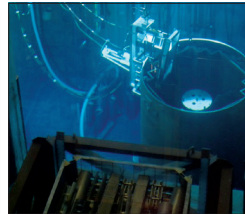


# Costs of Decommissioning Nuclear Power Plants





Nuclear Development

## **Costs of Decommissioning Nuclear Power Plants**

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NUCLEAR ENERGY AGENCY  
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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## Foreword

The average age of the worldwide operating nuclear fleet in 2015 was close to 30 years, with nearly 250 reactors more than 30 years old and some 75 beyond 40 years old. While refurbishments for the long-term operation or lifetime extension of nuclear power plants (NPPs) have been widely pursued in recent years, the number of plants to be decommissioned is nonetheless expected to increase in the coming years, particularly in the United States and Europe. These numbers demonstrate the scale of the task ahead, which will make decommissioning a sizeable market, expanding over the years in volume.

As past experience has shown, decommissioning can be carried out in a safe manner. However, examples of the fully completed decommissioning of commercial power reactors are limited and no fleet effect can yet be observed. Of the nearly 150 power reactors that have ceased operation, 16 of these have undergone complete decommissioning, most of which are primarily in the United States. Other reactors, mainly in Europe, are at advanced stages of decommissioning, and will allow for valuable experience to be gained.

It is important to understand the costs of decommissioning projects in order to develop coherent and cost-effective decommissioning strategies, realistic cost estimates based on decommissioning plans from the outset of operation and mechanisms to ensure that future decommissioning expenses can be adequately covered.

These issues have become increasingly important in recent years. At the national level, several studies on decommissioning costs have been carried out in individual countries, but these usually reflect national policy choices and practices. Cost estimates are therefore not directly comparable across countries. Overall, considerable variability exists in the format, content and practice of cost estimation both within and across countries. Initiatives have been launched by international and intergovernmental bodies on this subject, and useful reports have been produced over the years, describing national decommissioning approaches or making suggestions on how to analyse decommissioning costs. However, apart from the European region, where the Decommissioning Funding Group (DFG) of the European Commission (EC) has assessed decommissioning funding and its financial security, no recent comprehensive overviews of an international dimension have been undertaken on the state of knowledge of decommissioning costs and funding practices across countries. The last reviews of this kind, based on empirical country data, were carried out by the Nuclear Energy Agency in 2003 and the International Atomic Energy Agency in 2004 (see NEA, 2003 and IAEA, 2004).

During the last decade, the outlook in terms of nuclear decommissioning has evolved considerably. Today, experience being accrued internationally is providing new sources of information from real estimations or actual costs. Up-to-date analyses of the actual costs of decommissioning are increasingly being sought, particularly among regulators, so as to enable benchmarking of decommissioning cost estimations against actual experience.

The recent joint NEA/EC/IAEA publication on the *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations* introduces a standard in this regard, as well as a structure and itemisation of decommissioning costs to reflect experience

accumulated and to incorporate new IAEA radioactive waste specifications. The ISDC provides general guidance on developing decommissioning cost estimates and, through its itemisation, a tool for either cost estimations or for mapping estimates onto a standard, common structure for comparison purposes.

Against this backdrop, the present study was initiated under the auspices of the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC). The Ad Hoc Expert Group on Costs of Decommissioning (COSTSDEC) was established in early 2013 to carry out the work, with the overall objective of producing a report on the costs of decommissioning of nuclear power plants and funding practices adopted across NEA member countries.

The principal objectives of this study were outlined in the NDC Final Programme of Work for 2013-2014 as follows:

- To gather and assess available knowledge on completed decommissioning projects from different countries and, to the extent possible, to consider how related cost estimates have varied over time; how uncertainties were taken into account and what contingencies were built into the planning; and what have been the key factors driving costs.
- To review economic methodologies and related aspects for the management of NPP decommissioning in NEA member countries and, if possible, in selected other countries, including the funding mechanisms in place or under consideration, how the funds are managed and the extent to which they have increased.
- To consider a selected set of decommissioning programmes, either ongoing or prospective, to perform a review of related cost estimates and to define, to the extent possible, cost categories and estimates for high-level processes with the aim of identifying broad cost ranges.

This study is based on an analysis of data gathered through a questionnaire addressed to NEA member countries. Work was conducted in conjunction with the NEA Radioactive Waste Management Committee (RWMC) and its expert groups – the Working Party on Decommissioning and Dismantling (WPDD) and the Decommissioning Cost Estimation Group (DCEG) – given the relevance of the project to such activities, and in close co-operation with the EC and the IAEA in order to benefit from the substantial work undertaken by these entities and to capitalise on specific expertise existing in the field.

## Acknowledgements

This report could not have been produced without the valuable contributions of the members of the NEA Ad Hoc Expert Group on Costs of Decommissioning (COSTSDEC), as well as the individuals who collected and assembled the necessary information at the national level. The report is based on information received via the NEA questionnaire sent out in the course of 2013, and it reflects discussions that took place over two and a half years. A list of COSTSDEC members can be found at the end of this report.

COSTSDEC benefitted from the skilled joint chairmanship of Emilio Neri of Enresa (Spain) and Amanda French of the Nuclear Decommissioning Authority (NDA – United Kingdom). Their leadership was critical in reaching consensus on the final draft of the report.

The Secretariat of the project was ensured by Maria Elena Urso and Marc Deffrennes, nuclear analysts, and Geoffrey Rothwell, Principal Economist from the NEA Division of Nuclear Development. Their task to propose ways forward between sometimes divergent views and to draft a report based on these discussions was challenging but successful.

The NEA Division of Radiological Protection and Radioactive Waste Management, and in particular Ivan Rehak and Inge Weber, radioactive waste management specialists, ensured consistency with decommissioning projects and activities performed under the umbrella of the NEA Radioactive Waste Management Committee (RWMC), its Working Party on Decommissioning and Dismantling (WPDD) and its Decommissioning Cost Estimation Group (DCEG). This work was further reinforced by the very active participation in COSTSDEC of the Chairman of the DCEG, Simon Carroll, of the Swedish Radiation Safety Authority (SSM).

Simon Carroll also contributed to Chapter 4 on the funding of decommissioning, and Vladislav Daniska (Slovak Republic) examined the conversion of the United States data (Pacific Northwest National Laboratories [PNNL] study data) from the work breakdown structure (WBS) into the International Structure for Decommissioning Costs (ISDC) format, as summarised in Appendix 3.A2 of this report.





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## List of abbreviations and acronyms

BIDSF	Bohunice International Decommissioning Support Fund
BWR	Boiling water reactor
C&M	Care and maintenance
COSTSDEC	NEA Ad Hoc Expert Group on Costs of Decommissioning
COVRA	Centrale Organisatie Voor Radioactief Afval
D&D	Decontamination and dismantling
DCEG	Decommissioning Cost Estimation Group
DETEC	Department of the Environment, Transport, Energy and Communications (Switzerland)
DFG	Decommissioning Funding Group
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EDF	Électricité de France
Enresa	Empresa Nacional de Residuos Radioactivos S.A. (Spain)
EPRI	Electric Power Research Institute
ES	Energy Solutions
ENSI	Swiss Federal Nuclear Safety Inspectorate
EU	European Union
HLW	High-level waste
HNP	Haddam Neck Plant
IAEA	International Atomic Energy Agency
ILW	Intermediate-level waste
ISDC	International Structure for Decommissioning Costing
ISFSI	Independent spent fuel storage installations
JAVYS	Jadrová a vyrábacia spoločnosť, a.s.
LILW	Low- and intermediate-level radioactive waste
LLW	Low-level waste
LWR	Light water reactor

MAGNOX	Magnesium alloy graphite-moderated gas-cooled reactor
MIR	Medicine, industry and research
MODP	Magnox optimised decommissioning plan
MOP	Magnox operating programme
MWe	Megawatt electric
NCU	National currency unit
NDA	Nuclear Decommissioning Authority (United Kingdom)
NDC	NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle
NEA	Nuclear Energy Agency
NIS	NIS Ingenieurgesellschaft mbH
NLF	Nuclear Liabilities Fund
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission (United States)
OECD	Organisation for Economic Co-operation and Development
PNNL	Pacific Northwest National Laboratories
PWR	Pressurised water reactor
RBMK	Water-cooled, graphite-moderated reactor (Russian abbreviation)
RAW	Radioactive waste
RPV	Reactor pressure vessel
RWMC	NEA Radioactive Waste Management Committee
SF	Spent fuel
SLCs	Site licence companies
SNF	Spent nuclear fuel
SRLs	Safety reference levels
TLG	Thomas LaGuardia
TWh	Terawatt-hour
VLLW	Very low-level waste
VVER	Water-cooled, water-moderated reactor (Russian abbreviation)
WBS	Work breakdown structure
WENRA	Western European Nuclear Regulators' Association
WPDD	NEA Working Party on Decommissioning and Dismantling



## Executive summary

Owners and licensees of nuclear power plants are generally responsible for developing cost estimates of decommissioning, and a good understanding of these costs is fundamental for the development of estimates based on realistic decommissioning plans. Transparent cost estimates also provide a basis for accumulating the necessary funds with the aim of ensuring that these are available when needed to cover the actual cost of decommissioning activities.

This report reviews nuclear power plant decommissioning costs and funding practices adopted across NEA member countries, based on an analysis of survey data collected through an NEA questionnaire. The work has been conducted in conjunction with the NEA Radioactive Waste Management Committee (RWMC) and its expert groups – the Working Party on Decommissioning and Dismantling (WPDD) and the Decommissioning Cost Estimation Group (DCEG) – given the relevance of the project to their activities, and in close co-operation with the European Commission (EC) and the International Atomic Energy Agency (IAEA) in order to benefit from the substantial work undertaken by these entities and to capitalise on specific expertise existing in the field.

Work on this study was carried out by the NEA Ad Hoc Expert Group on Costs of Decommissioning (COSTSDEC), with members of the group bringing expertise on a wide range of issues in the field of decommissioning, including cost structure, financing mechanisms, national policies and other strategic aspects.

The principal objectives of this study were outlined as follows:

- To gather and assess the available knowledge on completed decommissioning projects from different countries and, to the extent possible, to consider how related cost estimates have varied over time; how uncertainties were taken into account and what contingencies were built into the planning; and what have been the key factors driving costs.
- To review economic methodologies and related aspects for the management of NPP decommissioning in NEA member countries and, if possible, in selected other countries, including the funding mechanisms in place or under consideration, how the funds are managed and the extent to which they have increased.
- To consider a selected set of decommissioning programmes, either ongoing or prospective, to perform a review of related cost estimates and to define, to the extent possible, cost categories and estimates for high-level processes with the aim of identifying broad cost ranges.

Full details of the costing approach used in individual countries or their specific project management process are not analysed or reproduced in the report, nor are judgements made on the appropriateness of costs derived within a given national context. No attempt is made to select a single global cost estimate for the decommissioning of a nuclear power reactor, owing to the inherent difficulties, risks and limitations of comparing whole-project decommissioning costs.

While the study has built on information already available to the NEA, the IAEA and the EC, a questionnaire was also used to collect additional up-to-date detailed data on decommissioning-related policies and strategies, cost estimates and funding mechanisms. The questionnaire consisted of three parts:

- Part I focused on national decommissioning policies and financial arrangements.
- Part II referred to plant or unit-specific decommissioning strategy details.
- Part III, based on the International Structure for Decommissioning Costing (ISDC) structure, aimed to collect information on unit-specific cost estimates; responders were encouraged to report data, to the extent possible, in line with the recent ISDC (NEA, 2012<sup>1</sup>).

This survey incorporated some specific items of the EC Decommissioning Funding Group (DFG) questionnaire from 2003 that explored different aspects of decommissioning financing in member states (reflected in the Commission's 2006 recommendation on decommissioning funding).

The scope of this study focuses on commercial nuclear power plants of all types, since the cost of decommissioning can vary considerably depending upon the type of facility. Similarly, those NPPs that have experienced accidental conditions were also excluded from the scope of this study, as such conditions could considerably affect decommissioning costs, and thus would not be representative of normal decommissioning activities.

The study demonstrates in particular, that:

- In most cases, effective decommissioning activities begin after all nuclear fuel has been removed from the plant areas that will be decommissioned. The activity is part of pre-decommissioning operations in such cases.
- The cost of managing spent nuclear fuel (SNF) following removal from the reactor, in particular interim storage of the fuel, is not always included in the cost of decommissioning, but is often treated separately. This is even more the case for the final disposal of fuel or related waste, which is a major source of costs in waste management, particularly for high-level waste.
- The selection of immediate versus deferred decommissioning, as well as the planned end point of decommissioning – for example, unrestricted site and facility release, partially restricted site and facility release, site and facility reuse in a radiological controlled fashion – are some of the main factors that will influence the overall costs of decommissioning and limit the validity of quantitative comparisons.

The report offers a descriptive review of different decommissioning policies, strategies and approaches across countries; an assessment of economic aspects, with actual decommissioning costs for a few completed decommissioning projects and estimates for several ongoing and future projects; an overview of appraisal funding mechanisms in place or under consideration, as well as means of managing funds; and some conclusions and recommendations.

The report is largely based on country and plant data obtained by means of the NEA questionnaire. However, only a few sets of quantitative cost estimates were retrieved through country responses to the questionnaire, using the ISDC format as a basis. It includes 4 sets of estimated costs for pressurised water reactors (PWRs) from France,

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1. NEA (2012), *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations*, OECD, Paris.

Spain and Switzerland, 3 of which are generic; 3 sets for boiling water reactors (BWRs) from Spain and Sweden, with 1 generic estimate; 2 sets for water-cooled, water-moderated reactors (VVERs) from Finland and the Slovak Republic and 11 sets for gas-cooled reactors (GCRs) from the UK NDA Magnox fleet. It is important to note that all such data are estimates related to future projects, with the exception of the José Cabrera NPP in Spain (single PWR unit) that is undergoing decommissioning, and for which cost figures refer partly to expenditures incurred for completed tasks and partly to estimates for outstanding activities. No detailed cost data have been made available through the survey on completed projects, or on more advanced accrued experience.

Given the limited information obtained through questionnaire responses, it was deemed necessary to broaden the database by gathering further quantitative data available in the public domain. Valuable information on the United States experience, for example, has been reported in recent studies, including the report developed by the Pacific Northwest National Laboratories (PNNL) and commissioned by the US Nuclear Regulatory Commission (NRC), hereafter referred to as the PNNL study (PNNL, 2011)<sup>2</sup>. The PNNL study appraises actual costs for four completed projects (Haddam Neck, Maine Yankee, Trojan and Rancho Seco NPPs); in the achievement of “NRC decommissioning closure (de-licensing)”, along with various site-specific cost estimates developed by the licensees for some operating reactors. However, there is no analysis presented of how the actual costs reported for the completed projects compare with the past decommissioning cost estimates prepared for these same projects, limiting the extent to which these can be compared directly with estimates. PNNL information nevertheless constituted an important pool of data to supplement those obtained from the NEA questionnaire, even if many of the estimates use the Thomas LaGuardia (TLG) cost estimation methodology. These estimates should be seen more as different iterations of the same calculation model, with differing input data. In addition, the cost data reported in the PNNL study, in line with long-established practices in the United States, follow cost breakdowns that differ from the ISDC format. This format was applied, as closely as possible, to the data obtained from the NEA questionnaire.

The two sets of data – those obtained from the NEA questionnaire and those extracted from the PNNL study – are thus appraised separately in the report. Nevertheless, the conversion of the United States cost structures (work-breakdown based) into the ISDC format, justified the inclusion of similar graphs for both sets of data (obtained for a few member countries through the questionnaire, and through the PNNL report for the United States data).

The information available or provided for this study does not enable general conclusions to be drawn concerning the adequacy of current decommissioning financing arrangements. A review of the adequacy of projects is currently hampered by the limited amount of reliable and comparable information on decommissioning costs. Enhancing transparency around such costs and putting in place better methods to collect and share information would contribute greatly to future assessments. The financing, review and oversight mechanisms described in this report nonetheless rely on a combination of features which together aim to manage risks and ensure the adequacy of decommissioning funding.

The cost of decommissioning is greatly influenced by several factors or drivers, which must be carefully managed to avoid escalation and overruns. Some useful qualitative recommendations may be provided for each of these drivers.

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2. PNNL (2011), “Assessment of the Adequacy of the 10CFR50.75(c) Minimum Decommissioning Fund formula”, manuscript completed in November 2011 (unpublished).

- *Decommissioning policy and strategy*  
A global decommissioning policy and strategy needs to be defined as soon as possible, ideally when building a plant. This will allow for a sharing of responsibilities between the diverse actors and for a streamlining of the process of cost estimation and its revision. This policy should also define the legal framework and modes of operation for the collection and use of the decommissioning fund, ensuring that a legacy (in particular, in terms of costs) is not left on the shoulders of future generations.
- *Roles and duties of the diverse actors, and the regulatory framework*  
The regulatory framework needs to be established with clarity and anticipation. While changes in the regulatory framework may be necessary to reflect natural evolution, long-term consistency needs to be ensured so that actors can fulfil their roles and duties while taking full responsibility for the costs incurred.
- *Planning and preparation phase prior to decommissioning, and site characterisation*  
Costs of decommissioning will be influenced by the nature and level of radioactivity of the materials being handled. While preparing the cost estimate, it is important to have a good understanding of these factors. Site characterisation is a vital precursor to actual decommissioning, and can avoid uncontrolled cost escalations during implementation.
- *Management of spent fuel and operational waste*  
Cost of spent fuel and operational waste management may not be seen as decommissioning costs per se and are therefore not often included in the decommissioning cost estimates. Clarity is needed in terms of what is included where and how all costs are covered in the end.
- *Dismantling operations and related waste management*  
The effective planning and management of dismantling operations and corresponding waste management can have a major impact on actual costs. Waste management means and routes in particular can have a strong influence on these costs during the decommissioning phases. As the return of experience becomes more and more available, it should be used to the maximum possible extent. Project management needs to be flexible enough to integrate unexpected factors when they appear, while minimising costs.
- *Prospects for waste (final) disposal, including spent fuel*  
Final disposal of radioactive waste, in particular intermediate-level waste (ILW) and high-level waste (HLW) (including spent fuel in the case of open fuel cycles), is usually not perceived as part of decommissioning costs. It is therefore vital to ensure clarity in terms of how the ultimate radioactive waste will be handled, and how strategies and processes for the long-term funding of this legacy are defined. For low-level waste (LLW), the clearance level is critical, and should be clearly defined and thoroughly implemented.
- *Final stage of decommissioning, de-licensing, site restoration and reuse*  
Such factors can have an impact on the costs of decommissioning, in particular on what is included in these costs, and thus clarity is also needed in these areas.
- *Manpower management, contractors*  
The cost of manpower would appear to be the main contributor to decommissioning costs, whether for preparation activities, project management, implementation of decommissioning activities, or waste management and surveillance. A search for efficiency in this regard is therefore important, particularly in relation to the re-employment of former operations staff and/or recourse to contractors for specific activities. Lessons learnt from return experience will be useful.

- *Risks management, uncertainties and contingencies*  
Any industrial activity taking place over a period of years has a certain degree of uncertainty and requires risk management. It will be important in the future to have a much better understanding of the uncertainties affecting decommissioning activities and how to best take them into account in cost estimations. The ongoing NEA/IAEA project in this area is expected to shed some light on this subject.

Beyond cost estimates and figures, ensuring that funding is available for the time when the actual decommissioning process takes place is a critical issue. This study demonstrates that a large diversity of approaches exists between countries and even within countries, although some general recommendations on funding can nonetheless be extracted.

- *Funding policy and strategy*  
The requirements for the financing of nuclear power plant decommissioning projects needs to be formally established according to the national legal system. There are considerable variations between countries in terms of the details of these formal legal requirements. In many cases, the systems currently in place have incorporated features intended to address deficiencies identified in earlier years, with countries introducing requirements for systematic reviews and for the various parties to be involved.
- *Roles and duties of the diverse actors, regulatory framework*  
Operators of nuclear power plants are generally responsible for financing the costs of decommissioning, with arrangements typically being based on the revenues earned from the sales of the electricity generated. Exact financing mechanisms vary from country to country but these must be clearly defined and associated with the regulatory framework. Exceptions to the general pattern include financing arrangements for some of the oldest facilities, or where there have been deficits arising from historical arrangements.
- *“During the plant operation” phase, prior to decommissioning activities: planning, collecting and securing the funding; updating the cost estimates; monitoring and adapting to financial conditions and financial risk management*  
The completeness, accuracy and regular updating of decommissioning cost estimates are important prerequisites for establishing adequate funds for future decommissioning.
- *“After the plant operation” phase, during decommissioning: disbursement and long-term management of the funds, and financial and technical risk management*  
Ensuring the availability of the necessary funds at the appropriate time is one of the cornerstones of a decommissioning financing system. Accordingly, the identification of risks and uncertainties in funding arrangements, and the implementation of appropriate measures to manage them, are essential elements of national decommissioning fund management and oversight. Decommissioning funding arrangements may still be vulnerable to earlier than expected plant closure or to the failure of a fund to reach a sufficient level of financing to cover the actual costs of decommissioning.
- *What if the funds are not enough? Management of liabilities, evaluation of the risk and contingency planning*  
States must put in place mechanisms to regularly review changes to calculated liabilities, fund growth and other changes to market conditions, as well as the timing of decommissioning in order to reduce the risks of inadequate decommissioning funding. The details of these national systems vary considerably, reflecting both current needs and the historical development of the systems. Special attention should be given to mechanisms mitigating the risks

and uncertainties for projects which are “funded” years or even decades before their real implementation.

Work performed by COSTSDEC over the past two and half years of this study has led to the general conclusion that enhancing transparency around decommissioning costs and financing is fundamental to overcome difficulties in collecting enough detailed and reliable quantitative data, both in terms of actual data from real finished or ongoing decommissioning projects and data for cost estimates for future projects. The two sets of data should be treated separately, as lessons must be drawn from the finished projects to better understand cost drivers, which help define priority areas and uncertainties for cost estimates. In case the diversity of boundary conditions does not allow real benchmarking of decommissioning costs from one country to another, comparisons might nevertheless be possible for specific activity or project components.

As this study has shown, in order to improve data collection, it must occur in confidence when related to specific detailed data, but it also must be organised so as to draw lessons, and make conclusions and recommendations from the generic figures. The Information System for Occupational Exposure (ISOE) may be used as an example that could be adapted for the purpose of collecting sensitive information on decommissioning costs and funding. It will be vital that the standard ISDC format be used for the collection of this information, associated with additional detailed information on the boundary conditions for further analysis of the data.

Future studies could benefit from effective collaboration with the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) and RWMC (in particular DCEG) in identifying the critical data needed for such a study, and the assessment framework for conducting the analysis. A “virtual mean case” could be created from data assembled in this way. This mean case would be globally representative of the generic figures and information, and could ultimately lead to important conclusions and recommendations. Sensitivity analyses could be performed around this mean case to illustrate the impact of the main factors influencing costs, as derived from the study of cost drivers extracted from actual finished or ongoing decommissioning projects. Such a method is already used by the IAEA for the cost of decommissioning of research reactors (data analysis and collection for costing of research reactor decommissioning – DACCORD Project).

