;
— establishing the costs for each category, including contingencies to cover uncertainties; and
— documenting the cost profile, in sufficient detail that funding provisions and associated responsibilities can be established.

The cost estimate provides the basic information required by planners in order to determine the funding requirements. It will need to be updated on a regular basis, depending on the needs of the project, e.g. each 3-5 years.

3.2.1. Waste inventory

The forecast of wastes for disposal will typically include the source of the waste (e.g. nuclear power plant - NPP) operational wastes, waste from research applications); chemical, physical and radionuclide characteristics; the waste package type; dimensions of any abnormal packages; volumes of conditioned waste and timing of package delivery to disposal facility. It should include an estimate of future waste arisings as well as those already in existence. Such information should be consistent with data in the national waste inventory database if such an inventory exists.

3.2.2. Reference scenario

The reference scenario for the cost calculation comprises the conceptual repository design and the duration and timing of each of the main project phases. It also includes the assumed annual throughput of wastes. The cost elements of these phases are discussed in detail in Section 3.3.

Typical information required will include the planned extent of any research and development programmes, extent of planned siting investigations, conceptual safety and environmental impact studies, conceptual design information in the form of layouts and specifications for each major facility above and/or below ground, expected subsurface conditions and assumptions about site infrastructure. It should also include information about requirements for services such as water supply, electricity supply, and effluent control.

3.2.3. Cost categories

The main cost categories applicable to a waste disposal project are discussed in Section 3.3 taking account of the main phases of the project. Costs may be generally categorised as either fixed or variable. Fixed costs are those that will apply to the repository project and are not dependent on the type or amount of waste disposed. Examples include pre-operational safety assessment and licensing costs, initial repository construction, and environmental monitoring. Variable costs are more dependent on the quantity and types of waste received. These categories are not mutually exclusive, however. For example, while labour costs may be largely fixed, some increase in employment levels may be required if waste receipts increase significantly. Other cost elements, for example local community benefit expenses, may be fixed or variable depending on individual Member State policy.

3.2.4. Calculation of base cost and contingencies

The detailed cost assessment may involve the development of functional descriptions of the facility, resulting in layout drawings, equipment lists, and labour force needs. The base cost for each cost item may include quantity-related costs, non-quantity related costs, and other costs such as costs for administration, design, procurement and inspection as well as temporary facilities. Quantity-related costs may be calculated directly from drawings and specifications, with knowledge of unit prices. Since all cost-relevant details will not be shown on the drawings, non-quantity related costs may be calculated from experience with other similar projects.

The estimated cost can be based on either:

— best estimate values for individual cost items, using a deterministic calculation, with a contingency amount to cover uncertainty in that estimate, or

— a range of values incorporating ‘low’, ‘high’ and ‘most likely’ estimates which are then combined together using probabilistic approaches (e.g. Monte Carlo simulations) to give a distribution function, from which the total cost corresponding to various confidence levels can be determined. The most likely costs are calculated on the basis of the reference scenario by means of a deterministic calculation but without allowances for variations and uncertainties.

The method of cost estimation used should be determined on a case-by-case basis, with the first method tending to less time-consuming, but perhaps leading to a more conservative result. This method is widely used for project cost estimation and may often provide sufficient information for the purposes of determining funding requirements. Contingencies are determined mainly on the basis of experience with similar types of projects.

The second method requires a higher input of specialist resources (e.g. specialist analysis groups are used to decide cost ranges for cost components and perhaps for alternative scenarios), allowing some benefit to be taken from a more detailed analysis of uncertainties in costs of individual cost items. The method provides indications of where the major uncertainties are. They can then be broken down and studied in greater detail, after which the calculation is repeated, leading to reduced uncertainties.

Section 3.4 discusses factors which may give rise to uncertainties in the overall cost estimate.

3.2.5. Documentation of the cost estimate

Typically, the cost estimate is presented in the form of a cost distribution over time, with total costs being sub-divided according to the year and to the main cost categories, as shown schematically in Figures 2 and 3. In practice the duration of the phases will vary widely from those indicated. For example, the operational phase may extend to 50 years or more, and the post-closure period for several hundred.

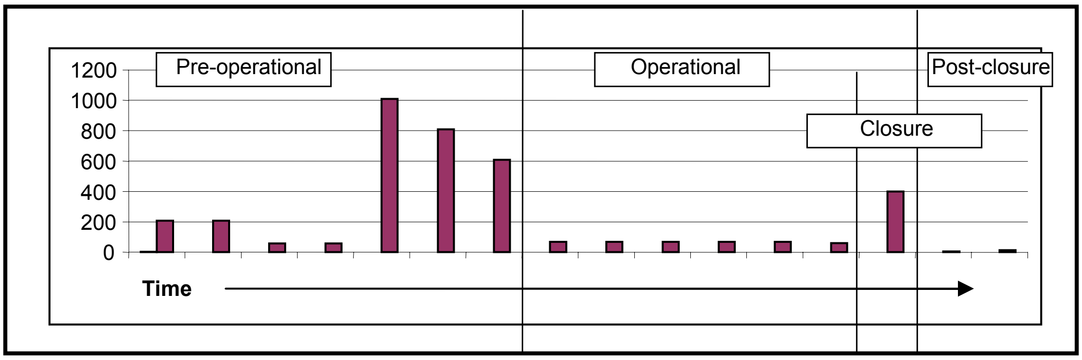

FIG. 2. Illustrative cost profile (total cost).

Cost Categories	Time →														
1	8	8	8	8	8	8	8		8	8	8	8				8
2	200	200														
3			50	40	400											
4					600	800	600									
5								6	60	60	60	60	40			
6																
7														400		
8															5	
9				10									10			5
	208	208	58	58	1008	808	608	6	68	68	68	68	50	400	5	13

FIG. 3. Illustrative cost profile (by main cost category).

For a given cost estimate, all costs should be provided for the current price level. The cost estimate will need to be recalculated on a regular basis, depending on the requirements of the local situation. The level of detailed information presented will vary according to the particular case and the needs of those responsible for financing.

3.3. FUNDAMENTAL COST CATEGORIES IN THE LIFE CYCLE OF A LILW DISPOSAL FACILITY

The cost of a disposal facility should be estimated for the entire life cycle of the facility from the pre-operational phase through the post-closure phase. Some major cost elements may be regarded as generic, applicable more-or less throughout many phases of the life cycle, or there may be special considerations that need to apply for a particular phase. Cost elements for each disposal phase are summarised in Table II and further discussed below.

Generic cost categories would include:

— research and development will be needed to support the development and verification of the design and the safety case for the facility.
— a particular consideration on resourcing at any phase of the life cycle is the degree to which sub-contracting is used by the WMO. It is evident that some aspects, such as construction would be outsourced, but research and development may be wholly or partly in-house.
— personnel costs, which will be dependant on the organisational structure for the particular phase and sub-phase under consideration, including administration, site selection, all R&D, construction, operation, maintenance, monitoring and QA/QC.
— cost of equipment would include initial and replacement plant and apparatus.
— material costs would cover building, backfill and capping items.
— overhead costs may cover project management, training/qualification of personnel, consultants and expert activities, travel expenses, consumable goods, utilities. This would also cover data management and preservation of knowledge about the waste which will be important throughout the life of the repository.
— social costs include community benefits which may be offered in the form of direct payments, job allocation, infrastructure development, support of local activities. The level of benefits may be dependent on the phase in question. Expenditures for public information may also be covered in this category and include use of local media, editing newsletters, organising site visits, operation of information centre.
— miscellaneous cost items may include taxation (e.g. property tax, corporation tax, local tax), insurance (facilities and properties) and interest. If no fund system is available, and a loan is used to cover the costs, interest charges will arise.
— regulatory bodies may require payment for their activities. This is likely to be most costly during the licensing process, but annual costs may arise subsequently which should be taken into account.

TABLE II. EXAMPLE OF REPOSITORY COST CATEGORIES FOR DIFFERENT LIFECYCLE PHASES

PHASE	COST CATEGORIES								
	R&D	**Sub-contracting**	**Personnel**	**Equipment**	**Material**	**Overhead**	**Social Costs**	**Miscellaneous**	**Regulatory Costs**
Pre-operational							X	X	
Project planning			X			X			
Siting	X	X	X	X		X			X
Licensing	X		X			X			
Facility design	X	X	X			X			
Construction		X	X	X	X	X			
Operational							X	X	
Licensing	X		X			X			X
Operation	X	X	X	X	X	X			
Construction		X	X	X	X	X			
Closure							X	X	
Licensing			X			X			X
Operation	X	X	X	X	X	X			
Decommissioning	X	X	X	X	X	X			
Post-Closure							X	X	X
Active institutional control		X	X	X		X			
Passive institutional control			X			X			

(1) Pre-operational phase

— The siting programme includes selection of potential locations from pre-existing geological and topographical data followed by detailed site-specific investigations. The land for the disposal facility may need to be purchased by the operator.

— Research and development would involve those activities necessary to permit the development of a disposal facility conceptual design and ultimately the detailed engineering design.

— A license would be needed for commencement of construction. Costs identified here would include those incurred by the developer for the production of licensing and building permit documents such as an environmental impact assessment and the safety case, and costs for associated public hearings. Costs may also be charged by the regulatory bodies in connection with the licensing process.

— Construction cost is dependent on the type of the disposal facility and engineered barriers being adopted in the facility. Cost items include site preparation, roads, boundary fence, construction camp, initial disposal units, waste processing building, laboratories, interim storage facilities, container fabrication plant, administration and security buildings, utility connections (water, electricity, etc.), and potential visitors' centre, recreation facilities. Some offsite construction may also be needed such as improvements to local road and rail transport.

— Base line environmental radiation and radioactivity monitoring is also an important part of this phase.

(2) Operational phase

— Before accepting wastes into the disposal facility, a license application for starting operation of the facility is submitted to the regulatory bodies in accordance with the legal framework of the Member State. Periodic renewal of the operating license with submission of a revised safety case may further be required.