One of the recommendations of COSTSDEC is to investigate the launching of such a process within a timeframe of three years following the publication of this report, if indeed there is sufficient willingness on the side of the main actors to share information on decommissioning costs and funding (actual and estimates), and to proceed with a shared analysis. This willingness will be demonstrated by the number of participants who would be prepared to effectively engage in the process.

## **PART I**

### **Analysis of decommissioning policies, costs and funding**





## Chapter 1. Introduction

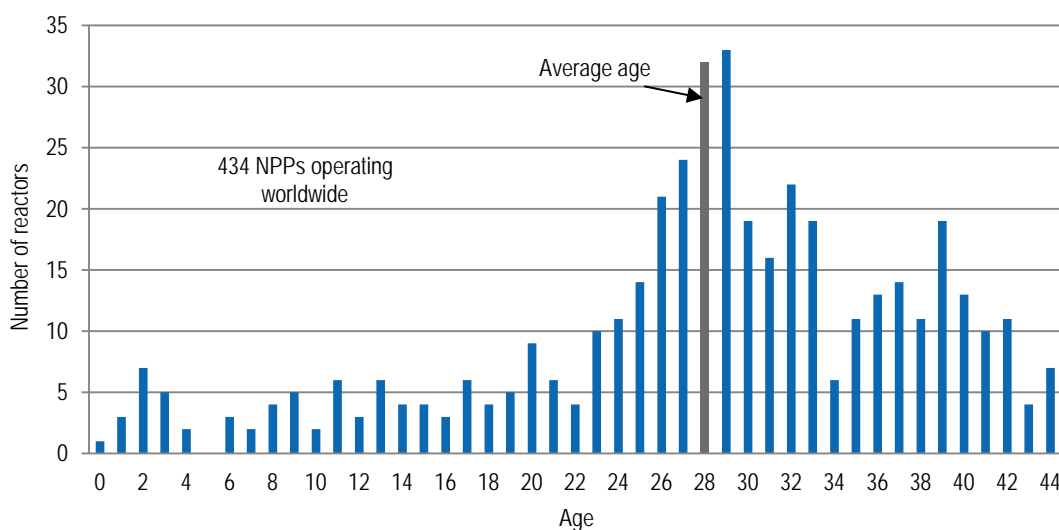
### 1.1. The current outlook

#### 1.1.1. A global ageing nuclear power reactor fleet

Nuclear installations, including nuclear power plants (NPPs), as any industrial facility, have a finite lifetime. After cessation of operation and withdrawal from service, facilities need to be decommissioned and all waste generated safely managed. Decommissioning, as a global concept, involves activities such as removal of fuel, dismantling of plant and equipment, decontamination of structures and components, demolition of buildings, remediation of contaminated ground and recycling or disposal of the resulting waste. Planning and preparation for these activities needs to start before a facility is shut down and adequate management needs to be ensured throughout the decommissioning implementation, until the eventual de-licensing (licence termination). Indeed, lifting, entirely or partially, the regulatory controls that apply to a nuclear site is one central purpose of decommissioning, which is attained through the progressive and systematic reduction of radiological hazards.

**Figure 1.1: Age distribution of operating nuclear reactors worldwide**

(as of August 2013)



Source: Derived from IAEA, 2013.

Depending on the authorised levels for residual radioactivity, the decommissioned site may be released for unrestricted or restricted use, usually called greenfield or brownfield respectively. Regardless of the end state of the decommissioned site, the underlying key requisite is to ensure the long-term safety of the public and the environment, and the continued health and safety protection of decommissioning workers (NEA, 2003).

While the newer generations of NPPs are designed to have lifetimes of up to 60 years, most of the older NPPs were designed for an operational lifetime between 30 and 40 years. International Atomic Energy Agency (IAEA) statistics reveal that within the operating civil nuclear reactor fleet, a substantial number of nuclear power plants have reached or are approaching their end of life as originally envisaged at the time of design. Figure 1.1 shows the age distribution of operating nuclear civilian power reactors, as of August 2013, skewed towards ageing operational lives.

Since the accident at the Fukushima Daiichi plant, energy policies and nuclear power programmes have been under review. In some cases, a nuclear phase-out policy has been decided or confirmed, which will lead to accelerated decommissioning processes. As an example, the German federal government has decided to end its nuclear power programme entirely and to phase out all of its nuclear power plants by 2022. Enacted in August 2011, this government decision confirmed the immediate shutdown of eight units, with the remaining units to cease operation between 2015 and 2022. The early and simultaneous phase-out of German NPPs will be challenging. Indeed, it will place substantial demands on Germany's decommissioning expertise and infrastructure. It will also require the safe management of rather large volumes of decommissioning waste. Likewise, in Italy, as a result of a referendum that followed the accident at the Fukushima Daiichi plant, termination of a new potential nuclear programme has been established by law. Following the decision, there has been an impulse to expedite decommissioning activities of the country's four shutdown nuclear power plants, along with other fuel cycle facilities and research centres, with a newly enacted law providing the legislative instrument to help accelerate decommissioning authorisation procedures (NEA, 2012a).

From Figure 1.1, one can derive that, in 2015, the average age of the operating nuclear fleet is close to 30 years, and nearly 250 reactors are more than 30 years old, and some 75 are beyond 40 years. Although in recent years, refurbishments for long-term operation and lifetime extensions have been pursued widely, with a number of licences granted for NPP life extensions up to 60 years in some countries (notably in the United States), the number of civilian NPPs to be decommissioned in the forthcoming years will naturally increase. This demonstrates the scale of the task ahead, making decommissioning a sizeable market, growing in volume and progressively becoming more competitive.

### **1.1.2. The legacy and experience**

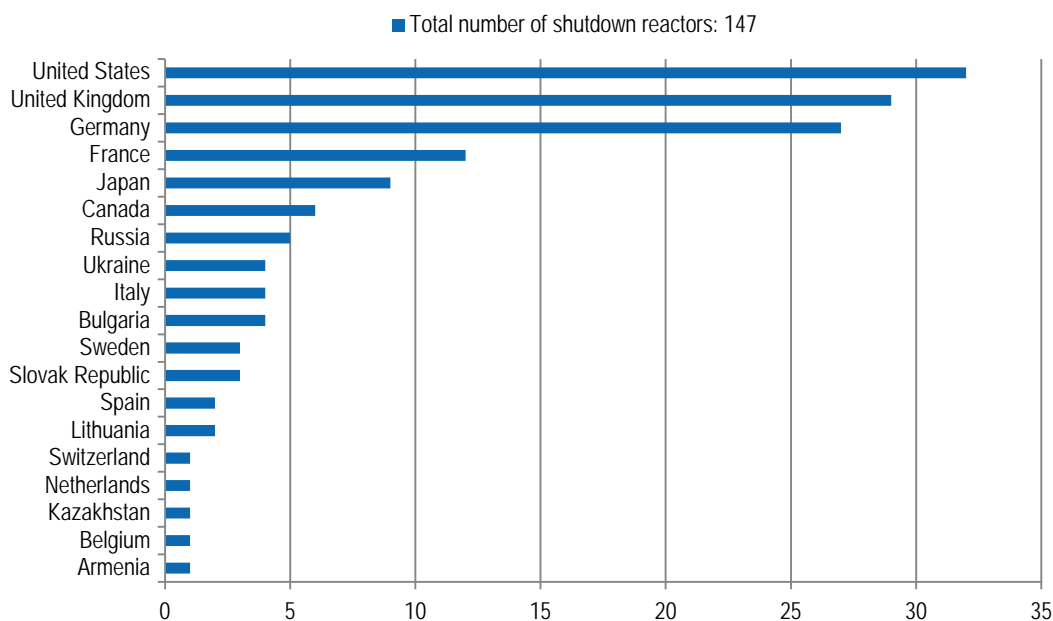
As shown in Figure 1.2, as of August 2013, 147 civilian nuclear power reactors had ceased operation in 19 countries, including 32 in the United States, 29 in the United Kingdom, 27 in Germany, 12 in France, 9 in Japan, 6 in Canada and 5 in the Russian Federation (IAEA, 2013).

These 147 reactors include mostly commercial power reactors, but also prototypes (~30) and experimental reactors (~15), either shut down as they reached the end of life originally envisaged in the design, or prematurely phased out due to political or other decisions. Eleven reactors, such as those at Chernobyl and Fukushima Daiichi that were shut down as a consequence of accidents or incidents, are included.

A complete list of shutdown units in NEA member countries is provided in Appendix 1.A1. In addition to the nuclear power reactors, more numerous fuel cycle and research facilities of various types have been shut down, including facilities used for the extraction and enrichment of uranium, and for fuel fabrication and reprocessing (NEA, 2008).

**Figure 1.2: Number of reactor shutdowns by country**

(as of August 2013)



Source: Derived from IAEA, 2013.

Many reactors shutdown are at some stage of decommissioning, with substantial activities ongoing in most of the major nuclear countries. However, there is at present only limited experience of fully completed decommissioning projects for commercial nuclear power reactors. Some experience has been accrued in the United States, where operation of more than 30 reactors has been discontinued, with 13 already fully decommissioned (including some experimental or prototype reactors) and the others for which decommissioning is expected to be completed within the next 2 decades. Tables 1.1 and 1.3 provide the lists of these plants (status as of 2013).

In France, many reactors and nuclear facilities are being decommissioned. These are detailed in Table 1.2, for the various parties responsible for the operation and for the management of liabilities related to nuclear civil installations. All French nuclear installation operators have accepted the principle of immediate dismantling, as recommended by the safety authority (Cour des Comptes, 2012).

French commercial NPPs are run by Électricité de France (EDF), and nine EDF reactors of the first generation fleet (using four different technologies) have been permanently shut down and are now being decommissioned: Chooz A, Brennilis, Chinon A1, A2 and A3, Saint-Laurent A1 and A2, Bugey 1 and Creys-Malville (Cour des Comptes, 2012). Completion of decommissioning activities for these reactors is expected between 2020 (Chooz A) and 2047 (Chinon A). Chooz A is the only pressurised water reactor currently being decommissioned in France. Despite some specific characteristics of this reactor and site (e.g. first-of-a-kind [FOAK] pressurised water reactor [PWR] imported in France, four loops but lower output than that of the other PWRs in the French fleet, as well as specific site conditions such as being fully located inside a cavern), EDF considers Chooz A as featuring all main technical issues that will be typically encountered by the industry when dismantling other PWRs. In particular, the Chooz A experience feedback should be especially useful when dismantling the primary system. EDF also makes full use of the experience gained during its power plant construction and operation phases and, in particular, from replacing main equipment, such as the steam generators.

**Table 1.1: Reactors under deferred decommissioning in the United States**

Name	Type	Location	Year of shutdown	Year of deferred decommissioning completion
Crystal River – Unit 3	PWR	Crystal River, FL	2013	2073
Dresden – Unit 1	BWR	Morris, IL	1978	2036
Fermi – Unit 1	FBR	Monroe Co., MI	1972	2032
Humboldt Bay <sup>1</sup> – Unit 3	BWR	Eureka, CA	1976	2017
Indian Point – Unit 1	PWR	Buchanan, NY	1974	2026
Kewaunee	PWR	Kewaunee, WI	2013	2073
LaCrosse	BWR	LaCrosse, WI	1967	2026
Millstone – Unit 1	BWR	Waterford, CT	1995	2056
Nuclear Ship Savannah	PWR	Norfolk, VA	1970	2031
Peach Bottom – Unit 1	HTGR	York Co., PA	1974	2034
San Onofre – Unit 1	PWR	San Clemente, CA	1992	2030
San Onofre – Units 2 and 3	PWR	San Clemente, CA	2013	2031
Three Mile Island – Unit 2 <sup>1</sup>	PWR	Middletown, PA	1979	2036
Vallecitos <sup>2</sup>	BWR	Sunol, CA	1963	2023
Vermont Yankee	BWR	Vernon, VT	2014	2073
Zion – Units 1 and 2	PWR	Warrenville, IL	1998	2020

Source: Derived from NRC and complementary web research for each unit.

1. On 28 March 1979, the unit experienced an accident that resulted in severe damage to the reactor core.

2. Experimental reactor.

PWR = Pressurised water reactor, BWR = Boiling water reactor, FBR = Fast breeder reactor, HTGR = High temperature gas reactor.

**Table 1.2: Distribution of nuclear civil installations by operator in France**

31 December 2013	EDF	CEA	AREVA	ANDRA	Others	Total
Operating	58 <sup>1</sup>	22	10 <sup>2</sup>	2	10	102
In decommissioning (including associated plants)	9 <sup>1</sup>	21	7	0	1	38
Total plants	67	43	17	2	11	140

Source: Cour des Comptes, 2012.

1. Revised by EDF.

2. This value does not include two operating facilities at Cadarache, which are operated by CEA and are accounted for as CEA's facilities, but whose dismantling costs are to be covered by AREVA.

In the United Kingdom, 29 reactors across numerous sites, have ceased operation and are at various stages of decommissioning. Of these there are ten domestic Magnox-type nuclear power stations that have ceased operation and are being managed on a fleet approach with activities ongoing in phases (as of May 2013):

- defueling at Calder Hall, Chapelcross, Dungeness A, Sizewell A and Oldbury;
- accelerated decommissioning at Bradwell and Trawsfynydd;
- decommissioning and demolition of facilities at Hunterston A, Berkeley and Hinkley Point A.

The Nuclear Decommissioning Authority (NDA) owns these (and other) nuclear sites (19 in total) and the associated civil nuclear liabilities and assets of the public sector, and is responsible for their decommissioning. Each of the sites is managed by one of seven site licence companies (SLCs) under contract to the NDA, responsible for day-to-day operations and the delivery of site programmes. The NDA has adopted an optimisation strategy, referred to as the Magnox Optimised Decommissioning Programme, which uses the “lead and learn” concept to drive efficiency (NDA, 2012a and 2012b). According to the programme, two lead sites, Bradwell and Trawsfynydd, have set the pace in hazard clearance and technology testing, with the lessons learnt to be subsequently applied at other sites. Of the eight operating nuclear power stations run by EDF Energy (comprising 14 advanced gas reactors – AGRs – and 1 PWR Sizewell B), all AGRs are planned to cease operation in the next decade (between 2016 and 2023), with Sizewell B, expected to cease operation in 2035.

### 1.1.3. Completed projects

Experience shows that decommissioning can be carried out in a safe manner. However, experience in fully completed decommissioning of commercial power reactors is presently limited and no fleet effect can yet be observed. As detailed in Table 1.3, of the 147 power reactors that have ceased operation, 16 have undergone complete decommissioning, mostly in the United States. A number of other reactors, while not fully decommissioned yet, are at advanced stages of decommissioning, mainly in Europe, allowing valuable experience to be gained. In addition to these, a few other experimental and prototype reactors have also been fully decommissioned.

**Table 1.3: Nuclear power plants decommissioned in NEA member countries**

Country	Facility	Type	Gross electrical power	Year of decommissioning completion	Comment
Germany	Grosswelzheim	Prototype HDR <sup>1</sup>	27 MW	1998	
	Kahl	Experimental BWR	16 MW	2010	
	Niederaichbach	GCHWR	106 MW	1995	
United States	Big Rock Point	BWR	71 MW	2006	ISFSI <sup>2</sup> only
	Elk River	BWR	24 MW	1974	Licence terminated by Atomic Energy Commission, pre-NRC regulator
	Carolinas-Virginia Tube Reactor	Pressurised heavy water reactor	19 MW	1967	Licence terminated by Atomic Energy Commission, pre-NRC regulator
	Fort St Vrain	HTGR	342 MW	1997	ISFSI only
	Haddam Neck <sup>3</sup>	PWR	603 MW	2007	ISFSI only
	Maine Yankee	PWR	900 MW	2005	ISFSI only
	Pathfinder	Superheat BWR	63 MW	1993	Licence terminated
	Rancho Seco	PWR	917 MW	2009	ISFSI only
	Saxton	PWR	3 MW	2005	Licence terminated
	Shippingport	PWR	68 MW	1989	Licence terminated
	Shoreham	BWR	849 MW	1995	Licence terminated
	Trojan	PWR	1 155 MW	2005	ISFSI only
	Yankee NPS (Rowe)	PWR	180 MW	2006	ISFSI only

1. Superheated steam reactor (HDR – Heizedampfreaktor). 2. Licence reduced only to the Independent Spent Fuel Storage Installations (ISFSI) (spent nuclear fuel [SNF] in dry storage under licence). 3. Also known as Connecticut Yankee. HTGR = High temperature gas reactor; PWR = Pressurised water reactor; BWR = Boiling water reactor.

A number of worldwide examples of successful projects across a spectrum of nuclear facilities are illustrated in NEA (2009). Lessons learnt from these experiences are identified and discussed in NEA (2010a).

#### **1.1.4. The challenges ahead**

The industry's performance in decommissioning will be critical for the future of nuclear power generation. Challenges faced are significant, spanning technical, financial, social and political issues. Pressure grows in some countries to speed up NPPs closure and decommissioning, shorten overall schedules and cut the costs. As decommissioning begins in countries with little or no previous experience and/or insufficient waste interim storage or disposal capacity, more and more questions are raised over the adequacy of the necessary infrastructure and human resources, as well as the ability and mechanisms to finance the costs. Decommissioning also requires regulatory approval and oversight, the directions of which are guided by national policies (NEA, 2003). All in all, appropriate national and international regulations are required, as well as sound funding, adequate technologies, readiness in and availability of waste interim storage or disposal solutions, and a large and competent workforce.

One main factor that adds complexity is the lack of globally coherent and reliable information on decommissioning costs, rendering the issue controversial. Since these costs will incur long after operations of a nuclear power plant have been discontinued and stopped generating income, expenses related to decommissioning constitute a future financial liability. From a governmental viewpoint, particularly in a deregulated market, it is essential to ensure that money for the decommissioning of nuclear installations will be available at the time it is needed, and that no "stranded" liabilities will be left to be financed by the tax payers rather than by the electricity consumers (NEA, 2003).

A good understanding of decommissioning costs is therefore fundamental, to develop: i) coherent and cost-effective decommissioning strategies; ii) realistic cost estimates based on decommissioning plans from the outset of operation; and iii) mechanisms to ensure that future decommissioning expenses are adequately covered. However, current cost estimates are not directly comparable across countries, making comparisons difficult. Moreover, the available cost estimations show significant differences and are affected by large uncertainties even between facilities of the same type. Overall, there is considerable variability in the format, content and practice of cost estimates both within and across countries (NEA, 2015, 2012b, 2010b).

Countries have put in place varying legal and regulatory arrangements defining different responsibilities on funds accumulation and management. However, it is not always clear, in today's provisions, the extent to which these funds are protected against financial crises or variations in the expected returns from the funds, or how potential changes in operating times of power plants could affect the time frame for the build-up of funds (NEA, 2008).

These issues have become increasingly important for the nuclear industry in recent years. At the national level, several studies on decommissioning costs have been carried out in individual countries, but these necessarily reflect national policy choices and practices; with results that are therefore not directly comparable with those of other countries. As discussed in Section 1.2, initiatives have been launched by international and intergovernmental bodies on the matter, and useful reports have been produced over the years, describing national decommissioning approaches or putting forward suggestions on how to analyse decommissioning costs. However, except for the European region, for which the Decommissioning Funding Group (DFG) of the European Commission has assessed decommissioning funding and its financial security (as described in Section 1.2), no recent comprehensive overviews of international dimensions have been undertaken on the state of knowledge of decommissioning costs and funding practices across countries. Among last reviews of this kind, based on empirical country

data, are NEA (2003), followed by IAEA (2004). During the last decade, the outlook on nuclear decommissioning has evolved from what was known and expected in the early 2000s. Today some experience has been accrued internationally: some projects have been completed and several are ongoing or planned, providing new sources of information from real experience on estimations or actual costs. In addition, up-to-date analyses of actual costs of decommissioning are increasingly sought, notably among regulators, to enable benchmarking of decommissioning cost estimations with actual experience.

Against this backdrop, the present study was initiated under the auspices of the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC). To develop the work, an Expert Group on Costs of Decommissioning (COSTSDEC) was established in early 2013, with the overall objective of producing a review of the costs of decommissioning of nuclear power plants and the funding practices adopted across NEA member countries.

After providing a brief synopsis of these studies and international initiatives on decommissioning, and particularly on related estimation and funding (in Section 1.2), this chapter defines the general objectives, scope and approach of the study (in Section 1.3).

## **1.2. Recent and ongoing international initiatives**

Over the years, decommissioning has been the object of several initiatives in the international arena. Among others, of central importance are the international instruments having a direct impact on the matter: the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (IAEA, 1995) and the European Union Council Directive 2011/70/Euratom (EC, 2011). Particularly prominent is the recent joint IAEA/EC/NEA project on the “International Structure for Decommissioning Costing (ISDC) for Nuclear Installations”. Revising the earlier NEA publication known as the “Yellow Book” (last updated in 1999 – NEA, 1999), the ISDC introduces a standard, restructured, itemisation of decommissioning costs, to reflect the experience accumulated and to incorporate new IAEA radioactive waste specifications. The ISDC provides a general guidance on developing decommissioning cost estimates and, through its itemisation, a tool either for cost estimation or for mapping estimates onto a standard, common structure for comparison purposes. Further, extensive efforts on topics related to decommissioning have been done by the Radioactive Waste Management Committee (RWMC) of the NEA, notably through specialised working parties and networks operating under its auspices (e.g. the Regulator’s Forum, the Forum on Stakeholder Confidence, the Integration Group for the Safety Case, the Working Party on Decommissioning and Dismantling – WPDD). Under WPDD, the Decommissioning Cost Estimation Group (DCEG) has been working for six years issuing reports on decommissioning costing, including the ISDC (as well as, e.g. NEA, 2012c, 2012d, 2010a, 2010b, 2010c, 2009 and 2006). The current priority of the DCEG is a joint project being undertaken together with the IAEA on uncertainties in decommissioning cost estimation. The project aims to produce a report by the end of 2016 which describes approaches for addressing uncertainties in decommissioning cost estimates, building on the ISDC structure for presenting decommissioning costs.

Equally, the IAEA has been active in the field of decommissioning. IAEA’s mandate encompasses the establishment of safety standards and the provision for their application, as well as, in parallel, the Agency’s role to encourage information exchange among member countries, including in decommissioning. Within the IAEA Safety Standards structure, decommissioning activities are addressed in Part 6 of the General Safety Requirements, which is in the process of being reissued. Several IAEA networks operate in the field of radioactive waste management, covering also decommissioning, with the overall goal of promoting methods and technologies that enhance the safety and environmental sustainability of these activities. Sub-goals notably include the organisation of training and demonstration programmes, as well as fostering the

exchange of knowledge and experience for greater competence. Projects which target specifically decommissioning issues are: DRiMa (on decommissioning risk management), DACCORD (on data analysis and collection for research reactor decommissioning), CIDER (global constraints to implementing decommissioning and environmental remediation projects). Beside the ISDC report, jointly published with the NEA and the EC, various IAEA technical reports relevant to decommissioning costing and financing have also been issued over the last decade, including IAEA (2012, 2005, 2002).