— Operational activities typically include waste reception, unloading, acceptance inspection, emplacement and backfilling. In some cases, the facility is divided into modules and after one is filled, the module may be backfilled and closed, including the provision of an interim cap, where appropriate. Additional cost elements include security-related activities, environmental monitoring of the site, maintenance, modifications and replacements, data management.

— As modules are filled, additional ones are constructed as required. These may require further licensing approval.

— Ongoing research and development may be required by the regulator in order to confirm site characteristics, or the operator may develop new technologies with the aim of improving safety and / or optimising operational costs.

(3) Closure [13]

— After emplacement of all of the waste, the facility is backfilled and provided with a final cap to provide long-term safety in the case of a near surface repository. For cavern-type or geological facilities, sealing of the tunnels or shafts would be undertaken. After final closure and sealing/capping, redundant operational facilities are decommissioned and removed. These activities may be initiated in the operational phase if a modular approach to repository construction is used. Operational costs during this phase include also security-related activities and monitoring.

— Final closure of the disposal facility generally requires further regulatory approval which may require preparation and submission of a safety case and environmental impact assessment.

(4) Post–closure phase [14]

— Post-closure activity costs are initially associated with active institutional control such as ongoing monitoring and surveillance, and security and maintenance of the site. In addition, site records will need to be prepared for archiving, possibly with the Member State's national archive and/or some international institution.
— Passive institutional control costs would be minimal but may include land use control.
— Procedures for termination of the license will need to be followed in accordance with the legal framework.

3.4. FACTORS TO BE CONSIDERED IN ASSESSMENT OF SENSITIVITY IN THE COST ESTIMATE

The reference scenario for the cost estimate is necessarily based on assumptions that may not correspond to the actual outcome. The cost estimate needs to consider the effect of different outcomes, and therefore key assumptions are tested against other scenarios or cost elements. These elements may be external to the project, and therefore may be uncontrollable, or project related over which the waste management organisation may be able to exercise some level of control.

These cost elements are discussed below, in relation to national policy, regulatory and economic framework, the reference disposal concept, project specific considerations, and political and social factors.

3.4.1. National policy and legal framework

3.4.1.1. National policy and legal framework

Future national policy requirements or changes in the legal framework may increase the disposal cost through the imposition of additional requirements on disposal facilities, such as building in requirements for monitoring and retrievability, and extending the period institutional control. A lack of a suitable waste management organisational infrastructure in the Member State would require costs to enable its establishment.

3.4.1.2. Regulatory change

The evolution of international recommendations and national regulation which results in changes in safety criteria or in more stringent waste acceptance criteria, for example, may result in additional expense to upgrade the facilities.

3.4.1.3. Environmental factors

The results of an environmental impact assessment may require measures to be taken to mitigate for adverse impacts which may arise for a particular type of facility at a particular site.

3.4.1.4. Economic factors [15]

Material and labour costs may be higher or lower than anticipated due to variations in productivity levels compared to initial assumptions, or the necessity to source materials or personnel from outside the Member State. If the repository is financed by a waste management fund, the investment performance of that fund may be below expectation; this is discussed further in Chapter 4.

3.4.1.5. Socio-political factors

Planning-related costs, including any community benefits that may be paid to the local municipality, including local taxes or fees may be higher than originally anticipated.

3.4.2. Disposal concept and plan

3.4.2.1. Time schedule

Schedule delays may increase the repository life cycle costs, for example by increasing administrative expenses, labour costs and waste storage costs. These delays may result, for example, if the licensing process takes several years longer than planned. When planning the disposal programme, the duration of the operational phase should be estimated based on the total waste volume prediction including timing of delivery to the facility.

3.4.2.2. Co-location with other nuclear facilities

If a disposal facility is co-located with another nuclear facility such as a nuclear power plant, the existing infrastructure and some services may be shared. For the same reason, co-disposal of nuclear power and institutional waste in a shared facility may bring significant cost savings.

3.4.2.3. Regional disposal facility [16]

If several countries decide to construct and operate a common disposal facility, the scale effect may result in significant infrastructure cost reductions. However, this benefit may be negated by increased transportation costs and costs associated with negative public perception [11].

3.4.2.4. Monitoring and retrievability

Monitoring and retrievability may be a requirement of the Member States. Depending on whether this applies during the operational phase or subsequent phases there may be significant cost increases.

3.4.2.5. Security

Repository security costs are a consideration during all phases of the repository life cycle. A higher level of security for a disposal facility for higher active wastes such as disused radioactive sources may be more of an issue and thus incur greater costs.

3.4.3. Project specific considerations

3.4.3.1. Waste volume

If the volume of arisings is much less than anticipated, then this will have an impact on the forecast income stream for the facility, leading to higher costs per unit (volume or activity) disposed.

3.4.3.2. Waste characteristics

The waste characteristics, especially the content of long-lived radionuclides, may limit the selection of options of disposal systems and thereby influence the total disposal cost.

3.4.3.3. Waste package requirements

Standardization of waste packages may impact favourably on the operational costs.

3.4.3.4. Technology to be applied

Cost estimation usefully includes contingency cost according to the status of the technologies to be utilised at the disposal facility. When the technology is well proven, the contingency will be also small. When the technology is not proven the contingency may be very large.