In Europe, the European Commission plays a central role in monitoring decommissioning. In particular, costing and funding, and the related mechanisms adopted in member states, are the object of regular reports by the commission to the European Council and Parliament. Acknowledging the complexity of decommissioning issues and noting the potential safety implications in case of inadequacy of decommissioning funds, the commission adopted a recommendation in 2006, which led to the establishment of the DFG. DFG activities focus on the adequacy and financial security of funding and its exclusive use for the intended purposes. It also improves the consultation with the European Union (EU) member states. On this basis, the commission issued a guidance (under DFG) to support an improved common understanding and application of the 2006 recommendation; and initiated the gathering of data to ascertain the consistency of arrangements with the recommendation. The results are summarised in two reports (EC, 2013, 2009), which provide an account of the current understanding of the issue at the European level. With the recent transposition into national legislation of the 2011/70/EURATOM Directive, in August 2013, member states are now required under this directive to report to the commission the content of their national programme; the first reports are due in August 2015.

For completeness, one has to mention the specific European Union Nuclear Decommissioning Assistance Programme through which financial assistance is given to Bulgaria, Lithuania and the Slovak Republic, to help their governments meet the commitment taken during the accession negotiations of closing some Soviet designed reactors (VVER 440-230 and RBMKs) in their territories.

Finally, within the Western European Nuclear Regulators' Association (WENRA), the Working Group on Waste and Decommissioning (WGWD) has issued a report (WENRA, 2011) that provides harmonised safety reference levels (SRLs) to ensure a safe decommissioning process. SRLs constitute the basis for a common approach to nuclear safety during decommissioning in the WENRA member states and, based on national action plans, should be implemented in the legal and regulatory framework system of each member state by end 2013 (WENRA, 2011).

### **1.3. Objectives, scope and approach of the study**

The overall initial aim of this NEA study was to produce a review of NPP decommissioning costs and funding practices adopted across NEA member countries, based on the collection and analysis of survey data collected via a dedicated questionnaire. The work has been conducted in conjunction with the Radioactive Waste Management Committee and its standing groups (WPDD – DCEG), given the relevance of the project for their activities. Close co-operation with the IAEA and the EC has been ensured during this study, which has drawn on the substantial work undertaken by these bodies and organisations to minimise duplication of effort and to capitalise on the specific expertise existing in the field.

This study has been carried out by the COSTSDEC. Members of the group have brought in expertise on a wide range of issues in the field of decommissioning, including cost structure, financing mechanisms, national policies and other strategic aspects.



The principal objectives of this study were outlined in NEA/NDC(2013)1 as follows:

- To gather and assess the available knowledge on completed decommissioning projects from different countries and, to the extent possible, to consider how related cost estimates have varied over time; how uncertainties were taken into account and what contingencies were built into the planning; and what have been the key factors driving costs.
- To review economic methodologies and related aspects for the management of NPP decommissioning in NEA member countries and, if possible, in selected other countries, including the funding mechanisms in place or under consideration, how the funds are managed and the extent to which they have increased.
- To consider a selected set of decommissioning programmes, either ongoing or prospective, to perform a review of related cost estimates and to define, to the extent possible, cost categories and estimates for high-level processes with the aim of identifying broad cost ranges.

This report does not analyse or reproduce the full details of the costing approach used in individual countries or their specific project management process, nor does it make judgements on the appropriateness of costs derived within a given national context. No attempt is made to make a single global cost estimate for the decommissioning of a nuclear power reactor, owing to the inherent difficulties, risks and limitations of comparing whole-project decommissioning costs (see for example NEA, 2012d).

While the study has built on information already available to the NEA, the IAEA and the EC, a questionnaire was used to collect additional up-to-date detailed data on decommissioning-related policies and strategies, cost estimates and funding mechanisms. The questionnaire consisted of three parts:

- Part I focused on national decommissioning policies and financial arrangements.
- Part II referred to plant or unit-specific decommissioning strategy details.
- Part III, based on the ISDC structure, aimed to collect information on unit-specific cost estimates; responders were encouraged to report data, as far as possible, in line with the ISDC (NEA, 2012b).

Largely based on a former questionnaire of 2003, this survey incorporated some specific items of the EC DFG questionnaire that explored different aspects of decommissioning financing in member states (reflected in the commission's 2006 recommendations on decommissioning funding).

The scope of this study focuses on commercial nuclear power plants of all types. Recognising that the cost of decommissioning can vary considerably depending upon the type of facility being considered, other types of nuclear facilities have not been covered. Similarly, excluded from the scope are those NPPs that have experienced accidental conditions, since these could considerably affect decommissioning costs, which would not be representative of normal decommissioning activities.

While looking at this study, the reader will notice:

- In most cases, effective decommissioning activities begin after all nuclear fuel has been removed from the plant areas that will be decommissioned. This activity is in these cases part of pre-decommissioning operations.
- The cost of managing spent nuclear fuel following removal from the reactor, the interim storage and the final disposal of fuel or related waste is not always included in the cost of decommissioning, but treated separately as being the major source of costs for (high-level) waste management.

- The selection of immediate versus deferred decommissioning, as well as the planned end point of decommissioning (unrestricted site and facility release, partially restricted site and facility release, site and facility reuse in a radiological controlled fashion, etc.) are main factors that will influence the overall costs of decommissioning and limit the validity of quantitative comparisons.

The outcomes of the COSTSDEC work are summarised in this report, which, beside this introductory chapter, includes the following parts:

- Chapter 2 developing a descriptive review of different decommissioning policies, strategies and approaches across countries.
- Chapter 3 assessing economic aspects, with actual decommissioning costs for a few completed decommissioning projects and estimates for some ongoing and future projects.
- Chapter 4 appraising funding mechanisms in place or under consideration, and the management of funds and historical trends.
- Chapter 5 summing up conclusions and recommendations.

These chapters are largely based on the country/plant data obtained by means of the questionnaire. In particular, Part I of the questionnaire formed the basis for Chapters 1 and 2; Part II and Part III have been the foundation of Chapters 3 and 4. Information received for Part II and III has been limited, and the impact of this limitation is further developed in Chapter 5.

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## Appendix 1.A1. List of shutdown nuclear power plants

**Table 1.A1.1: Shutdown power reactors**

Country	Name	Type	Gross electrical capacity	Decommissioning status
Belgium	BR-3	PWR	12 MW	
Canada	Douglas point	PHWR	218 MW	
	Gentilly-1	HWLWR	266 MW	
	Gentilly-2	PHWR	675 MW	
	Pickering-2	PHWR	542 MW	
	Pickering-3	PHWR	542 MW	
	Rolphon NPD	PHWR	25 MW	
France	Bugey-1	GCR	555 MW	Dismantling ongoing
	Chinon-A1	GCR	80 MW	Dismantling ongoing
	Chinon-A2	GCR	230 MW	Dismantling ongoing
	Chinon-A3	GCR	480 MW	Dismantling ongoing
	Chooz-A (ARDENNES)	PWR	320 MW	Dismantling ongoing
	EL-4 (MONTS D'ARREE)	HWGCR	75 MW	Dismantling ongoing
	G-2 (Marcoule)	GCR	43 MW	Dismantling ongoing
	G-3 (Marcoule)	GCR	43 MW	Dismantling ongoing
	Phenix	FBR	142 MW	Dismantling ongoing
	St. Laurent-A1	GCR	500 MW	Dismantling ongoing
	St. Laurent-A2	GCR	530 MW	Dismantling ongoing
Super-Phenix	FBR	1 242 MW	Dismantling ongoing	
Germany	AVR Juelich (AVR)	HTGR	15 MW	
	Biblis-A (KWB-A)	PWR	1 225 MW	
	Biblis-B (KWB-B)	PWR	1 300 MW	
	Brunsbuettel (KKB)	BWR	806 MW	
	Greifswald-1 (KGR 1)	PWR	440 MW	
	Greifswald-2 (KGR 2)	PWR	440 MW	
	Greifswald-3 (KGR 3)	PWR	440 MW	
	Greifswald-4 (KGR 4)	PWR	440 MW	
	Greifswald-5 (KGR 5)	PWR	440 MW	
	Gundremmingen-A (KRB-A)	BWR	250 MW	
	HDR Grosswelzheim	BWR	27 MW	
	ISAR-1 (KKI 1)	BWR	912 MW	
	KNK II	FBR	21 MW	
	Kruemmel (KKK)	BWR	1 402 MW	
	Lingen (KWL)	BWR	268 MW	

See notes on page 38.

**Table 1.A1.1: Shutdown power reactors (cont'd)**

Country	Name	Type	Gross electrical capacity	Decommissioning status
Germany	Muelheim-Kaerlich (KMK)	PWR	1 302 MW	
	MZFR	PHWR	57 MW	
	Neckarwestheim-1 (GKN-1)	PWR	840 MW	
	Niederaichbach (KKN)	HWGCR	106 MW	
	Obrigheim (KWO)	PWR	357 MW	
	Philippsburg-1 (KKP 1)	BWR	926 MW	
	Rheinsberg (KKR)	PWR	70 MW	
	Stade (KKS)	PWR	672 MW	
	THTR-300	HTGR	308 MW	
	Unterweser (KKU)	PWR	1 410 MW	
	VAK Kahl	BWR	16 MW	
	Wuergassen (KWW)	BWR	670 MW	
Italy	Caorso	BWR	882 MW	
	Enrico fermi	PWR	270 MW	
	Garigliano	BWR	160 MW	
	Latina	GCR	160 MW	
Japan	Fugen ATR	HWLWR	165 MW	
	Fukushima Daiichi-1	BWR	460 MW	
	Fukushima Daiichi-2	BWR	784 MW	
	Fukushima Daiichi-3	BWR	784 MW	
	Fukushima Daiichi-4	BWR	784 MW	
	Hamaoka-1	BWR	540 MW	
	Hamaoka-2	BWR	840 MW	
	Japan Power Demonstration Reactor	BWR	13 MW	
Russia	Tokai-1	GCR	166 MW	
	APS-1 Obninsk	LWGR	6 MW	
	Beloyarsk-1	LWGR	108 MW	
	Beloyarsk-2	LWGR	160 MW	
	Novovoronezh-1	PWR	210 MW	
Slovak Republic	Novovoronezh-2	PWR	365 MW	
	Bohunice A1	HWGCR	150 MW	Dismantling ongoing
	Bohunice V1-1	PWR	440 MW	Dismantling ongoing
Spain	Bohunice V1-2	PWR	440 MW	Dismantling ongoing
	José Cabrera (Zorita)	PWR	160 MW	Immediate dismantling ongoing
Sweden	Vandellós-1	GCR	500 MW	Dormancy period
	Agesta	PHWR	12 MW	Deferred
	Barsebäck-1	BWR	615 MW	Deferred
	Barsebäck-2	BWR	615 MW	Deferred

See notes on page 38.

**Table 1.A1.1: Shutdown power reactors (cont'd)**

Country	Name	Type	Gross electrical capacity	Decommissioning status
Switzerland	Lucens	HWGCR	6 MW	
United Kingdom	Berkeley 1	GCR	166 MW	
	Berkeley 2	GCR	166 MW	
	Bradwell 1	GCR	146 MW	
	Bradwell 2	GCR	146 MW	
	Calder hall 1	GCR	60 MW	
	Calder hall 2	GCR	60 MW	
	Calder hall 3	GCR	60 MW	
	Calder hall 4	GCR	60 MW	
	Chapelcross 1	GCR	60 MW	
	Chapelcross 2	GCR	60 MW	
	Chapelcross 3	GCR	60 MW	
	Chapelcross 4	GCR	60 MW	
	Dounreay DFR	FBR	15 MW	
	Dounreay PFR	FBR	250 MW	
	Dungeness-A1	GCR	230 MW	
	Dungeness-A2	GCR	230 MW	
	Hinkley point-A1	GCR	267 MW	
	Hinkley point-A2	GCR	267 MW	
	Hunterston-A1	GCR	173 MW	
	Hunterston-A2	GCR	173 MW	
	Oldbury-A1	GCR	230 MW	
	Oldbury-A2	GCR	230 MW	
	Sizewell-A1	GCR	245 MW	
	Sizewell-A2	GCR	245 MW	
	Trawsfynydd 1	GCR	235 MW	
	Trawsfynydd 2	GCR	235 MW	
	Windscale AGR	GCR	36 MW	
	Winfrith SGHWR	SGHWR	100 MW	
Wylfa 2	GCR	540 MW		

See notes on page 38.

**Table 1.A1.1: Shutdown power reactors (cont'd)**

Country	Name	Type	Gross electrical capacity	Decommissioning status
United States	Big Rock Point	BWR	71 MW	ISFSI only
	BONUS	BWR	18 MW	Entombed
	Crystal River-3	PWR	890 MW	Deferred
	Carolinas-Virginia Tube Reactor	PHWR	19 MW	Licence terminated
	Dresden-1	BWR	207 MW	Deferred
	Elk River	BWR	24 MW	Licence terminated
	Fermi-1	FBR	65 MW	Deferred
	Fort St. Vrain	HTGR	342 MW	ISFSI only
	Haddam Neck	PWR	603 MW	ISFSI only
	Hallam	EGSR	84 MW	Entombed
	Humboldt Bay	BWR	65 MW	Deferred 30 years
	Indian Point-1	PWR	277 MW	Deferred
	Kewaunee	PWR	595 MW	Deferred
	Lacrosse	BWR	55 MW	Deferred
	Maine Yankee	PWR	900 MW	ISFSI only
	Millstone-1	BWR	684 MW	Deferred
	Nuclear Ship Savannah	PWR	Naval	Deferred
	Pathfinder	BWR	63 MW	Licence terminated
	Peach Bottom-1	HTGR	42 MW	Deferred
	Piqua	EOMR	12 MW	Entombed
	Rancho Seco-1	PWR	917 MW	ISFSI only
	San Onofre-1	PWR	456 MW	Deferred
	San Onofre-2 and 3	PWR	2 x 1 127 MW	Deferred
	Saxton	PWR	3 MW	Licence terminated
	Shippingport	PWR	68 MW	Licence terminated
	Shoreham	BWR	849 MW	Licence terminated
	Three Mile Island-2	PWR	959 MW	Deferred
	Trojan	PWR	1 155 MW	ISFSI only
	Vallecitos	BWR	24 MW	Deferred
	Vermont Yankee	BWR	535 MW	Deferred
Yankee NPS (Rowe)	PWR	180 MW	ISFSI only	
Zion-1 and 2	PWR	2 x 1 085 MW	Deferred 15 years	

AGR = Advanced gas reactor; BWR = Boiling water reactor; EGSR = Experimental graphite-sodium reactor; EOMR = Experimental organic moderated reactor; FBR = Fast breeder reactor; GCR = Gas-cooled reactor; HTGR = High temperature gas reactor; HWGCR = Heavy water gas-cooled reactor; ISFSI = Independent spent fuel storage installations; LWGR = Light water graphite reactor; PHWR = Pressurised heavy water reactor; PWR = Pressurised water reactors; SGHWR = Steam generating heavy water reactor.



## Chapter 2. Policies, strategies and approaches

### 2.1. Introduction

Plant decommissioning in the nuclear industry is a complex, multifaceted and multidisciplinary endeavour. It is not simply limited to demolition activities, but, following fuel removal from the reactor area (usually considered as a pre-decommissioning activity), it involves a series of actions towards a systematic deconstruction of complex plants, and the dismantling and decontamination of its individual components. The definition of decommissioning provided by the International Atomic Energy Agency (IAEA) is generally accepted, even though there is no universally applicable definition and there are variations in the national definitions used in individual countries. As defined by IAEA (1999), “decommissioning encompasses all technical and administrative activities aimed at releasing the nuclear site or installation, removing (some or all of) the regulatory requirements and making it suitable to be used for other purposes (with or without restrictions)”. As such, decommissioning is a lengthy process whose preparation starts well before any physical decommissioning activity, through the provision and revision of appropriate plans, during the lifetime of the facility, or even at the stage of its design.

Generally accepted principles and overarching frameworks underlie decommissioning policies and strategies. These principles are discussed in Section 2.2. Section 2.3 develops an overview of decommissioning policies, options and strategies, implementation and waste management approaches adopted by some countries. This appraisal is based on data supplied in response to Part I of the survey (questionnaire) conducted within the framework of this project. Appendix 2.A1 reports a synoptic table summarising relevant national responses obtained through the survey, while relevant country specificities are explicitly discussed in the text.

To help set a common ground, a glossary can be found at the end of this report, defining terms and concepts used in this report, in relevant literature and as understood and agreed upon by the COSTSDEC.

### 2.2. Principles and frameworks

#### 2.2.1. Principles

Generally agreed principles underpin decommissioning practices, and are addressed by international instruments and national legislation (see, e.g. NEA, 2006). The safety of workers and the public during and after decommissioning of nuclear facilities is the overarching concern. This entails the protection of individuals, society and the environment against potential hazards and from harmful effects of ionising radiation, during and after the decommissioning process, including from the generated radioactive waste. Sustainable assurance of safety is reflected in two of the key principles in decommissioning: “intergenerational equity” and “user/polluter pays”, which also raise specific financial obligations. These and other principles are defined at length in the IAEA Safety Fundamentals (IAEA, 1995a).

The “intergenerational equity” principle states that each generation benefiting from nuclear power should deal with its radioactive waste in a manner that protects human health and the environment, now and in the future, without imposing undue burdens on future generations (IAEA, 1995b).

The “user/polluter pays” principle states that those causing pollution should meet the costs of clean-up and other costs relating to the creation of a pollutant. This principle translates into the requirement for “users/polluters” to build up financial means for a safe and secure disposal of the waste (NEA, 2006). A corollary to this requirement is the need to ensure that there are adequate funds and mechanisms in place for securing the funds. This principle also addresses the aim to achieve internalisation of all costs, associated with nuclear power production, including those arising in the future (e.g. decommissioning and the management of spent nuclear fuel and radioactive waste).

In addition to these general principles, there are additional criteria underpinning the establishment of adequate funds, including: sufficiency, availability and transparency (NEA, 2006):

- Sufficiency – contributions are to be in line both with the total fund collection period, and the overall funding goals that need to be reached according to the strategy chosen.
- Availability – to ensure a level of liquidity compatible with the timetable for liabilities and their costs, the management and periodical review of funds is vital; in addition, the funds are to be used only to cover the costs of the decommissioning obligations in line with the decommissioning plan, and not for other purposes.
- Transparency – funds, their accumulation, related expenses and the financial management must be transparent to the relevant national and regulatory authorities. It is also necessary that the funding system complies with national tax law.

Social issues and public involvement are also central to decommissioning activities. With safety, there are “pillars of trust” (NEA, 2003a) central to the strategy selection for decommissioning of nuclear facilities:

- Participation – stakeholder involvement includes early discussion of plans and then continued dialogue, in particular with local communities.
- Economic development – long-term economic activity, future use of the site and compensatory measures and benefits for the local communities need to be addressed.

### **2.2.2. International legal instruments on spent fuel and radioactive waste management**

The principles introduced above are incorporated into international legal instruments focusing on the management of spent fuel and radioactive waste (including the waste resulting from decommissioning activities, and the decommissioning of dedicated spent fuel and radioactive waste management facilities).

The IAEA (1997) Joint Convention on Safety of Spent Fuel Management and Safety of Radioactive Waste Management, states,

“Each Contracting Party shall take the appropriate steps to ensure that:

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

B) 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 disposal facility”.

Within the European Union (EU), a legally binding framework for the responsible and safe management of spent fuel and radioactive waste is defined through a Council Directive promulgated in 2011 (EC, 2011). According to this directive, all EU member states are to ensure that funding resources are available for waste management. In its preamble, the directive refers to an EC recommendation (2006a) and a guideline on the management of financial resources for the decommissioning of nuclear installations and the handling of spent fuel and radioactive waste (EC, 2006b). The guideline highlights, given the considerable variability in cost assessment methodologies adopted by different countries, “it is important that the national framework clearly defines the underlying hypothesis, all inputs and boundary conditions to be applied for the cost assessment, including the time periods between reassessments and the methodology for refinement”. Monitoring reports on the implementation of the recommendation are regularly issued by the European Commission (EC, 2013a, 2013b).

### **2.2.3. National legislation and regulatory requirements**

In general, regulations regarding decommissioning plans and related cost estimates and financing have their basis in law. National legal and institutional frameworks are essential for the management of liabilities from retired nuclear facilities, as well as for nuclear waste generated during their operation and decommissioning. Such frameworks are required to ensure that policies and strategies are set out and effectively implemented, and that financial and non-financial responsibilities are clearly defined and suitably allocated to those responsible for discharging the liabilities. They typically address issues such as the establishment of adequate funds, their sound administration (including consideration of inflation and escalation), their safeguarding against mishandling, inappropriate claims or use, and, in case of inadequate funding, the provision of financial guarantees and/or appropriate corrective actions. In particular, it is necessary that the continued fulfilment of responsibilities is ensured over the whole financing and spending period, including the accumulation of funds during operation and the entire decommissioning period, potentially spanning several decades after shutdown, depending on the strategy being followed.

At the national level, decommissioning and radioactive waste management are covered either in special statutes, or in general nuclear energy laws (NEA, 2013). In the latter case, specialisation of regulation occurs at a lower level of legislation and/or in administrative regulatory provisions. Laws are sometimes subject to regular revisions and can also be changed, should the boundary conditions change (NEA, 2013). Many of the countries with well-established nuclear power programmes already have in place comprehensive legislation (laws, acts, decrees, ordinances, codes, etc.) on decommissioning, in line with the general principles discussed earlier. However, in some cases, such legislation has only recently been enacted or is otherwise being developed. Statutory aspects related to financing are, in specific countries, of more recent implementation.

Even though commonly accepted principles and concepts form the basis of all legal provisions at the national level, country legislation can show substantial differences. Variability of regulation can emerge in the specific structure, degree of detail, and definition of boundaries and constraints. Laws can be, for instance, more prescriptive or, instead, define general guidelines or main principles, based on a goal setting approach. The national legislation can set constraints on policy decisions regarding the basic strategic options for decommissioning, i.e. immediate or deferred dismantling (see Section 2.3), or leave the decision to the operators, provided specific requirements, set in national regulatory frameworks, are enforced.

Regarding decommissioning cost estimates, regulations dictate to some extent the responsibilities of the principal parties involved (NEA, 2010a; EC, 2006a, 2006b). Owners/licensees are generally responsible for developing cost estimates and funding mechanisms, which are to be periodically submitted to the designated competent authority for review or approval. In most countries the designated competent authority plays a major role in approving the decommissioning strategy selected, reviewing the cost estimates developed, and reviewing (and in some cases prescribing) the funding mechanism used to assure adequate funding for decommissioning. The administrative aspects of various national requirements are reported in NEA (2010a) and EC (2013a, 2013b).

Nuclear decommissioning entails a high level of engagement and oversight by the nuclear regulatory authorities through a series of authorisations and/or licences (or licence amendments), bearing in mind the obligation of the licensee to adhere to a multiplicity of regulatory requirements. Aspects concerning safety, the protection of the public and the environment, the clearance of materials, etc., are also addressed in specific regulations by the pertinent regulatory authorities (at the national and/or local level).

In general, no specific licence is required for the plant shutdown itself (with some exceptions: e.g. Canada, the Czech Republic and France). However, in the majority of cases, the licensees must inform the relevant authorities of the intention to stop activity (see QP23 of Appendix 2.A1). In addition, at (or before) key transition points after closure (e.g. end of generation to defueling), the licensee could be required to submit reports for approval of proposed management and structural changes to support the transition arrangements (e.g. in the United Kingdom) or specific notifications. Conversely, in most cases, to actually start decommissioning of a nuclear power plant (NPP), a specific licence (permit or order), or amendments/revisions to the existing licence (e.g. Finland) are requested (see QP24 of Appendix 2.A1). Sometimes, preparatory activities can (e.g. in Switzerland) or must (e.g. in Spain<sup>1</sup>) be conducted before the decommissioning licence is issued. In a few cases, such as Sweden and the United States, no specific licence is required for decommissioning, although other authorisations are applied. For example, in the United States, decommissioning is considered to have far less risks than operating the reactor (for which the licensee was licensed) and is entrusted by the common defence provisions of US Nuclear Regulatory Commission (NRC) regulations. For countries requesting a decommissioning licence or other similar regulatory approval prior to decommissioning, the relevant application generally contains a decommission plan with several documents reporting general information and specific data, typically including the following (see QP25 of Appendix 2.A1):

- objectives, methods, time schedules, and technical procedures;
- method for the management of resulting radioactive substances: inventories, limits and conditions, means and plans;
- safety analysis report (and study of risk management on the operations);
- environmental impact assessment;
- details on changes;
- economic study of the dismantling process with financial investments and expected costs (e.g. in Spain), providing basis for financing of decommissioning

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1. In Spain, a difference is made between those activities to be carried out by the utility, i.e. unloading of spent fuel (SF) and conditioning of operational radwaste (RW), and those other preparatory activities carried out by *Empresa Nacional de Residuos Radioactivos S.A.* (Enresa) under the decommissioning permit, i.e. adaptation of systems and auxiliary installations.

- activities (e.g. in Switzerland – cost studies as a basis for making adequate provisions to funds);
- scope and method of measurement and evaluation of exposure, radiological status of the installation;
- on-site emergency plan;
- evidence of provision of physical protection;
- quality management programme;
- human and organisational factors.

Sometimes, evidence is also requested of the availability of sufficient suitably qualified personnel (e.g. in Switzerland). Additional specific requirements may be set, in individual countries, for instance in relation to the licence of repositories or storage facilities for the decommissioning waste (e.g. in Finland).

Requisites for the de-licensing of a site are set in a similar fashion, in most countries. Typically, such prerequisites include (see QP6 and QP23 to QP25 in Appendix 2.A1):

- the completion of decommissioning activities in accordance with the applicable regulations and the achievement of the predefined end point of decommissioning;
- the verification of technical conditions and monitoring established in the programme to achieve the predefined end point;
- demonstration that the installation no longer represents a radiological risk;
- the compliance with waste management obligations;
- the production or revision and approval of several documents and analyses (e.g. safety analyses, analysis of the soil conditions, etc.);
- the fulfilment of requirements for the clearance of the buildings and the site – notably limits on annual doses.

In general, on the basis of the analyses received and further inspections and monitoring conducted, the safety authority prepares a report to form the basis of a decision by the authority itself, or to serve as the basis for a decision by the concerned ministry or government. Close public participation can be required in the process. Conditions for the release of material, equipment, buildings or sites from regulatory control are based on dose limits from residual activity and vary across countries (see QP22 in Appendix 2.A1).

## **2.3. Policies, options and strategies, implementation and waste management**

### **2.3.1. Policies**

As defined in IAEA (2011, 2014), a decommissioning policy is a set of established goals or requirements for the safe and effective decommissioning of nuclear facilities. In some countries the policy on decommissioning may be part of the national policy on radioactive waste management. While generally complying with the relevant principles and international instruments discussed in Section 2.2, the detailed features of national policies are ultimately determined by multiple, sometimes interlinked factors that are typically country specific, reflecting national priorities, circumstances, structures, human and financial resources (IAEA, 2011). Principally established by the national government, a decommissioning policy embraces governmental (national and regional) choices that are set in laws, regulations, standards and mandatory requirements, shaping the framework of decommissioning implementation and execution. As illustrated in IAEA

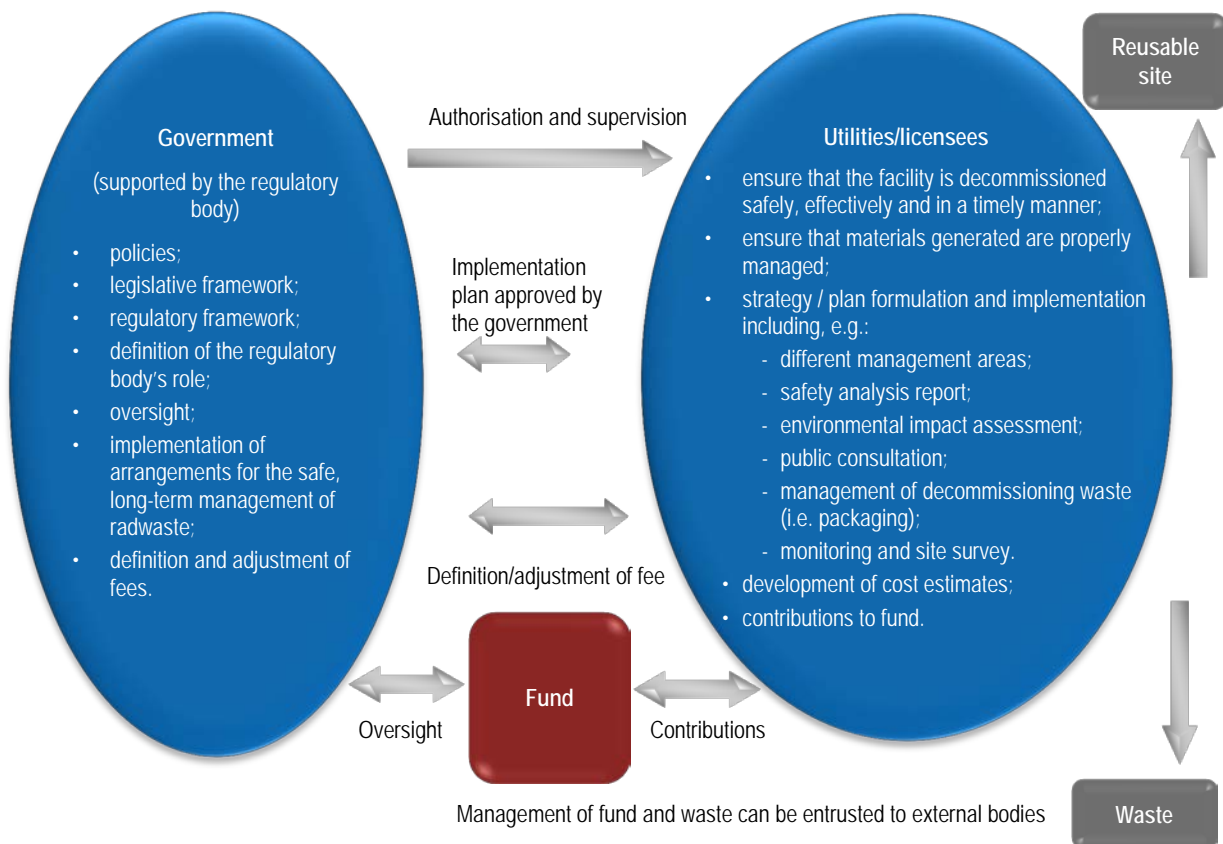
(2011), the main elements coming into place in the establishment of a national policy for decommissioning are:

- allocation of roles and responsibilities;
- provision of resources;
- decommissioning approaches;
- safety and security objectives;
- radioactive waste management;
- hazardous waste minimisation;
- end points for decommissioning;
- public information and participation.

The allocation of responsibilities is of crucial importance for the performance of decommissioning, as emphasised in an independent assessment (Öko-Institut, 2013). Unclear attribution of roles with diluted and dispersed responsibilities is identified as a major cause of inefficiencies and delays in specific decommissioning projects.

A possible structure of an institutional framework to foster effectiveness is illustrated in Figure 2.1, depicting the principal responsibilities of the government and the utilities/licensees.

**Figure 2.1: Example of institutional framework and associated responsibilities**



### 2.3.2. Options and strategies

The means for achieving the goals and requirements defined in a national policy for the decommissioning of nuclear facilities are set out in the decommissioning strategy, normally established by the facility owner or operator in accordance with any applicable nationally determined policy. In general, the decommissioning strategy lays out the approach to decommissioning and includes all aspects that are proposed to the national authorities in the context of the application for permission to decommission. However, the line separating policy from strategy is not always clearly defined, with some aspects and requirements that overlap and they can be specified either in the policy or in the strategy. For example, specific decommissioning methods and approaches may be explicitly defined in the national policy, or left to the decision of the strategy makers. Some countries may not distinguish between the two concepts and instead have a national plan that is a combined policy and strategy.

At present, the two industrial approaches generally accepted for decommissioning are immediate dismantling and deferred dismantling or safe enclosure, as defined in IAEA (2014):

- Immediate dismantling is the strategy by which the equipment, structures and parts of a facility containing radioactive and hazardous contaminants are removed or decontaminated to a level that permits the facility to be released for unrestricted use, or with restrictions imposed by a regulatory body. In this case, decommissioning implementation activities begin shortly after the permanent cessation of operations. This strategy implies prompt completion of the decommissioning project and involves the removal of all radioactive material from the facility to another new or existing licensed facility and its processing for either long-term storage or disposal. Sometimes, in case of unavailability of management routes for the spent nuclear fuel (SNF), this is kept in interim storage on-site. In these cases, while the bulk of the plant can be dismantled immediately, some parts must be kept until all SNF is removed. Immediate dismantling can make good use of the knowledge of the existing staff from the facility.
- Deferred dismantling is the strategy in which parts of a facility containing radioactive contaminants are either processed or placed in such a condition that they can be safely stored and maintained until they can subsequently be decontaminated and/or dismantled to levels that permit the facility to be released for unrestricted use or with restrictions imposed by the regulatory body. The deferral periods considered have ranged from 10 to 80 years (Deloitte, 2006). It may even be more in some cases.

Entombment, in which all or part of the facility is encased in a structurally long-lived material, is not considered a decommissioning strategy and is not an option in the case of planned permanent shutdown (IAEA, 2014). It may be considered a solution only under exceptional circumstances (e.g. specific sites conditions, or following a severe accident), and is still an option left open in some countries.

Immediate and deferred dismantling may be considered to present specific benefits and disadvantages, some of which are summarised in Table 2.1. However, national policies determine which approach is adopted and, for any selected approach, adequate funding is required as well as trained personnel, regulatory oversight, and adequate waste storage and disposal facilities (IAEA, 2006). Regardless of the option selected it is vital that early and clear decisions are taken about the timing of the closure of facilities and intended future use of the site (IAEA, 2014).

In some cases, specific options and unified strategies are set at the national level. This is the case for five countries responding to the survey: the Czech Republic, France, Korea, the Netherlands and Spain (see QP7 of Appendix 2.A1). More often, licensees are responsible for defining a decommissioning strategy for individual facilities, which fulfils

the national requirements (Belgium, Canada, Finland, the Slovak Republic, Sweden, Switzerland, the United Kingdom and the United States).

**Table 2.1: Perceived benefits and disadvantages of immediate and deferred dismantling**

	Immediate dismantling	Deferred dismantling
Possible advantages	<ul style="list-style-type: none"> <li>- availability of highly qualified nuclear workforce and their experience and knowledge on the operational history of the specific facility;</li> <li>- less risk of loss of knowledge and corruption of records;</li> <li>- dilution of economic effects for the region;</li> <li>- earlier reuse of site;</li> <li>- responsibility for the decommissioning is not transferred to future generations;</li> <li>- easier radiological characterisation and reduced effects of deterioration and ageing like corrosion.</li> </ul>	<ul style="list-style-type: none"> <li>- reduction of residual radioactivity due to natural radioactive decay: reduction of radiation hazard during dismantling and reduction of volume of radioactive waste;</li> <li>- possibility to co-ordinate the decommissioning of different units in multiple reactor sites;</li> <li>- possibility to wait for availability of disposal routes for rad waste or for expected improvements in techniques (e.g. robotics) could further reduce hazards and costs;</li> <li>- option to allocate and plan the limited available human and financial resources in case of several parallel decommissioning projects;</li> <li>- time for decommissioning funds to grow or to be additionally raised;</li> <li>- possibility to increase the size of the fund through effective investments policies.</li> </ul>
Possible disadvantages	<ul style="list-style-type: none"> <li>- higher radiation exposure during dismantling;</li> <li>- greater precautions needed during dismantling;</li> <li>- larger volumes of decommissioning waste classified as radioactive;</li> <li>- the motivation of personnel might be a problem when demolishing a plant where the workers lost their jobs.</li> </ul>	<ul style="list-style-type: none"> <li>- some materials or buildings, including concrete and steel, may deteriorate;</li> <li>- costs for maintenance and/or disposition may increase;</li> <li>- no foreseeable changes in boundary conditions e.g. availability of waste disposal routes or changes in the regulatory framework with major effects on the decommissioning;</li> <li>- knowledge of operational history lost over time;</li> <li>- new qualified staff required;</li> <li>- leaves the burden to be borne by future generations, in technical, but possibly also in financial terms;</li> <li>- risk of losing fund value.</li> </ul>

Appendix 2.A1 provides a synopsis of definitions and features of decommissioning strategies in different countries, as derived from the survey (notably through points QP7 to QP17). Sometimes, specific guidance for this selection is provided (e.g. Canada, the United Kingdom and the United States), to various degrees, but this is infrequent.

In countries adopting unified national strategies, the process of selection has been multilateral, involving several parties and leading to a joint decision (e.g. in France, Korea, the Slovak Republic, Spain and the United States). In most cases, together with the utility/operator, the regulatory authorities are involved (e.g. in France, the Slovak Republic, Spain and the United States). In a few instances, the national government also



participates in the process (France, the Slovak Republic and Spain) and, sometimes, regional governments do too, as is the case in France, Spain<sup>2</sup> and the United States. Stakeholders consulted usually include the national government through the responsible ministries, the local or regional administration, the regulatory authorities and the industry (e.g. operators, qualified experts). The public can also be involved in the process, e.g. through local consultations and public hearings, public debates at the local and national levels, including, in some cases, in the development of scenarios and the determination of the site-end state (NEA, 2010b). In recent years affected publics have also been increasingly encouraged to review decommissioning plans and in some cases cost estimates and funding arrangements. The consultative process may be facilitated through a local information commission (CLI in France) or a community oversight board, which may comment on technical issues and influence the direction being taken for the decommissioning of the facility (NEA, 2010b). In the Czech Republic, the process is unilaterally conducted by the utility/operator.

The factors affecting the broad-based optimisation for the selection of the decommissioning strategy are multifaceted; some of these are reported in Table 2.2 showing the degree of importance attached to these by different countries. This demonstrates how the strategy selection is highly dependent on country – and even facility-specific conditions. Even more, Table 2.2 as presented provides a tentative summary of the member country replies received via the survey. For each country, there may be further interpretation of weighting and priorities, depending on the specific organisations involved and their respective responsibilities (*inter alia* utilities versus regulatory authorities). The diversity of views between and within countries, which are all boundary conditions for establishing cost estimates, explains why benchmarking of decommissioning programmes and projects is very difficult, while comparison is possible and recommended for similar activities or project components.

In the process, strategic and technical matters need to be weighed against financial and socio-economic considerations. However, all decisions and resulting operations should be undertaken in a spirit of transparency and openness, with the involvement of the public and an understanding of their concerns. For this reason, multi-attribute analyses that take into account, for example, economic, technical, social and environmental aspects, are generally adopted in the selection and the optimisation of the decommissioning strategy (e.g. in Spain and in the Slovak Republic, scores and weights are used).

Selection processes also aim at implementing international standards and requirements, as well as national regulation and recommendations from the regulatory authorities. As reported in Section 2.2.3, national legislation may prescribe that specific strategy options / alternatives are included in the selection process.

Where deferred dismantling is considered, deferral periods range between 20 and around 100 years (e.g. 25 years in Spain, 30 years in the Slovak Republic, 40 years in the Czech Republic, 60 years in the United States, and a century in the United Kingdom).

Recently, there seems to be an increasing tendency to favour immediate dismantling, particularly in the European Union. In France, since 2003, regulations only allow immediate or slightly deferred dismantling of nuclear facilities. In the shift from deferred to immediate dismantling as the reference strategy, the position of the French nuclear safety authority has been key. In Italy there was a move from deferred dismantling to immediate decommissioning in 1999.

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2. Regional governments participate via the information process for the approval of the General Radioactive Waste Plan (GRWP) that defines national policy and related strategies for radioactive waste management and D&D. Their comments are received and assessed by the Ministry for Industry, Energy and Tourism (MINETUR) as the responsible department.

**Table 2.2: Factors considered in the choice of decommissioning strategies**

Factors	Czech Republic		Finland		France		Italy		Korea		Netherlands		Spain		Slovak Republic		Sweden		Switzerland		UK		US		
	*	**	*	**	*	**	*	**	*	**	*	**	*	**	*	**	*	**	*	**	*	**	*	**	***
Radiological protection and industrial safety		✓		✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Technical feasibility		✓		✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Radioactive waste disposal		✓		✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Regulations		✓		✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Costs	✓			✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Funds		✓		✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Uncertainties on regulations/other	✓			✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Social and political factors	✓			✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Site reuse	✓			✓	✓		✓		✓	✓	✓	✓		✓		✓		✓		✓		✓		✓	✓
Others	✓			✓ <sup>1</sup>																					✓ <sup>3</sup>

\* = low; \*\* = medium; \*\*\* = high.

1. Availability of skilled personnel is the key factor for the strategy at Loviisa NPP. The decommissioning of all units at the same time is the strategy at Olkiluoto NPP.
2. Human factors/knowledge transfer.
3. If there are multi-unit sites at the facility, it is likely the operator will chose deferred dismantlement and plan to decommission all of the units all together.

### 2.3.3. Implementation of decommissioning activities

The specific definition of decommissioning activities and their execution are the responsibility of the licensees. Different organisational models can be implemented, whereby this responsibility for the implementation of specific decommissioning activities may lie directly with the licensee, or in some cases can be transferred by the licensee to another body (as it is the case in Spain), where full responsibility is transferred by the licensees to Empresa Nacional de Residuos Radioactivos S.A. (Enresa), or in the United Kingdom, where current arrangements allow for other organisations to bid for the decommissioning work, called by Nuclear Decommissioning Authority (NDA).

Organisational aspects, including project and risk management, and the organisation of work, personnel, knowledge and competences, are of the essence in the execution of decommissioning projects. Organisational requirements emerging in decommissioning projects, however, differ substantially from those relevant to the operational phase of a plant, and are, in many ways, more similar to those of a construction project. As in the new build construction phase, project risk management is much more significant than during routine operations. At the same time, the risk profile changes from nuclear to industrial safety, because spent fuel is removed from the site. Transitional issues when moving from the operational to the decommissioning phase are critical, with a number of areas in the organisation necessitating changes. The scope and pace of implementation of such organisational transitions can have a determining impact on the effective execution of decommissioning activities and, hence, on their costs (Öko-Institut, 2013).

Specific details for the decommissioning activities are laid out in the decommissioning plan prepared by the licensee. Based on the decommissioning strategy, this includes a set of documents and data on the proposed decommissioning activities to support the regulatory authority's evaluation of their safe execution. The definition of an initial decommissioning plan is often required at the start of the life cycle of new nuclear plants (IAEA, 2014); this is the case in the majority of countries covered in the survey. In general, a preliminary decommissioning plan is to be drawn up before a new nuclear facility (typically a new nuclear power plant) can be built, as a requisite for the siting application or the operating licence. The initial decommissioning plan includes the feasibility of decommissioning, main steps of the decommissioning/dismantling and the end state of the facility and is the basis for the initial estimation of decommissioning costs. Specific aspects of preparation for decommissioning are to be included in each stage of the life cycle of a nuclear installation, as set out, e.g. in IAEA (2014). The initial decommissioning plan is of a general nature during the design phase and will be subsequently supplemented, updated and periodically resubmitted to the regulatory authorities during the operating phase, as appropriate. As the basis for commencing major decommissioning activities, a final decommissioning plan is generally requested before the beginning of the decommissioning phase together with the safety case. This detailed document will also be updated as required during the decommissioning stages. A detailed schedule of activities and corresponding milestones foreseen in the decommissioning plan are defined in the decommissioning programme, developed for planning and monitoring purposes.

In a few countries, requirements for the definition of the decommissioning plan come only at this late stage in the life cycle of the plant, closer to the decommissioning time. This is the case in:

- the United States – where it is normally requested at (about) five years before the scheduled end of an operating licence, or two years after a premature shutdown;
- the Netherlands – for existing plants a decommissioning plan is required directly after shutdown.

Key defining points for decommissioning activities are their exact start, the end point and the duration of decommissioning. These vary from country to country, based on national arrangements, or may even depend on the specific facility. In general these are defined in the site decommissioning plan (or project) and assessed by the regulatory authority (exceptionally, they may be also set in the national policy).

There are two minimal conditions required in all countries surveyed before the start of decommissioning: operations of the facility must have ceased and some form of authorisation is to be granted before the licensee can begin the main decommissioning activities. This generally entails the submission of documents and/or a set of activities to be undertaken in preparation of decommissioning. In certain cases, time constraints on the decommissioning start are specified in the national legislation. For instance, in France decommissioning must commence three years after shutdown and in the Netherlands directly after shutdown.

The intended end point of decommissioning is typically defined in the decommissioning plan, in line with regulatory requirements. In all cases, completing the decommissioning, implies the fulfilment of a specific number of regulatory requirements, including those for clearance. Other than national authorities, including local authorities, may have requirements concerning the end state and/or intended use. In most cases, no specific legislative requisites are set regarding the future intended use of the site after decommissioning. The end point defined in the decommissioning plan is also used for cost estimation studies. It is generally assumed that decommissioning is accomplished when the relevant authorities agree on de-licensing the plant or site, which entails that all radioactive and other hazardous waste is removed and any risks to health, safety, security of public and the environment are eliminated. To that end, the minimum condition is a sufficient degree of radiological decontamination, which allows restrictions imposed by the regulatory authority to be removed. In the United States, for example, the sufficient condition to complete decommissioning to NRC standards and regulations is the achievement of radiological decontamination; further obligations can then apply according to individual state jurisdictions. In other countries national regulations can set additional requirements, irrespective of the future intended use of the site; including, for instance, conventional demolition of all buildings on-site above a defined level and, sometimes, up to a given depth below grade, e.g. in France.

In most countries no mandatory time frames, prescribing by which time the end point of decommissioning needs to be achieved, are legally defined (see QP5 in Appendix 2.A1). However, time frames are generally defined in the decommissioning plan/project. Spain and the United States are among the few cases where a precise duration for decommissioning is fixed (respectively, 7 years as key assumption for cost estimate, planning and financing purposes, from the declared date of issuance of the decommissioning permit and transfer to Enresa, for immediate dismantling in Spain, and 60 years for deferred dismantling in the United States).

One implication of a preference for immediate dismantling in many countries is an expectation that decommissioning will be effectively completed in the shortest possible time. In France this is explicitly set in the administrative authorisation for dismantling.