3.4.3.5. Site conditions

The design of a disposal facility strongly depends on the site-specific conditions such as geomechanical and hydrogeological characteristics which may vary significantly from initial assumptions. Access to infrastructures (e.g. transport routes) influences construction costs.

3.4.3.6. Availability of key personnel and materials

Difficulty in recruiting personnel with appropriate competencies may have implications for the rate of progress of the project. Large amounts of engineering materials with specific qualities, e.g. for backfilling, may need to be transported over large distances if not available locally.

4. FINANCING MECHANISMS

4.1. INTRODUCTION

Chapter 3 identified the cost elements associated with repository development. It indicated four main phases: pre-operational, operational, closure and post-closure. This Chapter considers how each of these phases and their major cost elements could be financed. The main objective in deriving an appropriate financing scheme for a particular facility is to ensure that the money is available as and when required throughout the life cycle of the facility, that costs are allocated fairly and that value-for-money is optimised.

A study on radioactive waste management financing schemes in industrialised Member States, published in 1999 by the European Union [11], concluded that there was no ideal scheme, and therefore extreme caution should be exercised in attempting to transpose a model from one country to another. A particular scheme or mechanism adopted must be tailored to particular circumstances. Thus, this Chapter does not attempt to recommend an ideal system, but rather to present the attributes of a number of mechanisms which could be used.

A crucial aspect in determining the requirements of financing mechanisms is the production of a baseline plan or programme, underpinned by the cost database developed through the methodology of Chapter 3. This includes the estimation of when the waste will be delivered to the facility and in what quantities, as this will be a consideration for deriving the income stream in the operational phase. It will be necessary to produce an overall programme risk assessment cost that can be appropriately managed, by assessing the risk and sensitivities associated with each cost item, as discussed in Chapter 3. The programme plan would be revisited on a regular basis to test the assumptions, and reduce uncertainties.

This Chapter pays specific attention to the requirements of the Waste Management Organisation (or other implementing organisation for the repository project) which generally has the task of producing the programme plan, monitoring it as time goes on, and spending the money from whichever source(s) of funding is made available. This plan may be subject to regulatory approval or other oversight mechanisms established by the Member State.

Two base-cases are addressed. The first is for the case where the Member State in question has an existing civil nuclear power programme that is a major radioactive waste producer. The second case is for the Member State which only has to manage institutional radioactive waste. In the first case, it is possible that a facility is already planned or already exists to serve the requirements of the NPP and that could be made available to institutional waste producers also. In these States, a separate institutional waste disposal facility may also be developed. The second base case is also relevant to that situation.

Two subset cases may be envisioned: where the repository already exists and is in operation, or where the facility is planned to exist at some time in the future. There are, of course, possible combinations of these base cases. However, it is felt that the main elements presented here can be adopted as appropriate to individual Member State circumstances.

In the case of non-NPP Member States (or even in the case of NPP Member States) it may be necessary to make provision for centralised waste treatment, conditioning and storage facilities as well as repository services. Similar financing approaches to those described here may also be used as appropriate.

Section 2 of this chapter identifies individual financing mechanisms which may be appropriate for a particular phase or element of repository development. Section 3 describes these mechanisms in more detail. The fundamental assumption which underpins the approach is that the ‘polluter pays’ principle should apply wherever possible, although it is recognised that this may not always be practical or fully adopted as national policy. It further discusses the attributes of the mechanism and compares them against several criteria discussed in [11]; being that financing mechanisms should be:

- financeable – they should ensure that sufficient money is available when it is needed and that an undue burden is not transferred to future generations;
- fair – they should ensure that waste producers pay in proportion to the contribution which their wastes make to costs.
- understandable – it should be as straightforward as possible for all stakeholders to understand and agree the basis on which charges are determined; and

— efficient – they should ensure that unit costs are minimised by giving appropriate economic signals, e.g. for better control of waste streams, reduction of high cost drivers.

4.2. FINANCING MECHANISMS FOR THE PHASES OF REPOSITORY DEVELOPMENT

Table III shows possible financing mechanisms for each major sub-phase of repository development as described in Chapter 3 and distinguishing between countries operating and non-operating nuclear power plants. Note that where a repository is already in existence and new schemes are introduced, then obviously the pre-operational phase will not apply.

4.3. DESCRIPTION OF FINANCING MECHANISMS

4.3.1. State budget and state guarantees

4.3.1.1. State budget

The State budget may be the only practicable financial resource available at the early stages of developing waste management systems and infrastructure, especially in the case where no dedicated resources for waste management exist. Such a situation may emerge in non-NPP Member States with only institutional waste production as well as in nuclear Member States with non-existing disposal facilities and no financing schemes for waste management. In non-NPP Member States with only small waste producers and no provisions for waste management, resources from the State budget may be the only means to initiate a disposal programme and provide a disposal solution. Further, the State Budget may be the only means of financing the management of orphan and historic wastes, or other cases where the State assumes responsibility for waste liabilities.