#### **2.3.4. Management of decommissioning waste**

While volumes of radioactive decommissioning waste are significant, and far greater than the volumes generated during operations, its radioactivity is generally low. Radioactive waste from decommissioning waste is therefore predominantly categorised as low- (or very low-) level waste (LLW) to intermediate-level waste (ILW), with minimal high-level waste (HLW) involved (see IAEA, 2009, for waste categorisation). In the case of nuclear reactors, about 99% of the radioactivity at shutdown is associated with the spent fuel, which is removed following permanent shutdown. Once tanks and pipes are drained, the majority of the radioactive materials remaining are in solid form in the reactor

pressure vessel and its internals, which are less likely to enter the environment. A substantial proportion of materials to be handled during decommissioning never gets contaminated or activated, and can be released from nuclear control as non-radioactive waste. This category of non-radioactive wastes, including cleared materials, is by far the largest in terms of overall quantity and volume.

In some countries, the licensees or the responsible body have established methodologies and practices for clearance. In most cases, generic clearance levels and criteria are established nationally, and specified in relevant legislation (or regulation) (Finland, Korea, the Slovak Republic, Switzerland, the United Kingdom). Clearance levels are typically defined by the regulatory authority and expressed in terms of activity concentration and/or total activity, at or below which a source of radiation may be exempt or released from regulatory control. In addition, reference to the annual dose and radiation exposure deriving from the source may be made (e.g. in Finland). Beyond the IAEA Safety Standards, in the European Union, legally binding levels are also provided by the European Commission Basic Safety Standards (EC, 2013c).

Licensees, or the designated body that discharges their decommissioning responsibilities, can pursue clearance of waste and propose specific not licensed destinations (reuse, recycling, incineration or landfill disposal). The applicant must demonstrate compliance with the radiological criteria for clearance. In some countries, the licensees or the responsible body have established methodologies and practices for clearance. In the United Kingdom, the nuclear industry Safety Directors Forum supports the implementation of required regulation. Similarly, in Spain, the public body responsible for the management of radioactive waste (Enresa) has developed a methodology for clearance, which, however, is to be approved for individual decommissioning projects, together with clearance levels. If radioactive waste has a level of radioactivity that is too high for immediate clearance, but through decay the limit specified for free release can be reached within a known period of time (e.g. 30 years in Switzerland), temporary decay storage may be envisaged for this period, allowing subsequent transfer to a conventional disposal site. Some countries do not have defined clearance levels (e.g. France and the United States) and clearance can be specified by the regulatory authority on a case-by-case basis.

Basic decisions on the management of the radioactive waste generated have a profound influence on a facility decommissioning programme and costs. There are essentially two main strategic approaches to managing decommissioning materials (Öko-Institut, 2013):

- The first strategy can be referred to as “reconcentration”, since it aims at reconcentrating the contamination spread over larger parts of the facility into a small fraction of wastes to be later disposed of in a facility with a “high” isolation. This implies extended separation and decontamination efforts to minimise the amount of radioactive waste to be sent for final disposal. The intent is to release the greatest possible amount of non-radioactive waste, either unconditionally – via conventional waste streams (e.g. steel and concrete recycling), or conditionally – for specific use or conventional surface disposal. This is achieved through the application of specifically designed material processing and radiological control release procedures.
- The second strategy aims at separating only highly activated or contaminated waste for later disposal in a facility with a medium or high degree of isolation and removing all non-radioactive waste (with “no activation/contamination”), while disposing all of the remainder materials (with “small or scattered contamination”) in a facility with a low degree of isolation. This later waste category can still represent substantial volumes.

Another approach, dilution and dispersion of radioactive decommissioning waste, consisting of mixing radioactive with non-radioactive materials to below clearance levels, to be then released or recycled, was sometimes applied (e.g. in the early years of the domestic nuclear energy industry in the United States – see ACNW, 2007). However, the IAEA clearly states that the deliberate dilution of material to meet clearance criteria should not be permitted without the prior approval of the regulatory body (IAEA, 2008). Such an approach is usually not permitted (e.g. Sweden).

Repositories that accept some low- or intermediate-level decommissioning waste already exist in most countries and will often remain in operation for many years. Restrictions on specific activity, dose rates on the surface of delivered packages and on the content of long-lived radionuclides and alpha-emitters apply to these facilities. Usually restrictions also exist in relation to different chemicals and materials (NEA, 2003a). In some countries (e.g. Canada, Finland and the United Kingdom) each reactor site has some provision for its own waste storage or disposal facility.

Although the waste volume generated from decommissioning nuclear facilities is, by and large, non-radioactive, such waste may contain hazardous substances, such as toxic chemical compounds, asbestos or other materials that require a specific management scheme. These are managed according to the existing legislation (national and/or local) and regulatory framework established for hazardous waste generated from any other industrial activity.

Non-radioactive hazardous substances may also be mixed with radioactive waste from decommissioning, giving rise, when predefined concentration levels are exceeded, to what is often referred to as “mixed waste”. Mixed waste can also describe material that is both toxic and radioactive, including, for example, contaminated solvents. Handling requirements for such waste depend on its form, nature and specific activity. In general, the decommissioning licence application, submitted by the operator, must contain information on the objectives and means to deal with radioactive substances, including mixed waste and their appropriate destinations. This is addressed in safety analysis and environmental impact assessment reports (e.g. in Belgium). Some lower activity mixed waste may be consented to be disposed to commercial landfill (e.g. in the United Kingdom). When possible, mixed waste can sometimes be decontaminated or sorted, so that contaminated and hazardous phases are separated (e.g. in the Slovak Republic). Otherwise, in several cases, mixed waste is handled as radioactive waste (e.g. in the United Kingdom and the United States), with the application of relevant waste acceptance criteria. Sometimes, additional special requirements (such as encapsulation) are also necessary, in particular when this special waste is to be disposed of in near-surface repositories (e.g. in the United States). Depending on the composition of the non-radioactive waste and the acceptance criteria of the surface repository, mixed short-lived low- and medium-level waste could ultimately be destined to final disposal in a deep geological repository (e.g. in Belgium). In France, mixed waste is disposed of in a dedicated repository or storage facility while in the Czech Republic, it is dispatched to specialised companies authorised to manage different wastes. In some countries, no specific national policy exists for mixed waste. In Korea, it is temporarily stored on-site until appropriate technology is developed for its safe disposal.

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## Appendix 2.A1. Summary of national responses to the NEA questionnaire

**Table 2.A1.1: Synoptic table summarising national responses to Part I of the country survey – Questions QP1 to QP17**

Question	BE	CA	CZ	FI	FR	IT	KR	NL	SK	ES	SE	CH	UK	US
<b>DECOMMISSIONING DEFINITION</b>														
QP1	Legislation Countries have in place comprehensive legislation (laws, acts, decrees, ordinances, etc.) on decommissioning													
QP2	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
QP3	N	Y	N	N	Y	N	Y	Y	N	Y	N	N	Y	Y
QP4	N	Y	Y	N	N	N	Greenfield/ Brownfield	Y	Y	Y	Y	N	N	Y
QP5	N	N	N	N	Y ASAP	N	N	N	N	N	N	N	N	Y 60y
QP6	Conditions needed to de-license a site Several, including: completion of decommissioning activities in line with the regulations and the achievement of the defined end point; verification of technical conditions and monitoring; radiological risks no longer present; waste management obligations fulfilled; production and approval of several documents and analyses; requirements for the clearance of the buildings and the site accomplished.													
<b>NATIONAL DECOMMISSIONING STRATEGY</b>														
QP7	–	Y	Y	N	Y?	N	N	N	N	Y	N	N	Y	Y
	–	Y <sup>1</sup>		N/A	Achieve decomm. ASAP	N/A	N/A	N/A	N/A	On alternatives	Y	N/A	N/A	Y <sup>2</sup>
QP8	At what stage is a strategy/ plan to be defined? In the majority of cases covered in the survey, the definition of the decommissioning plan is required in the early phases of the life cycle of new nuclear facilities. In general, a preliminary plan is to be drawn up for the future decommissioning of the facility before it can be built; the preliminary plan is then supplemented, updated and periodically resubmitted to the safety authorities during the life of the facility.													
QP9	–	- Immediate - Deferred - Entomb	- Immediate - Deferred	N	N/A Immediate	N	N	N	- Immediate - Deferred (30 years) - Reactor safe enclosure (30 years) - Zero option	- Immediate - Deferred - Care and maintenance	N/A Immediate	N/A Immediate Preferred other strategies to be justified	N	- Immediate - Deferred - Entomb.
QP10	Y	Y	Y	Y	Y	N/A	Y	Y	Y	Y	Y	Y	Y	N
QP11	N	N	Y	N	Y	N	Y	Y	N	Y	N	N	N	N
QP12	Who participated in selecting this decommissioning strategy? In most cases, where a unified national strategy is adopted, the process of selection has been multilateral, involving several parties and leading to a joint decision. Together with the utility/operator, the regulatory authority is often involved; and, in a few instances, the national and regional governments. In the Czech Republic the process is unilaterally conducted by the utility/operator.													
QP13	N/A	N/A	See QP9	Immediate and deferred	See QP9	Immediate and deferred	Immediate	Immediate and deferred	N/A	See QP9	N/A	See QP9	N/A	N/A
QP14	What process was used? In countries adopting unified national strategies, mostly multi-attribute analyses were used (taking into account e.g. economic, technical, social and environmental aspects)													
QP15	Which stakeholders were consulted? In countries adopting unified national strategies, stakeholders consulted include: the national government through the responsible ministries; the regulatory authority; the local administration; representatives of civil society and the public (e.g. through local consultations and public hearings and debates); and the industry (e.g. operators, qualified experts).													
QP16	What were the main factors considered? See Table 2.3.													
QP17	Is there a requirement to periodically review the strategy? Countries adopting unified national strategies have no requirements for periodical reviews of the strategy.													

**Table 2.A1.1: Synoptic table summarising national responses to Part I of the country survey – Questions QP1 to QP17 (cont'd)**

Question	BE	CA	CZ	FI	FR	IT	KR	NL	SK	ES	SE	CH	UK	US
<b>DETAILS ON THE MANAGEMENT OF DECOMMISSIONING WASTE</b>														
QP18	<p>Are final repositories available for all radioactive waste types arising from decommissioning (other than spent fuel)?</p> <p>See also Table 2.3. Repositories that accept low- or some intermediate-level decommissioning waste exist in most countries and will often remain in operation for many years. When such facilities are not available or cannot accept all waste types generated from decommissioning (e.g. long-lived intermediate waste or the small volumes of high-level waste, typically destined to deep geological repositories), pending the adoption of a long-term management solution, such wastes are (to be) stored in interim storage facilities that might be located on-site or centrally at the national level. In some cases central interim storage facilities are being built (e.g. in France) or are planned for deployment in the forthcoming years (e.g. in Belgium, Spain and in the Slovak Republic).</p>													
QP19	<p>Details on existing radioactive waste repositories</p> <p>Restrictions on specific activity, dose rate on the surface of delivered packages and on the content of long-lived radionuclides and alpha-emitters apply to these facilities. Usually restrictions also exist in relation to different chemicals and materials (NEA, 2003). In some countries, e.g. Canada, Finland and the United Kingdom, each reactor site has some provision for its own waste storage facility.</p>													
QP20	<p>Details on future radioactive waste repositories</p>													
QP21	<p>What is the national policy on - hazardous non-radioactive waste - mixed waste from decommissioning?</p> <p>Hazardous non-radioactive waste and mixed waste are managed according to the existing legislation (national and/or local) and regulatory framework. Non-radioactive hazardous waste is usually managed in the same manner as waste generated from other industries, with conventional repository strategies that take into account the occupational safety requirements. For mixed waste, in general, the decommissioning licence application, submitted by the operator, must contain information on the objectives and means to deal with radioactive substances, including mixed waste and their appropriate destinations. When possible, mixed waste can sometimes be decontaminated or sorted, so that contaminated and hazardous phases are separated (e.g. in the Slovak Republic). Otherwise, in several cases, mixed waste is handled as radioactive waste (e.g. in the United Kingdom and the United States), with the application of relevant waste acceptance criteria. Sometimes, additional special requirements (such as encapsulation) are also necessary, in particular when this special waste is to be disposed of in near-surface repositories (e.g. in the United States). Depending on the composition of the non-radioactive waste and the acceptance criteria of the surface repository, mixed short-lived low- and medium-level waste could ultimately be destined to final disposal in a DGR (e.g. in Belgium).</p>													
QP22	<p>Are there specific clearance levels and/or procedures for categorising decommissioning waste as non-radioactive or for making such materials exempt from regulation?</p> <p>Clearance levels and procedures for categorising are stipulated in the national legislations, which provide details on the quantitative criteria applied. These include general clearance levels for solid material that does not require further regulatory control (to ensure the destination); and specific clearance levels for a particular use or destination (e.g. for recycling of metals, building rubble, etc.). In some countries, clearance principles, methodologies, guidance and practices have been developed (e.g. in Belgium, Spain and the United Kingdom). France and the United States have no general policy for the release of materials, which is stipulated and approved by the regulatory authorities on a case-by-case basis. Quantitative criteria on dose limits have been provided by a few countries, as summarised below. <b>Finland</b> – The individual dose arising from the use of the cleared site and buildings should not be greater than 0.01 mSv. In a case-specific clearance procedure where the future use of the site and the buildings is restricted, an annual individual dose up to 0.1 mSv may be permitted. It must also be demonstrated that even if the restrictions imposed on the use of the site were to fail, the annual individual dose arising from use of the buildings and occupancy at the site would remain below 1 mSv with high certainty. <b>United Kingdom</b> – Any residual radioactivity, above background activity remaining on the site will lead to a risk of death to an individual using the site for any reasonably foreseeable purpose, of no greater than 1 in a million per year. <b>United States</b> – For unrestricted, use less than 25 mrem (0.25 mSv).</p>													
<b>DECOMMISSIONING LICENCE</b>														
QP23	<p>Specific licence (different from the operating licence) for shutdown?</p> <p>N Y Y N Y N Licence amended Y N N N N Licence amended</p>													
QP24	<p>Specific licence for decommissioning?</p> <p>Y Y Y Licence amended Y Y Licence amended Y Y Y N Y Decommissioning order N N</p>													
QP25	<p>Documents to be submitted to proceed with decommissioning</p> <p>In the majority of cases, licensees must inform the relevant authorities of the intention to stop the activity and submit a licence application (authorisation request), containing several documents and specific information. Typically these include a detailed decommission plan with (some or all of) the following information: general information; objectives; safety analysis reports; means and plans to deal with resulting radioactive substances (including inventories, limits and conditions, scope and method of measurement and evaluation of exposure); environmental impact assessment; changes; technical procedures; method and time schedule; economic study of the dismantling process with financial investments and expected costs, providing evidence of availability of finance for decommissioning activities; radiological status of the installation; on-site emergency plan; evidence of provision of physical protection; quality management programme.</p>													

**Legend:** Country name abbreviations: BE – Belgium, CA – Canada, CZ – Czech Republic, FI – Finland, FR – France, KR – Korea, NL – Netherlands, SK – Slovak Republic, ES – Spain, SE –Sweden, CH – Switzerland, UK – United Kingdom, US – United States.

1. In Canada, licensees are required to follow various guidance documents (i.e. CSA N294-09 “Decommissioning of facilities containing nuclear substances” and G-219 “Decommissioning planning for licensed activities”).
2. In the United Kingdom, to support the licensees and based on strategic optioneering guidance is provided through: the NDA Strategy Management System – to develop a strategy in a controlled fashion through distinct stages, ensuring compliance with the regulatory framework; regulatory options assessments, including risk-based assessment, based on as low as reasonably practicable (ALARP)/as low as reasonably achievable (ALARA), best available techniques (BAT)/best practicable means (BPM) and best practicable environmental options (BPEO) assessment.
3. In the United States, licensees are required to follow various guidance documents (i.e. among others: the site-specific cost estimate NUREG-1713 and the General Information REG Guide 1.184).

## Chapter 3. Decommissioning cost estimates

### 3.1. Introduction

In this chapter, some economic aspects related to decommissioning are presented. This encompasses, in Section 3.2, a concise description of the different types of cost estimates that can be developed for decommissioning activities, highlighting the main elements and approaches.

In Section 3.3, a tentative appraisal of decommissioning costs is presented based on a limited number of estimates for ongoing and future projects, according to the inputs received via the questionnaire. The direct comparison of decommissioning cost estimates generated for different plants by different cost estimate providers (including within the same country) is a challenging endeavour, even if the results are presented using the International Structure for Decommissioning Costing (ISDC – see Appendix 3.A1). Indeed cost estimates may use different cost structures, combinations of individual cost items (or a higher level of aggregation), and different definitions of detailed cost elements and phases of activities. To broaden the basis for comparison beyond the limited inputs received, additional information was collected for the United States plants using a Pacific Northwest National Laboratories (PNNL, 2011) study performed for the US Nuclear Regulatory Commission (NRC). A general process of “translation” was undertaken to provide a conversion mechanism from cost structures most commonly used in the United States into the ISDC format, allowing comparable types of presentation of data to feed into Section 3.3. This translation process is explained in Appendix 3.A2. Appendix 3.A3 provides a set of graphs supporting Section 3.3.

Section 3.4 provides some insights on the treatment of uncertainties while preparing cost estimates. Section 3.5 introduces a set of case studies presented during the course of the project by the members of the Ad Hoc Expert Group on Costs of Decommissioning (COSTSDEC). The detailed case studies, provided for six countries, are given in Part II at the end of the report. They help understand the boundary conditions for the cost estimates collected during the survey and presented in Section 3.3 and Appendix 3.A3. The case studies also served as input material for the drafting of Section 3.6 looking at the variation and evolution of cost estimates over time. Finally, Section 3.7 draws lessons from this part of the project and lists potential challenges. Section 3.8 concludes Chapter 3.

### 3.2. Elements and approaches of decommissioning cost estimates

Owners/licensees are generally responsible for developing cost estimates. A good understanding of decommissioning costs is fundamental for the development of cost estimates based on realistic decommissioning plans. Transparent cost estimates also provide a basis for building up the necessary funds and further assessing the decommissioning process with the aim of ensuring that necessary funds are available when needed to cover the actual cost of decommissioning activities (NEA, 2012a).

Cost estimation methodology should be suitable for the intended purpose. Decommissioning cost estimation might be needed to:

- provide an input for the decommissioning funding during plant operational life;
- compare costs associated with different strategies for the decision-making process;
- prepare long-term budgeting and cash flow;
- provide a tool for project control.

Different cost estimation methodologies might need to be used depending on specific objectives and as a project advances. These include order of magnitude estimates, budgetary estimates, and definitive estimates (IAEA, 2005). Different costing methods have different data requirements, and thus their accuracy depends on the availability and applicability of reliable data and the extent of the analysis conducted. Inevitably, cost calculations are affected by uncertainties, regardless of the estimation methodology adopted. Some of the methods (detailed in IAEA, 2013 and NEA, 2015) comprise:

- “parametric techniques”, where known cost items from prior estimates are used;
- “cost review and update techniques”, where historical databases on similar systems or subsystems are considered and statistical analyses performed to establish correlations to specific parameters;
- “specific analogy techniques”, where a new estimate is constructed by examining previous estimates;
- “expert’s opinion techniques”, used when other techniques or data are not available.

There is no universally accepted standard at present for developing decommissioning cost estimates, which present considerable variability in format, content and practice (see e.g. IAEA, 2013; NEA, 2010a and 2010b). Cost estimates depend fundamentally on the decommissioning plans adopted, the assumed end state, and differences in basic assumptions as well as the context in and purpose for which the estimates were prepared. These differences can make cost comparisons arduous and can hinder transparency and, consequently, may impact stakeholders’ confidence. The adoption of more homogeneous methodologies and tools has been repeatedly advocated in the international arena. For instance, NEA (2010a) states that at least a standard reporting template should be developed, onto which national cost estimates could be mapped for the purposes of comparison both nationally and internationally. A standardised listing of cost items would facilitate making comparisons between estimates (IAEA, 2013; NEA, 2012b). International effort has been recently directed towards greater harmonisation of decommissioning cost estimation practices. Particularly notable is the establishment of the new ISDC, jointly developed by the NEA, the International Atomic Energy Agency (IAEA) and the European Commission (EC) (as discussed in Chapter 1) to enhance consistency and improve comparability of estimates across countries.

The ISDC (NEA, 2012b) provides a standard itemisation of decommissioning costs within a common reporting structure for purposes of comparison. The ISDC includes broad cost categories ranging from pre-decommissioning actions, facility shutdown activities, dismantling activities within the controlled area, waste processing, storage and disposal, project management, engineering and support, etc. The ISDC system of cost categories at the highest level of aggregation (“Level 1”) can be found in Table 3.2 below. A lower level of aggregation (“Level 2”) is given in Appendix 3.A1.

While the ISDC is a preferred international approach for reporting decommissioning costs, there are other examples of categorisation of decommissioning costs (NEA, 2010b). Descriptions of cost categories and elements can also be found in IAEA (2005 and 2013).

A widely used method is, the bottom-up technique, based on the approach known as the work breakdown structure (WBS). Its application entails a sufficiently detailed subdivision of a decommissioning project into discrete and measurable work activities.

The inclusion of cost categories and items in cost estimates is governed by the legal and administrative framework of the country, defining the estimates structure, organisation and scope. In some countries, further constraints and prescriptions can be defined on the type of estimates expected from the operators (e.g. broad cost structure and boundary conditions), as well as the degree of detail of reported costs. Most countries, however, allow the operator at least some degree of discretion as to the choice of cost calculation methods. In the majority of cases, methods are suggested as options, but not prescribed; or, when method are prescribed, specific exceptions and adjustments are permitted (NEA, 2012a). Some laws or regulations also include additional and targeted provisions for quality control. The use of life cycle planning models is prevalent in some countries, with worst case scenarios being used to bound the costs.

Virtually all national regulations require operators to provide an explanation and justification of assumptions and conditions, such as the year of the estimate, the point/site release criteria, transition activities, characterisation, remote handling techniques, spent nuclear fuel (SNF) and waste management, etc.

Any cost estimate methodology should present some key general attributes (see, for example, NEA, 2015). These include methodological consistency and accuracy; changes in project scope (e.g. decommissioning plans and end point); good characterisation, including detailed inventories; consistent regulatory requirements; involvement of the plant operator; the approach to present uncertainty; and, crucially, risk analysis. Current good practices also include the use of a standardised list of activities; a strong quality assurance programme; be based on site-specific decommissioning plans; and involve stakeholders in the development of decommissioning plans (NEA, 2010a and 2015). As emphasised by the Öko-Institut (2013), cost estimates performed on a more generic basis yield raw figures that can prove inaccurate when detailed plans and data becomes available. Extrapolations of costs from smaller or different reactor types, or with different operating history, can rarely be converted into reliable figures for another reactor or facility. Similarly rules-of-thumb, such as assuming a percentage of construction cost as a proxy for decommissioning costs, are not considered a good basis for accurately estimating decommissioning costs.

For a new facility, planning for decommissioning should begin early in the design stage and should continue through to termination of the authorisation for decommissioning; whereas for existing facilities where there is no decommissioning plan, a suitable plan for decommissioning should be prepared by the licensee as soon as possible (IAEA, 2014). In either case, the plan should be periodically reviewed and updated by the licensee. An initial decommissioning plan should identify decommissioning options, demonstrate the feasibility of decommissioning, ensure that sufficient financial resources will be available for decommissioning, and identify categories and estimate quantities of waste that will be generated during decommissioning. The decommissioning plan should be updated by the licensee and should be reviewed by the regulatory body periodically through the life of the facility and until decommissioning is completed. Because decommissioning planning begins decades in advance of the start of decommissioning operations, thus the calculated cost items are influenced by significant levels of uncertainty affecting individual input data, e.g. physical, radiological, decommissioning process and economic parameters (NEA, 2012a, 2015).