In Member States that operate NPPs but have no existing disposal facility nor have yet established financing mechanisms for long-term waste management, the State budget may also be the only feasible source of finance for the planning stage of a disposal facility. Financing from the State budget may also be necessary in Member States that phased out nuclear energy without providing financial resources for nuclear waste liabilities, or in Member States with NPPs and having an existing repository, if this facility is intended solely for the waste generated in nuclear power production. In such a case, State financing may be required in the pre-operational phase of an institutional waste facility. In non-NPP Member States with only non-power waste the need for State budget financing may be even greater since small producers may not be able to bear the full cost of implementation. In these circumstances, the full cost of the pre-operational phase, including repository planning, site selection and characterisation as well as repository construction may need to be financed by the State budget.

TABLE III. FINANCING SOURCES AND MECHANISMS

Phase	Sub-Phase	Nuclear Power Plant Base Case	Non-Nuclear Power Plant Base Case
Pre-operational	Project planning and design	State budget State guarantee Advance payments from waste producers Endowment WMO resources Waste management fund	State budget State guarantee Waste producers Endowment
	Siting and licensing	As above, plus: Loan	
	Construction		
Operational	All sub-phases	Fund WMO Resources Income from charging for services	Income from charging for services (may be State subsidised)
Closure	All sub-phases	Fund WMO Resources Waste producers	Fund Provisions State Budget
Post closure	Active institutional control		

State budget financing is sometimes required also in the repository operational phase, especially in non-NPP Member States. If the quantity of waste is small and the number of small producers limited, it may be difficult for them to cover the full disposal cost. Such small producers may realistically be able to fund the marginal costs associated with the wastes delivered by them for disposal. In such a case most operational fixed costs, such as labour costs, costs of regulation and control, facility maintenance is subsidised from the State budget. State budget financing may also be the only feasible resource for covering the cost of disposal of historic waste or other legacy waste for which there is no identified owner.

In the post-closure phase State budget financing may sometimes be required to meet other nuclear liabilities, such as remedial activities and post-closure monitoring if these are not covered by other means.

Where State budget financing is used for some specified waste management activities, it is important that responsibilities for implementation of these tasks are clearly specified. In such a way the provided financial resources can be used efficiently and for dedicated purpose, and transparency and financeability can best be achieved.

State budget financing may be utilised for solving waste management problems when there are no other funds available or when waste production is very small (as for institutional waste). However, there are also drawbacks. The budget may be subject to annual approvals or appropriations but due to national policy or economic factors, such a financing scheme can be vulnerable and there is no guarantee of continuous financing at the required levels.

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 material in non-power applications, including health, industrial safety and research applications.

4.3.1.2. State guarantees

Instead of the direct use of State budget resources, the provision of State guarantees may allow the WMO to obtain financial resources through bank loans or through other financial instruments. These are generally more applicable in the early stages of repository implementation (e.g. in pre-operational stage) but they may also be used for particular activities in later stages. Their use may also be convenient when the WMO does not have sufficient commitments from the waste producers to provide its own security for a bank loan. It may also be advantageous for the State budget since it does not directly drain State resources. From the WMO's point of view, the main disadvantage is the fact that the state guarantee might not be given at the time it is needed or at the level required. However, it is an understandable and efficient mechanism.

4.3.2. Endowments

In some cases, the initial capital to start waste management activities by the WMO or other body, is provided by the State in the form of an endowment. This is a lump-sum, one-off payment provided for a clearly specified purpose and without the need for reimbursement.

Endowments can be considered to be appropriate for financing the early phases of repository development, particularly the pre-operational stage. It is more applicable to non-

NPP Member States as well as to nuclear States lacking other financial mechanisms for waste management.

In nuclear States without adequate financial provision for waste management, endowments can be used for the creation of the WMO or for the preparation of the waste management programme. In Member States with only institutional radioactive waste this financing mechanism may be particularly appropriate for providing the resources for developing a waste management infrastructure.

Initial endowments may also be provided by the Government, waste producers or others to help establish a waste management (or reactor decommissioning) fund in the case where a repository is already in its operational phase and is not generating enough income from waste suppliers to finance the closure and post-closure phases. A similar situation would arise for a reactor decommissioning fund which is started part way through the reactor operation, but for which not enough lifetime is left to generate a sufficient fund through a tariff on electricity sales.

4.3.3. Waste management fund

4.3.3.1. General

The basic function of a fund is to collect and invest contributions and revenues from nuclear utilities, other major waste producers, and possibly from the State Budget. In this way, money is made available for satisfying cash flow needs throughout the life cycle of the repository. In principle, the fund takes advantage of the time value of money, by earning interest from medium or long-term investment in financial instruments. Figure 4 shows a fund model in which contributions are made at a level rate throughout the life cycle of the facility; in practice the rate of contributions may vary according to factors such as the income stream from the waste generating activity. Funds build up over time from contributions and from investment returns and then decreases as costs are incurred. For the given set of assumptions any particular time the size of the fund is assumed to shrink to zero as the last costs are incurred; in practice the financing needs will continually change as these assumptions are overtaken by real outcomes.

There are a number of ways in which contributions to the fund may be made. Alternatives include a levy on electricity production, as is the case in a number of existing financing schemes, or through a tariff system applied to different categories of waste at the time of delivery to interim storage. This latter source of funding will be further discussed in Section 4.3.7. in connection with income from charging for services. In principle, both systems may be combined. Nuclear electricity producers may fund through a levy, while the tariff system is more appropriate for small producers.

In some NPP States, the assets available in the fund are supplemented by a system of performance bonds, bank credit lines or deposits, insurance policies or other guaranteed provisions to provide confidence that unavoidable costs, including contingencies, will be covered in the long term. This may be necessary, as at any given time only part of the fund in the form of cash or financial instruments may be available, or repository costs are greater than originally was anticipated. The allocation of these unavoidable costs to the different producers, and the State in the context of legacies, could be made by applying capacity reservation, either on a volume basis, or considering multiple attributes of the waste forms in the repository, like activity, toxicity, disposal package characteristics [11].

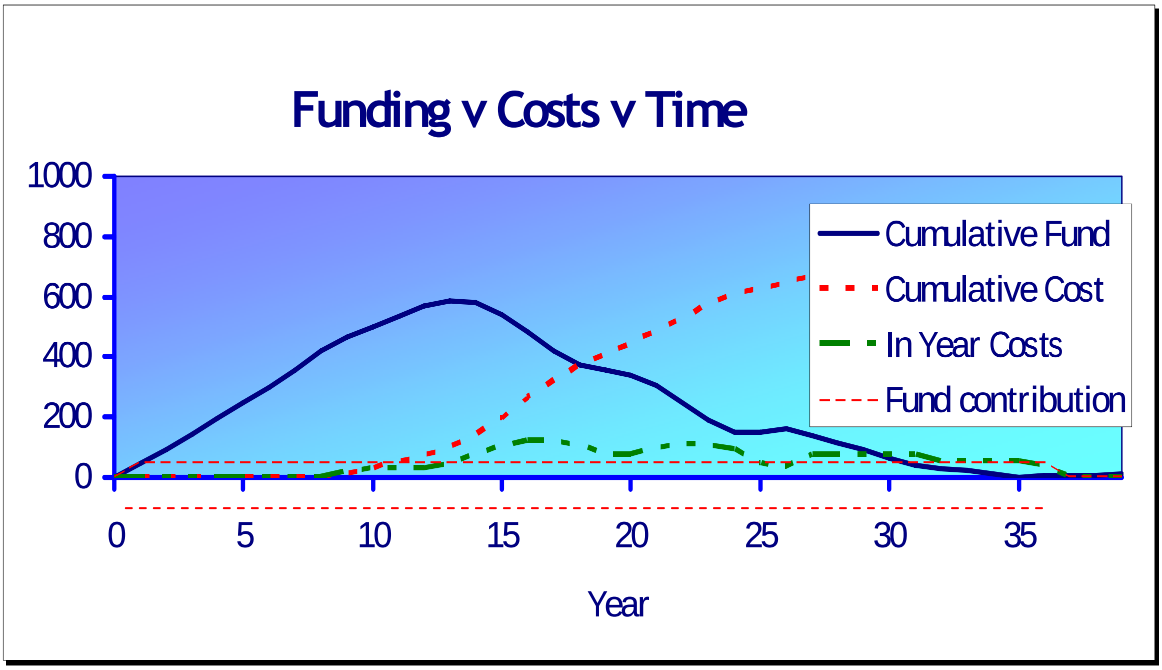

FIG. 4. Illustrative time projection of funding costs.

The guaranteed provisions may be fully funded by the waste producer, generally an electricity utility or other major waste producer, or exist in the form of provisions in their financial accounts.

Establishing a waste management fund for financing future liabilities meets the financeability, understandability and efficiency criteria discussed in Section 4.1, and at the same time it facilitates an equitable sharing of risk between the different stakeholders: producers, WMO, and government.

A waste management fund provides an understandable and efficient way of financing future liabilities from existing resources. Contributions are collected by revenues often a long time before cash withdrawals occur, so there is no need to supply liquidity on a short-term basis by means of loans at variable future interest rates, or by other sources external to the WMO or other implementing organisation. Given a sufficient level of confidence in the cost analysis and assumed contingencies, the fund should be able to provide sustainable and uninterrupted financing to the WMO in implementing the disposal life cycle.

The fund resources may be invested in industrial or public activities, including company shares, corporate or governmental bonds. In certain cases money can be borrowed back by waste producers provided sufficient guarantees are provided to the effect that the money will be returned when needed.

A cautious and diversified investment strategy provides assurance against uncertainties in the evaluation of medium to long-term liabilities. A fundamental element of such evaluations is the choice of an appropriate discount rate, which, in existing schemes is generally between 2% and 4% in real terms [11]. Excess returns above the discount rate help to compensate for cost underestimates. As the volatility of the asset value over a longer time period diminishes, a well-diversified portfolio may generate an excess return over long time.

At the same time a fund is an adequate instrument for pooling individual stakeholder risks, given that individual contributions to the fund correspond to a fair sharing of the burden, according to the 'polluter-pays' principle.