Risk analysis is a major factor potentially affecting the planning and cost estimation of decommissioning work. In any case, estimates should be continuously updated using cost data from actual decommissioning projects, thus providing better control of uncertainties, improving the cost assessment, and facilitating the preparation of an

annualised schedule of expenditures for each facility (NEA, 2010). The lack of cost data from actual decommissioning projects is a major hindrance to the benchmarking and validation of decommissioning cost estimates.

### 3.3. Appraisal of decommissioning cost data

To gather country up-to-date information on decommissioning cost estimates and some of the surrounding narrative relevant to their interpretation, a survey was launched in the framework of this study, as detailed in Chapter 1, using a questionnaire. A few sets of estimates were retrieved through the country responses to the questionnaire, using the ISDC format as a basis, and include 4 sets of estimated costs for pressurised water reactors (PWRs) (from France, Spain, Switzerland; 3 of which are generic); 3 sets for boiling water reactors (BWRs) (from Spain and Sweden; with one generic estimate); 2 sets for Russian-designed water-cooled, water-moderated reactor (VVERs) (from Finland and the Slovak Republic); and “11 sets” for gas-cooled reactors (GCRs) (United Kingdom Nuclear Decommissioning Authority – NDA Magnox fleet). Importantly, all such data are estimates related to future projects, with the exception of one case, José Cabrera nuclear power plant (NPP) in Spain (single PWR unit) that is undergoing decommissioning and for which cost figures refer partly to expenditures actually incurred for completed tasks, and partly to estimates for the outstanding activities. No detailed cost data have been made available through the survey on fully completed projects, or on the more advanced experience accrued in countries like Germany and the United States.

In accordance with the national regulatory systems, cost items can be excluded from decommissioning cost estimates, but actually accounted for through different means. Table 3.1 summarises some key cost items that can be found in decommissioning cost estimates, indicating whether or not these are included in the estimates received from the questionnaire. The table clearly manifests a significant degree of non-homogeneity in the scope of the estimations considered. Items whose inclusion is most variable across the sample are the transport, storage and disposal of spent fuel and radioactive waste (originating from operation and decommissioning), as well as the treatment of contaminated ground.

This degree of non-homogeneity is an issue of crucial importance in interpreting the data and in determining differences or similarities. The substantive disparity existing among cost estimations across and within countries, in format, content and practices, and the consequent hindrance it can pose in the development of comparisons are widely acknowledged (NEA, 2012a and NEA, 2010c). Care must be taken in avoiding oversimplification in comparative exercises. Another important aspect that can create further issues in the data interpretation and comparison is the lack of harmonisation in the treatment of uncertainties between cost estimates. This is further discussed in Section 3.4. Inhomogeneity also arises from the use of different currencies and reference years in the calculations, and appropriate correction factors must be used.

A prerequisite for undertaking meaningful analyses of similarities and differences among decommissioning costs is the access to a sufficiently broad base of reliable data. Given the limited information obtained through the survey responses, it proved necessary to attempt broadening the database, by gathering further data available in the public domain. Some valuable information on the United States experience is reported in recent studies, including the report developed by the PNNL commissioned by the NRC (hereby referred to as the PNNL study) (PNNL, 2011). The PNNL study appraises actual costs for four completed projects (Haddam Neck, Maine Yankee, Trojan, Rancho Seco NPPs), regarding the achievement of “NRC decommissioning closure (de-licensing)”, along with various site-specific cost estimates developed by the licensees for some operating reactors. But, there is no detailed analysis presented of how the actual costs reported for the completed projects compare with the past decommissioning cost estimates prepared for these same projects. This limits the extent to which these can be compared directly

with the estimates. This PNNL information nevertheless constituted an important pool of additional data to supplement those obtained from the questionnaire, even if it must be recognised that many of the estimates use the cost estimation methodology developed by Thomas LaGuardia, and therefore these estimates should be seen more as different iterations of the same calculation model, with differing input data. In addition, their use was not straightforward, since the cost data reported in the PNNL study, in line with long-established practices in the United States, follow cost breakdowns that differ from the ISDC format, which was applied, as closely as possible, to the data obtained from the questionnaire.

**Table 3.1: Items included (or not) in the scope of decommissioning cost estimates**

Items included in the scope of the decommissioning estimates	Finland	France	Slovak Republic	Spain	Sweden	Switzerland	UK
De-fuelling	Y	N	Y	N <sup>1</sup>	N	Y <sup>2</sup>	N
On-site storage of fuel	N	N	Y	N	N	N <sup>3</sup>	N
On-site storage of radwaste from decommissioning	Y	N	Y	N <sup>4</sup>	N	N	N
On-site storage of operational radioactive waste	N	N	Y	N	N	N <sup>5</sup>	Y
Retrieval and packaging of accumulated operational waste	N	N	Y	N <sup>4</sup>	N	Y <sup>2</sup>	Y
Removal of reactor building	Y	Y	Y	Y	Y	Y	Y
Removal of conventional plant/buildings, e.g. turbine halls	N	Y	Y	Y	Y	Y	Y
Removal of non-radioactive structures above ground level	N	Y	Y	Y	Y	Y	Y
Removal of non-radioactive structures below ground level	N	N	Y	Y <sup>6</sup>	N	Y <sup>7</sup>	Y
Transport and disposal of radioactive waste	Y	N	Y	N	N	Y	Y
Disposal or recycling of non-radioactive waste	N	N	Y	Y	Y	Y	Y
Contaminated ground remediation	N	N	Y	Y	Y	N <sup>8</sup>	Y
Landscaping and site de-licensing	N	Y	Y	Y	Y	Y	Y
Final site surveys	Y	Y	Y	Y	Y	Y	Y
De-licensing of the site	Y	Y	Y	Y	Y	Y	Y

1. Costs related with SNF temporary storage on-site are not included in the scope of the estimate. The underlying assumption is to transfer SNF to the future centralised temporary storage before starting the execution of decommissioning project.
2. The costs for defueling and packaging of radwaste are allocated to the post-operational phase that is added to the decommissioning costs. Costs for fuel casks and their storage are allocated to the waste management costs.
3. On-site and central storage of fuel are allocated to the waste management costs, separate from decommissioning costs.
4. Waste processing, storage and disposal cost item only takes in account tasks related with waste processing and temporary storage on-site during the execution of the dismantling activities. Decommissioning cost estimate does not consider any category of radioactive waste (high-, intermediate- and low-level) disposal cost.
5. Central storage of operational radioactive waste costs are allocated to the waste management costs, separate from decommissioning costs.
6. The removal of non-radioactive structures below ground level may be included or not depending on the intended end point of individual decommissioning plans. In principle, non-radioactive structures could remain on-site if they do not constitute an obstacle for achieving the expected goal.
7. Removal of non-radioactive structures below ground level to be executed up to a depth of 2 metres.
8. No ground contamination is assumed.

The two sets of data, those obtained from the questionnaire and those extracted from the PNNL study, are therefore appraised separately in Sections 3.3.1 and 3.3.2. At the same time, a process of translation from United States cost structures (WBS-based) into the ISDC format is developed in Appendix 3.A2. The outcome justifies the drawing of the same type of graphs for both sets of data (obtained for a few member countries via the questionnaire on one side, and via the PNNL report for US data on the other side).

### 3.3.1. Cost data for high-level decommissioning processes from the questionnaire

Two distinct tables, both based on the ISDC, were used in the survey to gather details on decommissioning costs from member countries. In the first table, reproduced below as Table 3.2, in line with the ISDC format, cost items are aggregated into 11 high-level processes (ISDC Level 1), and split into three categories: labour, capital and expenses. Information on contingencies, along with labour hours and, of course, totals, was sought. Respondents were asked to compile a second table too, where costs are further disaggregated to a much greater degree of granularity (ISDC Level 2), and where each of the cost items identified in Table 3.2 are further subdivided into individual activities or sets of activities. This table is reproduced in Appendix 3.A1.

Most respondents provided data at the lower degree of detail by filling Table 3.2 only. In many responses, this was even only sparsely populated, with possible discrepancies compared to the original cost itemisations with the ISDC.

**Table 3.2: High-level (level 1) cost data sought through the country survey, according to the ISDC**

Cost item	Cost group					Total NCU
	Labour		Capital	Expenses	Contingency	
	Hours	NCU	NCU			
01 Pre-decommissioning						
02 Facility shutdown						
03 Additional activities for safe enclosure						
04 Dismantling activities within the controlled area						
05 Waste processing, storage and disposal						
06 Site infrastructure and operation						
07 Conventional dismantling demolition and site restoration						
08 Project management, engineering and site support						
09 Research and development						
10 Fuel and nuclear material						
11 Miscellaneous expenditures						
<b>Total</b>						

NCU = National currency unit.



Total costs were provided in all responses, and in several cases contingencies were also specified; however, only in three cases were cost categories (labour, capital and expenses) also detailed. Data related to projects assuming immediate dismantling as the adopted strategy, are summarised in Table 3.3, as provided by individual contributors in their responses to Part III of the questionnaire, in the national currency unit (NCU) and for the entire site, when costs were reported for multi-unit plants. Due to the specific nature of the United Kingdom nuclear fleet (Magnox reactors) and the deferred nature of the decommissioning strategy, the United Kingdom data have not been integrated in the tables and figures presented further in this report. The case study presented in Chapter 11 at the end of this report provides details on the decommissioning approach by NDA in the United Kingdom. To have the data expressed in a common monetary value, they have been converted into 2013 USD in Table 3.4 in using exchange rates and yearly gross domestic product (GDP) deflators (from OECD statistics).

The values reproduced in Table 3.5 refer to unit costs. For multi-units sites, where reactors are identical, the total site costs have been divided by the number of reactors. This does not apply to the Oskarshamn site, in particular, where reactors are different.

Figure 3.1 reports the percentage distribution of costs attributed to different ISDC Level 1 items, whereas estimated cost values summarised in Tables 3.4 and 3.5 are directly reproduced in graphical form in Appendix 3.A3, Figures 3.A3.1 and 3.A3.2, per site and per unit.

The percentage distribution of costs of ISDC Level 1 items (Figure 3.1) varies broadly across countries, and, in some cases, even within countries. Changes in the relative distributions could stem, e.g. from:

- Differences deriving from different allocations of expenses, e.g. due to the adoption of different methodologies or to permeability across ISDC items. Even when a specific reference structure (the ISDC in this case) is used to report cost breakdowns, there is still a degree of flexibility across ISDC categories.
- Real differences in expenditures of different types, related to the specific context and background of individual national cases and giving rise to differences in the relative contributions of such expenditures.

By presenting absolute values of cost estimate items at ISDC Level 1 (in Appendix 3.A3), differences in actual estimates become apparent. However, at the level of individual cost items, data are hardly readable for the purpose of distilling commonalities and differences.

Therefore, further consideration was more closely given to the principal items of the cost estimates made available, which were partly grouped together within broader categories:

- Dismantling activities, including dismantling activities within the controlled area and conventional dismantling, demolition and site restoration – corresponding to ISDC items 04 and 07.
- Project management, including project management, engineering and site support and site infrastructure and operation – corresponding to ISDC items 08 and 06.
- Waste management, including waste processing, storage and disposal – corresponding to ISDC item 05.

Table 3.3: ISDC level 1 cost items reported per site in the national currency unit of the given year

Country	Name	ID	NCU	Year of cost estimation	Type	# units	MWe	ISDC Level 1 – Items										
								1	2	3	4	5	6	7	8	9	10	11
Spain	José Cabrera	ES-P1	EUR <sub>2013</sub> M	2013	PWR	1	160	12.8	4	N/R	42.1	9.7	66.1	14.8	52.7	-	41.7	14.3
Spain	Generic-ESP	ES-P2	EUR <sub>2013</sub> M	2003	PWR	1	1 066	13.8	1.1	N/R	53.3	17.1	68	82.3	72.2	-	-	8.6
Switzerland	Generic-CH	CH-P1	CHF <sub>2013</sub> M	2011	PWR	1	1 000	53.8	448	N/R	89.8	108.9	314.9	43.6	52	-	7.1	-
France	Generic-FR	FR-P1	EUR <sub>2008</sub> M	-	PWR	4	3 600	-	88	N/R	433	200	62	92	87	-	-	96
Spain	S M Garona	ES-B1	EUR <sub>2013</sub> M	2011	BWR	1	466	13.7	3.2	N/R	48.8	14.1	93.7	21.2	40	-	-	10.4
Spain	Generic-ESB	ES-B2	EUR <sub>2013</sub> M	2006	BWR	1	1 092	13.5	1.1	N/R	56.4	25.8	66.2	83.3	67.2	-	-	8.5
Sweden	Oskarshamn	SE-B1	SEK <sub>2013</sub> M	-	BWR	3	2 576	79.5	135.4	N/R	2 363.2	512.9	332.1	910.9	899.7	-	-	37.2
Finland	Loviisa	FI-V1	EUR <sub>2013</sub> M	-	VVER-213	2	976	-	58.5	N/R	159.5	30.2	10.8	-	8.3	-	-	91.7
Slovak Republic	Bohunice	SK-V1	EUR <sub>2013</sub> M	2012	VVER-230	2	880	47.1	60	N/R	145.4	326.7	146.4	187.2	183.3	-	27.5	17.7

Notes: ISDC 01 – Pre-decommissioning, ISDC 02 – Shutdown, ISDC 03 – Safe enclosure – not relevant for immediate dismantling, ISDC 04 – RC dismantle, ISDC 05 Waste management, ISDC 06 Site infrastructure and operation, ISDC 07 Conventional dismantling, demolition and site restoration, ISDC 08 – Project management, engineering and site support; ISDC 09 – R&D, ISDC 10 – Fuel and nuclear material, ISDC 11 – Miscellaneous.

ESB = Spain BWR; ESP = Spain PWR; N/R = Not received.

\* The decommissioning of José Cabrera NPP is ongoing and cost figures are therefore derived from actual expenditures and estimates of residual activities.

**Table 3.4: ISDC level 1 cost items reported per site in USD<sub>2013</sub> million**

Country	Name	ID	Type	# units	MWe	ISDC Level 1 – items											Currency conversion	
						1	2	3	4	5	6	7	8	9	10	11	Exchange rate	GDP deflator
Spain	José Cabrera	ES-P1	PWR	1	160	16.9	5.3	N/R	55.5	12.8	87.2	19.6	69.5	-	55.1	18.8	0.758	
Spain	Generic-ESP	ESP2	PWR	1	1 066	18.2	1.5	N/R	70.3	22.6	89.7	108.6	95.3	-	-	11.3	0.758	
Switzerland	Generic-CH	CH-P1	PWR	1	1 000	57.8	481.2	N/R	96.4	116.9	338.1	46.8	55.8	-	-	7.6	0.931	
France	Generic-FR	FR-P1	PWR	4	3 600	-	121.4	N/R	597.4	276	85.5	126.9	120	-	-	132.5	0.758	1.046
Spain	S M Garona	ES-B1	BWR	1	466	18.1	4.2	N/R	64.4	18.6	123.7	28	52.7	-	-	13.7	0.758	
Spain	Generic-ESB	ES-B2	BWR	1	1 092	17.9	1.5	N/R	74.4	34	87.3	109.9	88.7	-	-	11.2	0.758	
Sweden	Oskarshamn	SE-B1	BWR	3	2 576	12.2	20.7	N/R	361.6	78.5	50.8	139.4	137.7	-	-	5.7	6.535	
Finland	Loviisa	FI-V1	VVER-213	2	976	-	77.3	N/R	210.5	39.9	14.2	-	11	-	-	121	0.758	
Slovak Republic	Bohunice	SK-V1	VVER-230	2	880	62.2	79.1	N/R	191.9	431	193.2	247.1	241.8	-	36.2	23.4	0.758	

Note: Conversion performed using exchange and gross domestic product (GDP) deflator rates obtained from OECD statistics – no discounting because no respondent explicitly stated that discounting was used in calculating the costs reported in Part III of the questionnaire.

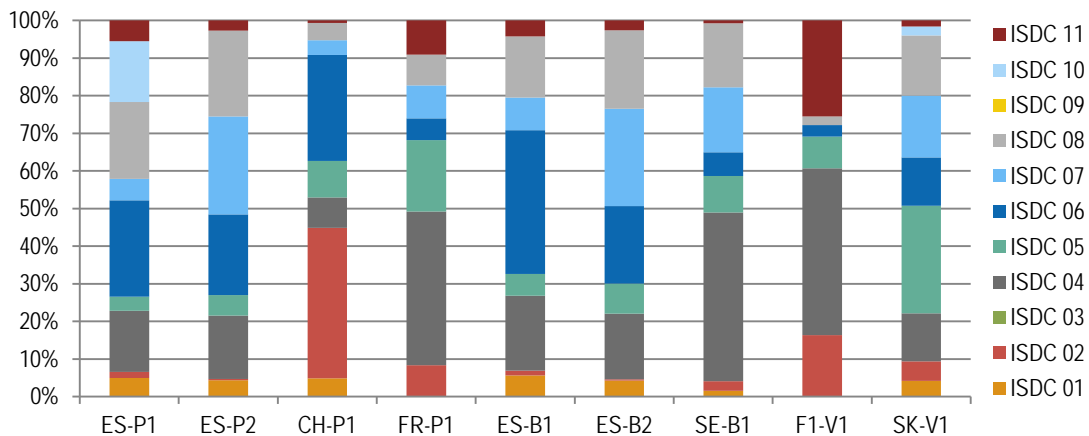
ISDC 01 – Pre-decommissioning, ISDC 02 – Shutdown, ISDC 03 – Safe enclosure – not relevant for immediate dismantling, ISDC 04 – RC dismantle, ISDC 05 Waste management, ISDC 06 Site infrastructure and operation, ISDC 07 Conventional dismantling, demolition and site restoration, ISDC 08 – Project management, engineering and site support; ISDC 09 – R&D, ISDC 10 – Fuel and nuclear material, ISDC 11 – Miscellaneous.

ESB = Spain BWR; ESP = Spain PWR; N/R = Not received.

**Table 3.5: ISDC level 1 cost items reported per unit in USD<sub>2013</sub> million**

Name	ID	MWe	ISDC Level 1 – items											Total
			01	02	03	04	05	06	07	08	09	10	11	
José Cabrera	ES-P1	160	16.9	5.3	N/R	55.5	12.8	87.2	19.6	69.5	–	55.1	18.8	340.6
Generic – ESP	ES-P2	1 066	18.2	1.5	N/R	70.3	22.6	89.7	108.6	95.3	–	–	11.3	417.5
Generic – CH	CH-P1	1 000	57.8	481.2	N/R	96.4	116.9	338.1	46.8	55.8	–	–	7.6	1 200.6
Generic – FR	FR-P1	3 600/4	–	30.4	N/R	149.4	69.0	21.4	31.7	30.0	–	–	33.1	365.0
S M Garona	ES-B1	466	18.2	4.2	N/R	64.4	18.6	123.7	28.0	52.7	–	–	13.7	323.6
Generic – ESB	ES-B2	1 092	17.9	1.5	N/R	74.4	34.0	87.3	109.9	88.7	–	–	11.2	424.8
Lovisa	FI-V1	976/2	–	38.6	N/R	105.2	20.0	7.1	0.0	5.5	–	–	60.5	236.9
Bohunice	SK-V1	880/2	31.1	39.6	N/R	96.0	215.5	96.6	123.5	120.9	–	18.1	11.7	753.0

ESB = Spain BWR; ESP = Spain PWR; N/R = Not received.

**Figure 3.1: Percentage distribution of costs attributed to individual ISDC level 1 items**

Notes: ISDC 01 – Pre-decommissioning, ISDC 02 – Shutdown, ISDC 03 – Safe enclosure – not relevant for immediate dismantling, ISDC 04 – RC dismantle, ISDC 05 Waste management, ISDC 06 Site infrastructure and operation, ISDC 07 Conventional dismantling, demolition and site restoration, ISDC 08 – Project management, engineering and site support; ISDC 09 – R&D, ISDC 10 – Fuel and nuclear material, ISDC 11 – Miscellaneous.

Another important category is fuel management, a key process that can generate substantial costs. This, however, is not strictly linked to decommissioning for some cases reported in the questionnaire, and hence is often excluded from the estimate scope. Moreover, costs related to SNF management can vary enormously depending on the fuel cycle adopted in different countries, and even depending on the different reactor technologies and the specific strategy chosen for individual units. For these reasons, drawing comparisons on fuel management costs was not deemed feasible without additional data of a more technical nature, not available through the survey. It should be noted that some of these aspects have been the object of analysis in a recent NEA study (NEA, 2013) on the economics of the back end of the nuclear fuel cycle.

Other miscellaneous expenditures could be aggregated to constitute another broad category. Costs related to this remaining category, however, generally amount only to a limited fraction of the total decommissioning cost.

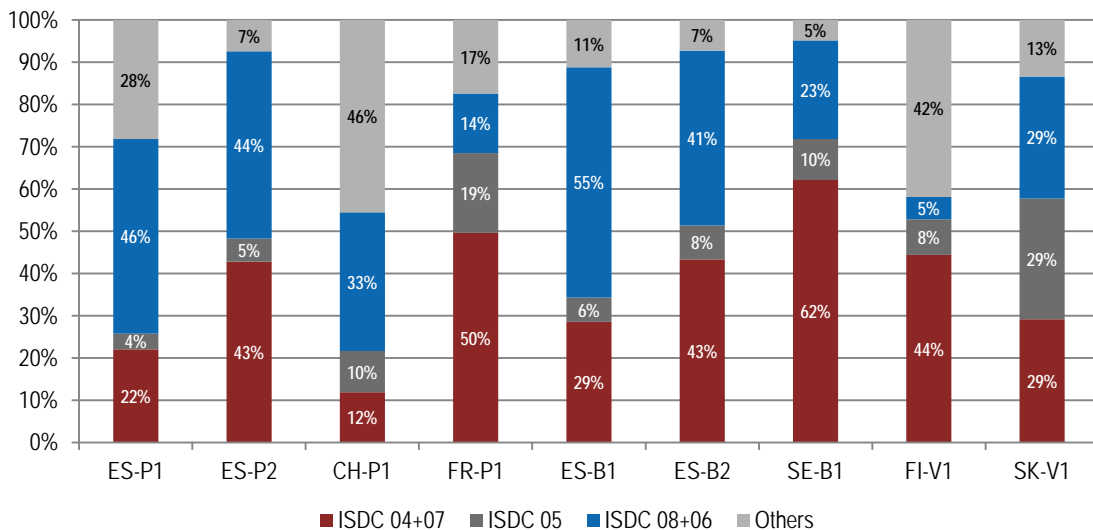
Aggregated costs for the three “main” categories identified above are reported in tabular and graphic form, in Table 3.6 (for the site) and Table 3.7 (by unit), and Figures 3.A3.3 and 3.A3.4 (in Appendix 3.A3). Figure 3.2 provides the percentage distribution of costs associated with the aggregated categories of Tables 3.6 and 3.7.