4.3.3.2. Fund management and risk considerations

Financial risks need to be taken into consideration before establishing a fund to manage financial resources. The two main types of risk return risk and liquidity risk. These risks imply constraints on the way the available cash can be invested for medium to long-term periods:

- Return risk reflects the choice of investment portfolio. This risk can be managed by carefully defining an investment strategy. Some Member States have limited the acceptable investment classes to bonds with high ratings, sometimes only governmental bonds with relatively low credit risks;
- Liquidity risk is usually a more serious risk and may be present even when the only investment is in corporate or government bonds. This is because the exact dates of the life cycle of the repository are not known, and thus the date when cash will be needed will also be uncertain. This risk could prevent the use of the money at a time when important cash withdrawals are required on a short-term basis, such as the pre-disposal phase of the repository.

However, investment strategy in a particular country may be based on specific approaches. As an example, the strategy that the Swedish Nuclear Waste Fund has adopted consists of setting a target for investment returns and in defining a strategy for managing financial risks. In order to limit the financial risks, the administration of the Fund should be conducted within an established framework. The framework may consider the number of issues, such as:

- interest rate risks;
- credit risks;
- liquidity risks;
- currency risks;
- long-term distribution between investments with nominal and real returns to reduce the inflation risk;
- maturities;
- administrative risks;
- follow-up activities.

The use of a waste management fund is generally most appropriate in phases of the life cycle which are distant in time, such as the operating and subsequent phases of a future repository, and the post closure phase for an existing repository. The use of a fund is a particularly good instrument for financing the institutional-control phase of the post closure period. Regarding the mechanism of funding, it can be thought of as a perpetuity payment mechanism for financing during that period. The proposed approach is to keep a defined capital reserve growing at the rate of inflation. The interest above inflation of this untouched capital generates the perpetuity, which would correspond in principle to the annual costs of institutional control.

An additional institutional risk for the fund is that the usage of the available assets could be diverted for other purposes than financing the disposal life cycle. Ideally the fund should be legally protected or segregated for its sole purpose ('ring fenced') and managed by an independent body under the supervision of an experienced audit committee.

Note that some Member States maintain separate funds for decommissioning of NPP and for waste management. In these cases it needs to be decided which fund will provide the resources for disposing of decommissioning waste.

4.3.4. Waste management organization resources

4.3.4.1. Accumulated profits

In some Member States the WMO is allowed to make profits and as a result it may accumulate financial resources. Those resources could be utilised to finance certain activities in the repository life cycle. They may be generally used at an early phase of the life cycle such as planning, identification of requirements, preliminary costing. The advantage of such a mechanism is that it allows the WMO to act proactively and independently from the regulator, the waste producers and the State allowing for example development of alternative disposal options. The financial risk lies with the WMO and to be sustainable, this cash outflow from has to be balanced in the future through prospective profits.

4.3.4.2. Accumulated reserves

A further possibility for WMO financing is directly to charge the waste producers for services rendered, as described below. One option for WMO financing is to charge the waste producers a 'once and for all' charge at the time of delivery or collection of waste, covering all past, present and future services associated with the management of their waste.

If no repository exists at the time of payment, a large portion of the fee is reserved on the WMO's accounts and financial balance sheet. In the case of an existing repository, part of the fee could be reserved for future closure costs and post-closure monitoring costs.

Reserves accumulated by the WMO from direct payments are a source of financing. The advantage of financing through accumulated provisions is the greater certainty that the resource would be available at time it is needed. One drawback is that this approach relies on an early prospective cost estimate. Should the requirement for resources be increased with time as the project develops, there may be no possibility for the WMO to recover additional costs from the waste producer, unless this is specifically covered by contract, i.e. the financial risk is taken by the WMO and not the waste producer.

4.3.5. Bank loan

This source of financing might be used when repository planning is at an advanced stage and where cost requirements are known with some degree of confidence. A loan could be used at the construction stage, to implement equipment replacement, or at the closure of the repository. At the closure stage, it may be the WMO that takes financial responsibility and not the waste producer. In that specific case may be afforded the opportunity to realise a profit in return for accepting risk.

The advantage of this source of financing is that funds are readily available, when needed, should the WMO offer a reasonable guarantee to the bank. To be fully sustainable this source of financing needs to be associated with firm contractual commitments from the waste producers to make payments to the WMO covering the interest and capital associated with the loan. It might be in the WMO's interest to link this payment to the bank's requirements and not to the time at which waste is delivered to the facility.

The drawback of this method of financing is that it assumes that the waste producers will have adequate resources to cover the initial WMO commitment during the duration of the loan.

4.3.6. Advance payment

This method of financing applies mainly at the early phase of repository implementation (planning, construction, siting) or to finance larger capital investments such as the construction of the final cap for the repository at the time of closure.

The required amount of finance is distributed among the waste producers in proportion to their forecast future use of the capacity with payments being made through regular instalments, as agreed with the WMO. In return for the advance payment for construction, the waste producers are normally guaranteed access to reserved capacity in the repository for their particular waste.

This method of financing respects the 'polluter pays' principle. Should the project fail or should the reserved capacity not be used, the WMO would have no obligation to pay back the waste producer. The financial risk here lies with the waste producer.

The main advantages of this method of financing are that funds are available to the WMO when needed, and the expenses are shared in an equitable manner between the waste producers. The efficiency of this system is guaranteed through the contractual agreements. A drawback of this method is that the waste producers may need to be encouraged to provide advance payments, possibly through interventions by the Regulator or other authority. There may also be disagreement between the WMO and the waste producers over the amounts required. This method is more appropriate for large future users and may not be practical for situations with only institutional waste.

4.3.7. Income from charging for disposal services

Apart from the limited cases of Member States with NPPs which apply an electricity levy to finance the disposal programme, additional revenue streams are generated from payments associated with waste disposal operations during the operational phase of the repository.

Such an income stream may utilise a pricing system for selling repository space to the waste producers and/or to the State in regard to legacy wastes. The pricing may thus include:

- Proportional costs per unit volume related to the handling and disposal of the waste;
- The amortisation of prior financing commitments, mainly the capital costs of infrastructures and other pre-operational costs, which have been the object of loans contracted by the WMO with banks, or other pre-financing mechanisms described in other sections of this chapter;

— Contributions to funding the closure and post-closure phases of the repository, setting apart provisions to that end, mainly for institutional control and post-closure monitoring.

For non-NPP States or for institutional wastes in general, the last two items may sometimes be omitted, i.e. pricing may be related only to the occupation of space in the repository. The main reason for this exclusion is to avoid imposing too heavy a financial burden on small or occasional waste producers; this approach diminishes the risk of waste being undeclared and/or not being delivered to the WMO for the safe-keeping.

There are two main techniques to establish a suitable pricing structure for space reservation: volume-based per-unit tariffs and multi-attribute charges. Both techniques have advantages and drawbacks, which can be summarised as:

4.3.7.1. Volume–based tariffs

This is most common system, being uncomplicated and transparent to the waste producers, and it generally meets the financeability criterion. Another important advantage of a tariff system is that it is efficient, because it delivers a clear economic signal to producers to reduce waste quantities. By contrast, there is evidence [9] that Member States imposing an electricity levy for funding may experience a smaller decrease in their waste arisings, because of the lack of a clear economic signal to the waste producers.

The drawbacks of the scheme are that a volume-based tariff may not reflect all dimensions of the fair share of the burden imposed by the waste generation, by omitting factors such as activity, toxicity, complicated disposal item. Also there is a risk waste producers will reduce overall volumes without altering the total activity of the waste and thus the charges levied on those producers may be reduced, without a commensurate reduction in the radiological burden and the associated cost drivers.

4.3.7.2. Multi-component charges

This is a less common system having many of the same advantages as the volume-based tariff giving rise, in addition, to a more equitable method of pricing for disposal, taking account of cost factors such as activity, toxicity and container geometry. Thus, in principle, the limitations of a volume-only approach are avoided. Separate charges can be estimated for long-term monitoring as the detrimental impacts on the environment can be specifically attributed to long-lived nuclides and/or toxic materials.

Nevertheless a multi-component approach is more complex to establish and to explain to waste producers, and the relative weighting of the individual attributes is partly subjective. For these reasons this approach is less commonly used than volume-based charges.

5. CONCLUSIONS AND RECOMMENDATIONS

This report presents information on major cost elements, cost estimating approaches and alternative financing mechanisms for low and intermediate level radioactive waste disposal. It has been developed in light of the considerable experience gained in Member States in the planning, development and ongoing operation of existing repositories, and the available but more limited experience with repository closure and post-closure activities.

This information is intended to contribute to timely, systematic and comprehensive consideration of the financial aspects of repository planning and development beginning at an early stage in this process. Timely planning is particularly relevant given the uniquely extended timescale covered by the full repository life cycle and the lessons learned from past experience.

The approach taken by the report is intended to be generic and to apply to all repository types with the specific exception of deep geological repositories for high level radioactive waste and spent fuel. It is further intended to be suitable for use in various Member States ranging from those that have nuclear power plants and multiple institutional low and intermediate level waste producers to those with small inventories of waste from a limited number of research, medical or other institutional applications.

The approach incorporates the complete life cycle of the repository types considered, consistent with current international requirements, principles, standards and guidance. The main focus of the report is on approaches to estimating cost and on potential financing mechanisms. IAEA publications and other relevant publications are referenced to provide details on pertinent technical and non-technical cost factors relating to repository development, operation, closure and post-closure.

It is important to recognise that while national policy and legal frameworks for repositories is likely to be broadly similar in many Member States, specific circumstances directly relevant to comprehensive cost estimation and evaluation of available financing schemes may be very different. These differences include the responsibilities and obligations of the waste producers, the Waste Management Organisation and the regulators. Other important considerations impacting on costs are the repository design, its disposal capacity and planned operating life time. Important factors bearing on the choice of an appropriate financing scheme include the available sources of financing; charging arrangements and application of the 'polluter pays' principle for repository and for related waste management tasks; payment timing; fund management responsibilities and investment policy; and methodologies for estimating costs and considering uncertainties over the full repository life cycle.

No single approach or set of approaches to cost estimation or financing have been recommended for general application by the IAEA. While the information presented is considered to be a valuable contribution to the repository planning and development process, it is recommended that Member States utilise the information presented in full consideration of Member State policies and case-specific circumstances.

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