**Table 3.6: Costs related to aggregated categories per site**(in USD<sub>2013</sub> million)

Name	ID	Dismantling activities ISDC 04 + 07	Waste management ISDC 05	Project management ISDC 08 + 06
PWR José Cabrera – 160 MWe	ES-P1	75.1	12.8	156.7
PWR Generic P (ES) – 1 066 MWe	ES-P2	178.9	22.6	185.0
PWR Generic (CH) – 1 000 MWe	CH-P1	143.2	116.9	393.9
PWR Generic (FR) – 3 600 MWe	FR-P1	724.4	276.0	205.6
BWR SM Garona – 466 MWe	ES-B1	92.4	18.6	176.4
BWR Generic B (ES) – 1 092 MWe	ES-B2	184.2	34.0	176.0
BWR Oskarshamn – 2 576 MWe	SE-B1	501.0	78.5	188.5
VVER Loviisa – 976 MWe	FI-V1	210.5	39.9	25.2
VVER Bohunice – 880 MWe	SK-V1	439.0	431.0	435.0

**Table 3.7: Costs related to aggregated categories per unit**(in USD<sub>2013</sub> million)

Name	ID	Dismantling activities ISDC 04 + 07	Waste management ISDC 05	Project management ISDC 08 + 06
PWR José Cabrera – 160 MWe	ES-P1	75.1	12.8	156.7
PWR Generic P (ES) – 1 066 MWe	ES-P2	178.9	22.6	185.0
PWR Generic (CH) – 1 000 MWe	CH-P1	143.2	116.9	393.9
PWR Generic (FR) – 3 600 MWe	FR-P1	181.1	69.0	51.4
BWR SM Garona – 466 MWe	ES-B1	92.4	18.6	176.4
BWR Generic B (ES) – 1 092 MWe	ES-B2	184.2	34.0	176.0
BWR Oskarshamn – 2 576 MWe				
VVER Loviisa – 976 MWe	FI-V1	105.2	20.0	12.6
VVER Bohunice – 880 MWe	SK-V1	219.5	215.5	217.5

**Figure 3.2: Aggregated categories – percentage distribution**

Beyond this point, a more detailed analysis is proposed for each of the three main aggregated categories of costs:

- Dismantling activities (ISDC 04 + 07): in the controlled area and conventional dismantling, demolition and site restoration.
- Project management (ISDC 08 + 06): with engineering and site support, as well as site infrastructure and operation.
- Waste management (ISDC 05): waste processing, storage and disposal.

The analysis is based on Tables 3.6 and 3.7 and Figures 3.A3.3 and 3.A3.4, but also on information collected via the survey and the case studies presented in Section 3.5 and Part II at the end of this report.

#### 3.3.1.1. Dismantling activities (ISDC 04 + 07)

Costs incorporated in this aggregated category (corresponding to ISDC 04 and 07) are affected by the degree of inclusion in the scope of the decommissioning cost estimate. From Table 3.1, it is apparent that these can vary significantly between estimates. In particular, removal of non-radioactive structures (above and below ground level) and conventional plants and buildings, as well as the remediation of contaminated ground and the landscaping of the site are not systematically or homogeneously covered in the cases considered. Notably, looking at the Finnish case, estimates for this cost category only include radioactive parts and assume no contaminated ground on-site, yielding to cost projections lower than in other cases. This is also naturally linked to the assumed end state of the site, which, for Loviisa, is brownfield, since the site has been designated for further use for industrial purposes after clearance. Such reduced requisites limit substantially the scope of activities for the decommissioning of Loviisa, as it is manifest from Table 3.1. This is in apparent contrast with the case of the Slovak VVER Bohunice V1 decommissioning, whose estimates assumes the brownfield with restricted use with the complete remediation up to the bottom of the construction pit for the end state, and is based on the most comprehensive scope, partly explaining the considerable higher estimates.

Factors that can affect these category costs are the actual degree of contamination, in line with the specific release criteria and clean-up levels applied for the plant, as well as the particular technological approaches adopted for the various processes of decommissioning, dismantling and demolition, notably whether single/large piece removal or segmentation and small piece removal are adopted. These factors, that may, in turn, be affected by other factors, such as the availability of particular waste management routes, can induce considerable deviations in the costs. For instance, a key element in the decommissioning project of Loviisa is the availability of an on-site disposal facility able to receive large uncut components, including the reactor pressure vessel, steam generators and concrete structures. Thus reactor vessel and internals will be removed in one piece and the vessel will be used as package for some other activated components (e.g. shielding elements). Contaminated components (primary circuit loops, steam generators (SG), pressuriser, and some others) will be disposed without cutting and without packaging. This context, and the possibility of applying specific technological approaches that derive from that, can considerably reduce and facilitate dismantling tasks, keeping the costs down. In the case of the Slovak Bohunice V1 decommissioning project the large components of primary circuits will be cut and fragmented into the specific containers and stored on-site in the integrated storage facility built for this purpose until the final disposal facility is available. The Swiss case is the only one envisaging the dismantling of primary circuit components by contact working (after full system decontamination); in all other cases this will be done semi-remotely.

This being said, it is not unreasonable that some activities related to dismantling activities, conventional dismantling and demolition broadly depend on the unit capacity and configuration. For example, in the case of José Cabrera, a single-loop PWR of 160 MWe, the reported figures (which include actual and estimated costs, because the project is ongoing) are lower than the similar costs reported for the generic estimates developed for a 1 000 MWe PWR. However, caution needs to be exercised when making such general assumptions as this may be in part an artefact of the estimating models used. The lack of clear relationships between plant size and decommissioning costs as a whole can be seen for example in an Electric Power Research Institute (EPRI) study based on US data (EPRI, 2011).

The operational history and the actual degree of contamination, as well as the specific release criteria and clean-up levels applied to individual plants, naturally have also a strong influence on dismantling costs. Many of the cases considered across the sample are generic estimates for which a specific operational history does not apply; for site-specific estimates, no significant occurrences were reported in the replies to the survey that may have caused increased contamination and/or significantly impact the costs for this category. Therefore, from the data available, no conclusions can be drawn as to the extent to which these may influence decommissioning costs in relation to other components of the overall costs.

### 3.3.1.2. Project management (ISDC 08 +06)

Estimated costs associated to the activities included in these aggregated categories of costs (corresponding to ISDC 08 and 06) are not dependent on the plant capacity. This was also emphasised in NEA (2003), where the non-linearity of such costs with the capacity was attributed to the fixed costs of project management (PM), plant survey, security and engineering, which are all nearly independent of the size of the plant, and therefore relatively higher for smaller plants. Other elements have instead a far greater influence in determining such costs. Similarly, EPRI (2011) found no significant trends in decommissioning staffing costs with plant size in the United States.

#### *Structure of the decommissioning organisation, including fleet and multi-unit approaches*

Undoubtedly, the type of structure adopted or assumed for the management of the project is an important factor affecting the associated costs and also their allocation, which, of course vary, whether the actual project is completely executed by the licensee, or whether and to what extent this is outsourced to external contractors, with the former only providing control and supervision over the programme. The type of site and even the structure of the licensed organisation have also significant bearing, allowing varying degree of project cost pooling. Tasks related to project management, engineering, site support and site infrastructure and operation that can be largely shared among different units within a site or even across a fleet may gain from co-ordinated approaches and sharing of efficiencies. This may at least partly explain the low costs reported in this category for the French case, where generic estimates are provided for a 4-unit 900 MWe PWR. In the French licensee organisation, a common approach is adopted for a fairly homogeneous fleet of 58 reactors, and a dedicated unit for decommissioning activities has been created within the organisation, including a specific entity devoted to feedback implementation. Such types of fleet approach, another example being the Magnox decommissioning programme adopted by the NDA in the United Kingdom, are intended to allow strategy optimisation, the enhancement of resource use, including through the implementation of special contracts and the sharing of best practices and lessons learnt, with the aim of facilitating series effects and gains from first-of-a-kind (FOAK) to n<sup>th</sup>-of-a-kind (NOAK) experience.

Some details of project management and organisational aspects are illustrated below for a few specific cases.

## § Finland

According to the information provided, it is anticipated that the Loviisa NPP decommissioning will benefit from a multi-unit approach and sharing of efficiencies. Some activities (e.g. preparatory work and removal of activated material) will be sequential but will happen in a short time distance for the two units; other will be conducted together for the two units (e.g. activities related to contaminated material).

It is assumed that the responsibility for decommissioning is to be kept by the licensee and not transferred. The planning implementation of the decommissioning project will mainly be done by “former” operations personnel of Fortum Power and Heat, the operator of the Loviisa plant, to take advantage of their in-depth knowledge of the plant. Specific work and self-contained tasks will be subcontracted as necessary. As the decommissioning progresses, the operating organisation of the Loviisa power plant will change in stages to become purely responsible for decommissioning. When the actual decommissioning starts, the licensee staff will be responsible, e.g. for planning of work; supervision and guidance of contractors; operation and maintenance of the necessary process systems; storage and transport of spent fuel and decommissioning waste; radiological protection; measurement and free releasing of waste; accounting, accommodation and office services. On the other hand, work carried out by subcontractors will include the dismantling, cutting and packaging of the process systems; constructions of systems containing radioactive substances; and the necessary cleaning. Table 3.8 shows the staffing needs foreseen over the various years of decommissioning. The spent fuel will be stored at the plant site for 35 years after the shutdown of the power plant. The greatest staffing requirements will be almost 430 people. Three distinct peaks can be recognised in the manpower demand. They will occur at the beginning of the preparatory phase of Loviisa unit 2, the launching of the actual decommissioning of Loviisa unit 2, and the dismantling of the contaminated auxiliary systems after all spent fuel has been taken away from the plant. The amount of work required for the decommissioning of the Loviisa power plant will total to about 2 955 person-years, of which just under 60% (57%) accounts for the power plant’s own personnel.

**Table 3.8: Total yearly workload for the decommissioning of Loviisa nuclear power plant**

Years after the shutdown of Loviisa 1	Power plant’s own organisation (man-years)	Workload of the subcontractors (man-years)
1	156	29
2	156	33
3	135	101
4	297	82
5	297	130
6	141	107
7	141	82
8	141	130
9	18	6
39	71	279
40	71	242
41	71	39
<b>Total</b>	<b>1 695</b>	<b>1 260</b>



During the 30-year period following the first 8-year phase of decommissioning (from 2027 to 2035), spent nuclear fuel will be kept on-site for cooling, and the only other additional effort will go towards the maintenance of the final repository and the securing the area. The second decommissioning phase will involve the dismantlement of the spent fuel storage and the waste solidification plant, to be conducted, together with sealing of the repository between 2066 and 2068. The years between these two phases are not included in the decommissioning plan.

## § France

For the decommissioning of the Électricité de France (EDF) fleet, the responsibility is maintained within EDF and not transferred to another body. A dedicated engineering unit was created within the utility in 2001 specifically to look after decommissioning operations and environmental aspects: Centre ingénierie déconstruction et environnement (CIDEN). With CIDEN's engineering design and construction supervision capabilities, EDF can maintain internally a necessary level of technical competence. CIDEN is EDF's prime contractor in some key areas of decommissioning; and, during decommissioning, at the operational level, the responsibility of the NPP is transferred within EDF from the operator (Division production nucléaire – DPN) to the CIDEN. A fleet approach is adopted for the EDF PWR fleet, and generic numbers for a 4-unit 900 MWe PWR have been used to derive estimates. Studies developed for and experience gained from the first decommissioned units will be made available for the rest of EDF's fleet. The creation of CIDEN is a central milestone for the implementation of such fleet approach within EDF.

## § Spain

The organisation and responsibilities for decommissioning are laid out in the Law 11/2009 on the Management of Radioactive Waste. According to this law, the management of radioactive waste, including spent nuclear fuel and the dismantling and decommissioning of nuclear facilities, is an essential public service that must be ensured by the state: Empresa Nacional de Residuos Radiactivos (Enresa) is commissioned for the provision of this service. Relevant functions related to decommissioning defined in its mission include managing the dismantling and decommissioning operations of nuclear and radioactive facilities; the development of technical, economic and financial studies necessary to take into account the deferred costs arising from its duties to establish financial needs; the management of the fund to finance relevant activities. During decommissioning, hence, the responsibility of the plant is transferred from the operator to Enresa.

Enresa's decommissioning organisation consists of own staff people on-site who assume key positions and responsibilities for project implementation. The project is strongly supported by departments from the head office i.e. decommissioning engineering, low-level waste (LLW) engineering, and on-site contractors. As a reference, José Cabrera NPP decommissioning project has had a peak of 250 people from contractors.

Such model is aimed to distribute the work among several work packages and adjust the scope of the contracts according to the latest available information. While this approach allows a better control of the project and less controversies with contractors, it requires also a deeper involvement and more Enresa resources.

## § Slovak Republic

The V1 NPP (units 1 and 2 at Bohunice) decommissioning is carried both by Jadrová a vyradovacia spoločnosť, a.s. (JAVYS) internal employees, as well as by external contractors. JAVYS endeavours to contract short-term low added value work (e.g. common demolition or dismantling works), or, conversely, highly specialised tasks (e.g. remote fragmentation of main primary circuit components). The specific nature of the project, in part financed by the European Commission and managed by the European

Bank for Reconstruction and Development (EBRD), required the establishment of dedicated Project Management Unit with the involvement of external technical and financial consultant to the EBRD. This form of financing requires the implementation of specific procedures for planning, preparation and procurement of partial decommissioning projects with multiple formal approval procedures, which results in longer periods in pre-contractual phase and higher engineering cost. This however covers the full scope of items mentioned in Table 3.1, and partly explain the higher costs reported for the decommissioning of Bohunice V1.

### Duration

The duration is a key parameter in the combined cost category of dismantling activities, since most of the services for the management and for the site support must be provided all along the project execution, and thus are linked to the schedules of the activities. Some services are to be kept even during periods of quiescence. Thus, any delay may induce a significant increase in cost. The time assumed for the phases of a decommissioning project are summarised for a few examples in Table 3.9, based on some typical projects in the given countries. Within the sample of examples considered, where immediate dismantling is the decommissioning option assumed, the duration of active decommissioning should last 5 to 13 years (following preparation and defueling).

Resulting time frames are longer in the Swiss study, spanning up to 20 years from final shutdown<sup>1</sup> to achieve the release of the plant from nuclear regulations (de-licensing). The spent nuclear fuel wet storage facility decommissioning is assumed to start 19 years after final shutdown and to last 2 years. The incorporation of the post-operational phase and the increased support functions during dismantling (operations during dismantling) in combination with a somewhat longer duration are the major factors for the higher costs reported in the Swiss estimates. Another factor may be the specific labour costs (labour effort reported in the questionnaire was 585 man-years, in total, including pre-decommissioning). While labour rates are a key parameter affecting this category costs, no analysis of labour requirements could be developed because of the lack of relevant country data.

**Table 3.9: Assumed duration for typical phases in various decommissioning projects**

Country	# units	End state	Preparatory work	Dismantling	Decontamination	Conventional demolition/site restoration
Finland	2	Brownfield	2 years	2 years	3 years	Not included
France	4	See note <sup>1</sup>	3 years	7 years	3 years	2 years
Slovak Republic	2	Brownfield	3 years unit 1; 5 years unit 2	3 years	10 years	
Spain	1	Greenfield <sup>2</sup>	2 years	4 years	3 years	
Switzerland	1	Greenfield	5 years	10 to 15 years		

1. In France, all decommissioning projects include conventional demolition of all the buildings on-site up to one metre below ground level.
2. Greenfield is the target end state. However, the duration of seven years is only an assumption for the cost estimate, planning and financing, rather than a mandate.

For the Slovak case of Bohunice, where the assumed end state of the plant is brownfield (down to the bottom of the construction pit), the time frames foreseen for the project are longer than those considered in other cases, including 14 years following pre-

1. The estimates assume that the fuel has been removed from the plant five years after shutdown.

decommissioning activities. This reflects the technological complexities of the decommissioning project and the prolonged preparation in accordance with applied EBRD procurement rules and formal approval process and is also be one of the reasons the reported costs related to project management, engineering and site support, are on the high end. Units 1 and 2 of Bohunice NPP (V1) were shut down in December 2006 and 2008 respectively as a result of the accession to the European Union. Many system modifications of interconnections with the operating NPP V2 (units 3 and 4) on-site (including the costs resulting from the change of ownership of NPP V1) were necessary, for the preparation of the anticipated decommissioning and the related licensing; costing approximately EUR 60 million. In general, it is acknowledged that premature and unplanned shutdown may induce cost escalations, due to the insufficient preparation to undertake decommissioning.

### 3.3.1.3. Waste management (ISDC 05)

This category corresponds to ISDC 05, however there is considerable variation to the extent to which the estimates provided incorporate these costs. While it might not be unreasonable to expect waste management costs to be an increasing function of waste volumes (see PNNL, 2011), other analysis (see EPRI, 2011) found no significant trends in radioactive waste costs for decommissioning projects with plant size. Data related to this cost category show the most significant scatter, compared to other aggregated costs. Each observation stands almost on its own and cannot be analysed without considering, as far as possible, the context and background behind it. Based on the available information, some of these elements are discussed next.

A first differentiator across the dataset is the defined scope of the cost item itself. Not all countries include each cost sub-item identified under the category waste management. For instance, data related to the Spanish plants do not incorporate costs for waste transport and disposal. However, if these costs are not computed as decommissioning costs, they are accounted for through different arrangements.

Another factor expected to drive waste management costs, to the extent to which these are included in the estimates, is the inventory of waste: the specific waste categorisation, volumes and expected activities/dose rates. Some details on waste inventories obtained through the survey are summarised in Figures 3.A3.5 and 3.A3.6 in Appendix 3.A3. Waste inventories and categorisation appear to vary quite widely from case to case and even within the same country, depending on the type of estimate, the technology and the capacity (for instance in the Spanish cases). Where waste storage and disposal costs are included in the decommissioning cost estimates, the availability of a clear waste management route, its nature and costs, are important determinants in this cost category.

In the case of the Finnish decommissioning project of Loviisa, a particularly favourable context is the fact that an on-site disposal facility able to receive uncut large components will be available. This also reduces costs for on-site waste handling in the estimate – e.g. on-site storage of the radioactive waste during decommissioning is actually not needed in Loviisa, as this will be directly disposed of. Only some facilities on-site will be used for buffer storage, to take care of the material flows between the plant and the final repository. Built in the 1990s in granite host rock at a depth of ~100 m, the final repository can receive low- and intermediate-level radioactive waste (LLW and ILW) from operation and decommissioning activities, the latter in separate extensions. Moreover, the construction of the repository has been financed under the funding arrangements for operational radioactive waste management; and only its extension will be covered as part of the decommissioning cost.

In France and Switzerland, pending availability of repositories, the radioactive waste will be stored at interim storage facilities, and, for some waste exceeding the acceptance criteria approved for the El Cabril disposal facility, in Spain. For Spain the estimate for this cost category takes into account the co-ordinated national approach being followed.

For the Swiss case, despite the estimated volumes are relatively low (in particular those classified as radioactive), costs related to waste management are high in absolute and relative terms. These costs comprise the treatment, packaging and final storage of the decommissioning waste in an LLW deep geological repository.

In the Slovak Republic, waste is to be disposed of directly to a waste repository when available or stored on-site pending the availability of a waste repository. Initially, only very low-level waste (VLLW) and LLW will be transported off-site to already operational national repository (two double-rows – out of six planned – of the national repository are operational in Mochovce for LLW from operations and decommissioning, while VLLW repository is under construction). The radioactive waste not disposable in Mochovce National Repository will be conditioned in new integrated storage facility (currently under construction) in Bohunice. Waste treatment costs were derived from costs of the existing radioactive waste (RAW) treatment unit, and include the provisions for future decommissioning of RAW treatment facilities. The higher costs for decommissioning of Bohunice cover also the financing of construction of additional double-rows in National Repository, construction of integrated storage facility in Bohunice and rehabilitation of existing waste treatment and disposal facilities.

### 3.3.2. Cost data for high-level decommissioning processes for PNNL data

As reproduced in Table 3.10, the PNNL data are grouped in high-level processes, which are further aggregated in direct costs, including decontamination/removal, waste disposition and other direct costs; management costs, comprising costs related to programme management, SNF management and site operation and management; and other expenditures, such as insurance and regulatory costs, expenses for energy consumption, characterisation and licensing and property taxes. Most quantitative data are reported at the highest level of aggregation as direct, management and other costs, for which a direct equivalence with ISDC cost groups cannot be drawn. The only cost data in the PNNL report sufficiently detailed for such comparison are those provided in Table 5.2 of the PNNL report and reproduced here below in Table 3.11. This table lists decommissioning costs by plant and by cost category (in USD, of the estimate year). Costs are converted into 2013 USD using yearly gross domestic product deflators reported in OECD statistics and are presented in Table 3.12.

**Table 3.10: Cost structure used in the PNNL study**

Licence termination costs (do not include conventional dismantling)		
Direct costs	Decontamination/removal	Decontamination
		Removal
		Packaging
		Transportation
	Waste disposition	Waste disposal
		Waste processing
	Other direct	Spent fuel pool isolation
		Miscellaneous equipment
Management costs	Programme management	
	SNF management <i>not included in licence termination costs</i>	
	Site operation and management	
Other costs	Insurance and regulatory	
	Energy	
	Characterisation and licensing	
	Property taxes	

**Table 3.11: Decommissioning costs – actual and estimates for selected United States plants reported in USD million of the estimate year – “immediate dismantling”**

Plant	Year	PM <sup>1</sup>	D&D	INS.	Property taxes	Energy	Waste packaging	Waste transport	Waste burial	Site restoration <sup>3</sup>	Total w/o site restoration	Total including site restoration
Actual costs – PWRs												
Haddam Neck	1997-2007	311	290	1	16	N.A.	Not provided	102	Not provided	43	721	764
Maine Yankee	1997-2005	176	122	18	12	N.A.	Not provided	95	Not provided	16	424	441
Trojan	1993-2005 <sup>2</sup>	111	58	N.A.	N.A.	N.A.	14	11	13	18	208	226
Estimates – PWRs												
Braidwood 1	2009	201	124	8	12	5	16	11	65	68	442	510
Braidwood 2	2009	243	173	8	13	6	14	9	63	91	529	620
Byron 1	2009	208	120	8	17	4	16	11	65	68	448	516
Byron 2	2009	242	165	7	16	4	14	9	63	92	521	613
Diablo 1	2002	288	95	11	0	7	13	5	126	39	545	584
Diablo 2 and Common	2002	291	116	10	0	6	13	5	126	88	566	654
Prairie Island 1	2008	273	92	13	11	12	18	7	62	34	488	522
Prairie Island 2	2008	295	115	12	11	13	18	7	66	55	538	593
Salem 1	2002	234	115	11	0	8	12	12	98	Not reported	489	-
Salem 2	2002	272	133	9	0	7	12	12	99	Not reported	545	-
Three Mile Island	2008	238	134	8	6	6	13	15	84	78	504	582
Estimates – BWRs												
Cooper	2008	231	111	27	0	4	13	9	111	37	506	543
LaSalle 1	2009	235	164	8	9	6	20	12	92	50	547	597
LaSalle 2	2009	245	179	6	9	6	21	13	95	67	573	640
Monticello	2005	208	101	10	13	7	10	7	91	Not reported	447	-
Oyster Creek	2003	174	132	10	11	2	12	6	134	52	480	532
Vermont Yankee	2006	228	97	12	0	2	12	13	104	45	469	514

1. Project management, in addition to labour, includes costs that cannot be directly allocated to a decommissioning activity (i.e. equipment rental, supplies, etc.).
2. Although decommissioning occurred between 1993 and 2005, actual costs were provided in 1997 USD.
3. From Table 3.5 of the PNNL (2011) for the estimates. For the actual cases the figures are extracted from the detailed cases analysis in the report.

**Table 3.12: Decommissioning costs – actual and estimates for selected United States plants reported in USD<sub>2013</sub> million – “immediate dismantling”**

Plant	Project management	D&D	INS.	Property taxes	Energy	Waste packaging	Waste transport	Waste burial	Site restoration	Total w/o Site restoration	Total including site restoration
<b>Actual costs – PWRs</b>											
Haddam Neck	341	318	1	18	N.A.	Not provided	112	Not provided	48	788	836
Maine Yankee	204	141	21	14	N.A.	Not provided	110	Not provided	19	490	509
Trojan	151	79	N.A.	N.A.	N.A.	19	15	18	25	283	308
<b>Estimates – PWRs</b>											
Braidwood 1	214	132	9	13	5	17	12	69	72	471	544
Braidwood 2	259	184	9	14	6	15	10	67	97	564	661
Byron 1	222	128	9	18	4	17	12	69	72	479	551
Byron 2	258	176	7	17	4	15	10	67	98	554	652
Diablo 1	361	119	14	0	9	16	6	158	49	683	732
Diablo 2 and Common	365	145	13	0	8	16	6	158	110	711	821
Prairie Island 1	293	99	14	12	13	19	8	67	37	524	561
Prairie Island 2	317	124	13	12	14	19	8	71	59	577	636
Salem 1	293	144	14	0	10	15	15	123	Not reported	614	-
Salem 2	341	167	11	0	9	15	15	124	Not reported	682	-
Three Mile Island	256	144	9	6	6	14	16	90	84	541	625
<b>Estimates – BWRs</b>											
Cooper	248	119	29	0	4	14	10	119	40	543	583
LaSalle 1	250	175	9	10	6	21	13	98	53	582	635
LaSalle 2	261	191	6	10	6	22	14	101	71	611	683
Monticello	241	117	12	15	8	12	8	105	Not reported	518	-
Oyster Creek	214	162	12	14	2	15	7	165	64	591	655
Vermont Yankee	256	109	13	0	2	13	15	117	51	526	577

It should be noted that, under NRC standards and regulations, NPP decommissioning is accomplished, allowing the plant licence termination, upon completion of radiological decontamination. Thus, the demolition of non-radiological facilities or the demolition of radiological facilities that have been decontaminated to below the licence termination criteria, are not considered decommissioning activities and so the associated costs are not itemised among the “licence termination costs” in estimates provided for the NRC. However, as decommissioning is also conducted under US state-level supervision, other estimates may require that such costs are included. Equally, decontamination and remediation activities to achieve clean-up criteria that are more restrictive than the NRC’s clearance levels are not considered decommissioning activities by the NRC and are therefore not included in the licence termination costs for the NRC, but may be required to meet US state-level requirements. Site restoration cost data are thus available for selected US plants and the related costs are separately reported in the PNNL study (e.g. PNNL, 2011: Table 3.5).

For twin-unit sites, common costs for each of the items are attributed to one of the units. The three principal categories identified in Section 3.3.1 were also used to aggregate the data reported in Table 3.12; and the resulting aggregated costs are listed in Table 3.13 and Table 3.14, per unit and by site respectively.

**Table 3.13: Aggregated cost categories per unit – actual and estimates for selected United States units reported in USD<sub>2013</sub> million – “immediate dismantling”**

Plant	Decontamination and dismantling	Waste management <sup>1</sup>	Project management	Site restoration	Total
Haddam Neck	318	112	341	48	819
Maine Yankee	141	110	204	19	474
Trojan	79	52	151	25	307
Braidwood 1	132	98	214	72	516
Braidwood 2	184	92	259	97	632
Byron 1	128	98	222	72	520
Byron 2	176	92	258	98	624
Diablo 1	119	180	361	49	709
Diablo 2 and Common	145	180	365	110	800
Prairie Island 1	99	94	293	37	523
Prairie Island 2	124	98	317	59	598
Three Mile Island	144	120	256	84	604
Cooper	119	143	248	40	550
LaSalle 1	175	132	250	53	610
LaSalle 2	191	137	261	71	660
Oyster Creek	162	187	214	64	627
Vermont Yankee	109	145	256	51	561

1. Waste management = waste packaging + waste transport + waste burial.

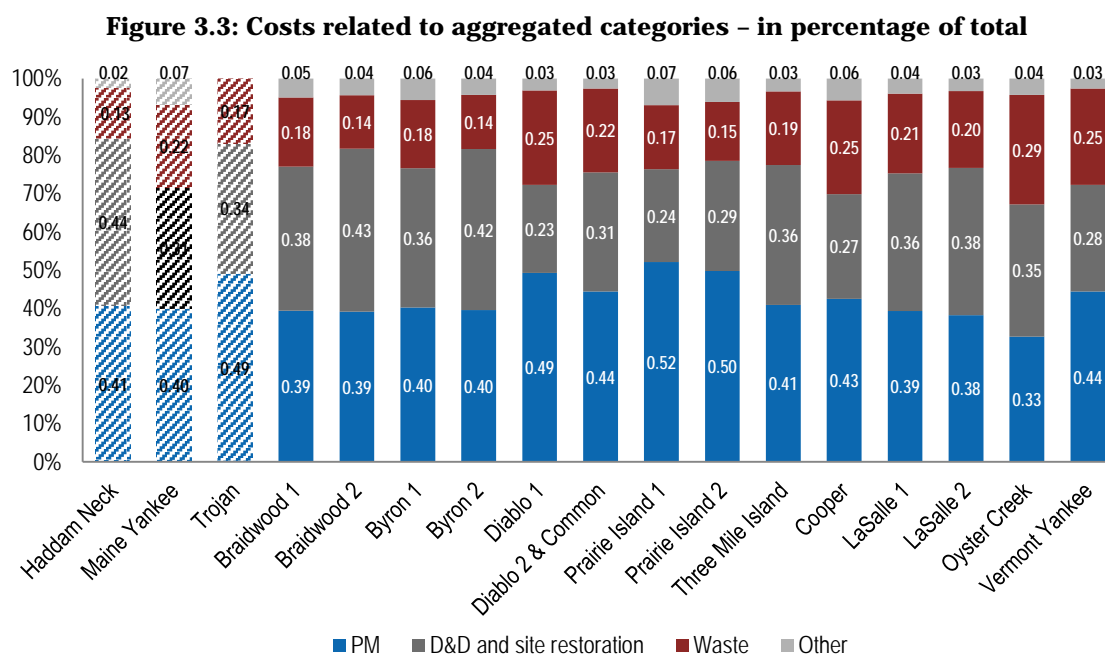
**Table 3.14: Aggregated cost categories per site – actual and estimates for selected United States plants reported in USD<sub>2013</sub> million – “immediate dismantling”**

Plant	D&D + site restoration	Project management (PM) per site	Waste management site <sup>1</sup>
Haddam Neck	366	341	112
Maine Yankee	160	204	110
Trojan	104	151	52
Braidwood 1 and 2	485	473	190
Byron 1 and 2	474	480	190
Diablo 1 and 2	423	726	360
Prairie Island 1 and 2	319	610	192
Three Mile Island	228	256	120
Cooper	159	248	143
LaSalle 1 and 2	490	511	269
Oyster Creek	226	214	187
Vermont Yankee	160	256	145

Waste management = waste packaging + waste transport + waste burial.

D&D = Decontamination and dismantling.

Figure 3.3 provides a global vision of the ranges of the different aggregated categories of costs, in percentages of the total. In Appendix 3.A3, Figure 3.A3.7 shows the absolute values; Figures 3.A3.8 and 3.A3.9 present the values per site and unit, for the three aggregated categories.



PM = Project management; D&D = Decontamination and dismantling.



### 3.3.2.1. Decommissioning and dismantling (D&D) and site restoration activities

For the PNNL data, cost listed under the heading D&D of Table 3.11 are to be combined with site restoration costs contained (by and large) in Table 3.5 of the PNNL (2011) report.

For the decommissioning of Trojan various factors contributed to keep this cost category exceptionally low. First, the possibility to pursue one piece removal of large components, which was feasible thanks to the availability of an adequate waste disposal route at the Hanford Atomic Reservations, and which led to much reduced times and costs. Moreover, the results of the site environmental survey indicated that no radioactivity had spread to the environment, including surface water and groundwater, in quantities requiring remediation, in line with the relevant clearance levels. This also held costs down. The demolition of non-contaminated buildings and site restoration is yet to be completed and, accordingly, alongside the costs already incurred, the corresponding cost data contain an estimated quote for the outstanding work.

Quite different was the experience in decommissioning Haddam Neck Plant (HNP). For HNP the reactor pressure vessel (RPV) internals were segmented; and, because the RPV activity was estimated to be greater than the limits accepted in the disposal facility for LLW (800 000 Ci versus 50 000 Ci limit at the selected disposal facility) such segmented internals were removed and stored on-site at the ISFSI.<sup>2</sup> The segmentation of the internals proved to be a very challenging project, taking approximately 29 months. Such schedules were well in excess of those originally estimated, as was also the total radiation exposure accrued for the operations. Similarly, as discussed later, the decontamination of exposed faces of buildings and foundations, as well as the remediation of soil, were extensive tasks, owing to the strict release criteria set by the State of Connecticut. Soils not meeting the applicable limits were removed and disposed of as radioactive waste. Also, because of the lack of project-related information during the period when activities were outsourced to an external contractor (decommissioning operations contractor [DOC] as referred to in the PNNL study), DOC costs that are typically computed as programme management costs, were categorised under “decontamination”, along with some cost items that would normally be assigned to the “waste disposal” and “spent fuel management” categories. All these factors contribute to the escalation (real or induced by cost allocation) of this aggregated cost category for the HNP decommissioning project.

### 3.3.2.2. Project management

Experience for the completed projects show how pronounced can be the impact of management changes during the execution of the project. For Trojan the licensee decided to perform the decommissioning of the plant, which was conducted efficiently and without major changes or setbacks. Conversely, while the initial plan for both Haddam Neck and Maine Yankee was for the licensee to manage the project, the work was subsequently contracted to a DOC. In both cases, further down the line the licensees chose to resume the execution of the project activities. In the case of Maine Yankee this was due to bankruptcy of the contracting company, and in the case of Haddam Neck it was decided following the significant effort associated with managing contract changes concerning the scope of the DOC. In both cases, such management changes induced complications and delays in the programme, and ultimately considerable escalated of costs. Greater delays and therefore greater costs were experienced in completing the HNP project, notably due to additional issues such as the complexity of reactor internals segmentation, the inclusion of a groundwater monitoring period, more stringent licence termination clean-up criteria, etc.

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2. Treated as “Greater than Category C” low-level waste – this waste category is discussed later, with the LLW classification system adopted in the United States.

As already noted, the duration of the project is a key parameter in this combined cost category. The PNNL study also emphasises how unavailability of SNF management routes can cause significant scheduling hindrance and additional costs. This often entails the need to build (or expand) interim SNF storage on-site (as it is the case in most US plants for which immediate dismantling is assumed). During such time, the fuel remains in wet storage in the existing fuel pool(s), sometime for fairly lengthy periods following shutdown (e.g. for 12 years for Diablo Canyon units 1 and 2). When fuel is kept in fuel interim storage on-site, additional security and safeguard standards are required. Sometimes this is a key argument in the decision of delaying dismantling. Avoiding constraints on the decommissioning of the fuel handling buildings, the delayed dismantling option can alleviate such issues by allowing the planning of the activities in accordance with the deployment schedule of disposal facilities, so that SNF inventory can be removed from the site before the initiation of decontamination and dismantling.

### 3.3.2.3. Waste management (packaging, transport, burial)

Looking at Table 3.11, for the PNNL data, this category corresponds to the sum of the three cost items related to waste management: waste packaging, transport and burial. As noted in Section 3.3.1 an important factor expected to drive waste management costs is the inventory of waste (assumed – in estimates, or actually generated – in completed projects) to the extent that such wastes are included in the values provided: waste volumes and specific waste management costs are compared for the US cases in Appendix 3.A4.

Looking at costs for completed project, in conjunction with the volumes generated, the comparatively high waste management costs incurred for the decommissioning HNP can be partly explained by the amounts of waste produced, substantially greater than those observed in other completed cases. These are mostly attributable to the release criteria and clean-up levels adopted by the State of Connecticut. The PNNL study reports that “regulation of HNP decommissioning by multiple government agencies complicated the process for obtaining approval of site release criteria”. Such limits are significantly more restrictive than those established by the NRC (PNNL, 2011) and entailed, *inter alia*, the requirement to remove above-grade portions of site buildings and structures and to demolish structures, systems and components to 4 feet below grade. Most notably, the groundwater beneath the Haddam Neck site was classified for residential use, bearing the need for a very rigorous subsurface soil remediation and the consequent removal of substantially more soil than would have been necessary to meet the NRC requirements for the site licence termination. Soils not meeting the applicable limits were removed and disposed of as radioactive waste. Hence very large quantities of waste were produced during the decommissioning of Haddam Neck. The packaging, transport and disposal of such waste volumes were major project undertakings, generating a large fraction of the overall decommissioning cost.

Data on total waste volumes generated from actual decommissioning suggest no clear relation with the plant capacity. This is also consistent with the findings reported by EPRI (2011). Furthermore, looking at the available cost data for waste management, not always do costs vary congruously with the relative waste volumes (to be) treated. Waste costs appear to be more sensitive to the management strategies and solutions selected or assumed, for the specific plant, and the related unit costs individually applied. The accessibility of waste management routes can even determine the way the decommissioning of the reactor is undertaken. For example, one piece removal can be favoured if an adequate repository is available for its disposal. This, in turn, can have considerable bearing on the time frames involved and the costs incurred, not only for the management of waste, but also other decommissioning cost categories. In this respect, the actual waste management costs incurred for the decommissioning of Trojan are indicative. For the decommissioning of Trojan, essentially 100% of the total volume of LLW was shipped and directly disposed of at the US Ecology LLW disposal facility at

Richland, Washington. The charges incurred from this process were comparatively low, and were limited by annual revenue constraints applied at the time to that disposal facility (PNNL, 2011). Importantly, owing to the access to this waste management route, the reactor vessel was removed as a “package”, with intact internals, and transported by barge for disposal, as was the steam generators and the pressuriser. This approach presented a number of advantages, including: decreased waste volumes, reduced personnel exposure and much fewer radioactive shipments; which, in turn, yielded significant savings. The most challenging aspect of the project was obtaining several state and federal approvals needed for this disposal option. Without regulatory changes, the option to dispose of the reactor pressure vessel and internals in a single package will not be open to other commercial NPP decommissioning projects in the United States. In this respect conditions experienced at Trojan for waste management, both in terms of approach as well as specific charges applied, are unique.

From the volume data reported in Appendix 3.A4 is interesting to note that the volumes expected for future projects are considerably lower than what was experienced in all of the completed projects (by an order of magnitude if compared to Haddam Neck and Maine Yankee, and by nearly 50% if compared to Trojan). A possible source of systematic bias is that the majority of estimates are based on the same methodology. Thus many of the apparently different estimates are simply iterations of the same model, with differing input parameters reflecting specific plants.

The highest waste management estimated costs are for Oyster Creek, because its LLW costs include the “remediation of a significant volume of contaminated soil”. However, the actual volume of contaminated soil is not reported. The LLW volume for Vermont Yankee includes also a large quantity of contaminated soil (135 000 ft<sup>3</sup> – 3 800 m<sup>3</sup>), making costs for its management somewhat higher than costs for plants of similar capacities (e.g. Monticello and Cooper, but not as high as Oyster Creek).

### **3.4. Considerations on uncertainties, contingencies and risks in decommissioning**

#### **3.4.1. Uncertainties due to lack of knowledge**

For a new facility, planning for decommissioning should begin early in the design stage and should continue through to termination of the authorisation for decommissioning; whereas for existing facilities where there is no decommissioning plan, a suitable plan for decommissioning should be prepared by the licensee as soon as possible (IAEA, 2014). In either case, the plan should be periodically reviewed and updated by the licensee. An initial decommissioning plan should identify decommissioning options, demonstrate the feasibility of decommissioning, ensure that sufficient financial resources will be available for decommissioning, and identify categories and estimate quantities of waste that will be generated during decommissioning. The decommissioning plan should be updated by the licensee and be reviewed by the regulatory body periodically through the life of the facility and until decommissioning is completed. As decommissioning planning begins decades in advance of the start of decommissioning operations, the calculated cost items are influenced by significant levels of uncertainty affecting individual input data, e.g. physical, radiological, decommissioning process, and economic parameters (NEA, 2012b, 2014).

Risk analysis is a major factor potentially affecting the planning and cost estimation of decommissioning work. In any case, estimates should be continuously updated using cost data from actual decommissioning projects, thus providing better control of uncertainties, improving the cost assessment, and facilitating the preparation of an annualised schedule of expenditures for each facility (NEA, 2010). The lack of cost data from actual decommissioning projects is a major hindrance to the benchmarking and validation of decommissioning cost estimates.

### 3.4.2. How uncertainties are factored in

In addition, in the execution of decommissioning projects, a variety of factors – technical, safety, regulatory and workflow issues – can intervene, posing risks that have the potential to force a replanning of processes, with consequences on costs and timing. From a cost estimation standpoint, risks and uncertainties need to be addressed through the estimate process and risk analysis.

General guidance on recommended practices and cost engineering standards exist, e.g. on the level of accuracy of the estimates depending on their nature and purposes (Association for the Advancement of Cost Engineering International, Recommended Practice 18R-97), and on the margins for technological and project risks, depending on the level of planning and the knowledge of technologies (e.g. EPRI margins). Some guidance specific for decommissioning cost estimation is provided in the ISDC. However, there is a general lack of consistency and of clarity in the analysis of uncertainties in decommissioning cost estimates. This can be seen even in a limited sample of approaches used in estimates made available for this report, as set out in Table 3.15.

**Table 3.15: Some approaches to uncertainties used in estimates**

Country	Contingency – method	Average	Range % <sup>2</sup>
Czech Republic	Using computational models and partially based on experience	Not provided	
Finland	Based on experience. 10% reservation is used to cover unexpected costs	-9%	9.08-9.1
Slovak Republic	Using risk analysis and risk assessment. Based on costing methodology	8%	0.2-16.5
Spain	Contingency factors are considered for the different phases of the project taking into account uncertainties related to specific activities	Not provided	
Switzerland	30% <sup>1</sup> required in the new ordinance. Numbers presented in this study are without this general contingency	30%	
United Kingdom	Combination of computational modelling (Monte Carlo simulation using 3-point estimates) and management judgement based on experience of previous projects	17%	1-24 <sup>3</sup>

1. On totals. New ordinance entered into force on 1 January 2015.

2. Depending on activities/cost items.

3. Also depending on reactor and specific phases.

### 3.4.3. Uncertainties in decommissioning cost estimation according to the ISDC

While the international acceptance towards harmonised cost structures for point estimates is generally rising through increasing application of the ISDC, it is apparent there is no harmonisation in the treatment of uncertainties between cost estimates. This continues to give rise to problems of interpretation and comparison between estimates.

The ISDC presents a common reporting format for costing undertaken on a deterministic basis. Uncertainties in the ISDC approach mainly are addressed through the application of contingency as part of the cost estimate. The definition of contingency as used in the ISDC is “specific provisions for unforeseeable elements of cost within the defined project scope”. In addition guidance is provided on how a cost estimate should

reflect contingency provisions to deal with uncertainties relating to activities within the defined project scope that might reasonably be expected to occur. Probabilistic methods for inclusion of uncertainties in cost estimates are not addressed in the ISDC.

This definition confines contingency to cost elements within the project scope. As costs are generally calculated in the first instance on the basis of standard conditions and expected efficiencies of activities, the contingency factor ensures that the estimate is made more realistic. It should be noted that contingency does not account for price escalation and inflation in the cost of decommissioning over the remaining operating life of the nuclear installation.

#### **3.4.4. Risk assessment to take into account out-of-scope elements**

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

A risk analysis can be qualitative or quantitative. In either case, top-down or bottom-up processes, and experience feedback are used for the identification of risks and opportunities and for planning improvement. For example a risk register is compiled by technical experts, where risks are categorised, e.g. as high, medium or low, and methods for their mitigation are identified. The risk register is maintained as a living document and updated periodically as the project proceeds and whenever changes or new conditions arise during the decommissioning project. Risk levels (low, medium, high) may be assessed when necessary; and adjusted according to the application of mitigation methods. In quantitative risk analyses detailed probabilistic simulations, such as Monte Carlo, are used to supplement the more qualitative approaches.

#### **3.4.5. International initiatives to address uncertainties in decommissioning projects and cost estimation**

The first meeting of the NEA Decommissioning Cost Estimation Group (DCEG) (Krefeld, Germany, May 2008) included a topical session on “Risks and Uncertainties in Decommissioning Cost Estimates”. This discussed contingencies within the planned scope of decommissioning project and uncertainties out of the project scope, and addressed the need to use risk management tools, etc.

In 2013, the DCEG held a topical session on risk and uncertainties in decommissioning cost estimation and the DCEG meeting subsequently agreed that consideration should be given to undertaking further work, on a collaborative basis with IAEA, aimed at fostering a better understanding in how uncertainties could be addressed in decommissioning cost estimates. Subsequently, recognising the need for more specific guidance on treatment of uncertainties and risks in decommissioning cost estimation, the IAEA and NEA have initiated a joint project to address these specific issues, building on the existing guidance in the ISDC. This work started in 2014 and it is intended to be complete by the end of 2016. This joint project aims to produce a new report on uncertainties in decommissioning cost estimation. Contingency and risk analysis will be addressed in the report through descriptions of different approaches. The report will include suggestions for presenting the results of risk analysis in a way compatible with the ISDC, in a non-prescriptive manner, with illustrative examples of good practice. Information on experiences concerning contingency and risk analysis, their treatment in decommissioning cost estimates, and their impact on actual project costs and schedules in participating countries and projects will also be presented. The implications for funding of uncertainties and risks in decommissioning cost estimation will be addressed but financing schemes per se will not be discussed in this project.

### 3.5. Case studies

In addition to providing detailed answers to the questionnaire and values for actual costs or estimates for decommissioning projects using the ISDC format, members of COSTSDEC were also asked to deliver a more descriptive presentation of concrete decommissioning strategies and projects: case studies.

Part II at the end of this report provides the six case studies which have been delivered during the course of the project:

- Finland: Loviisa NPP with twin operating units VVER 440.
- The Netherlands: Dodewaard NPP, a BWR of 55 MWe, shut down in 1997.
- Slovak Republic: Bohunice V-1 with twin units VVER 440 shut down in 2006 and 2008 respectively.
- Spain: José Cabrera NPP, a PWR of 160 MWe, shut down in 2006 and undergoing decommissioning.
- Switzerland: National approach covering all operating NPPs, but with more details for a 1 000 MWe PWR.
- The United Kingdom: National approach by the Nuclear Decommissioning Authority for the Magnox fleet.

While not following a strict table of contents, the cases studies are addressing elements of:

- scope and boundary conditions for the decommissioning activities, at national and/or project specific level (National decommissioning policy and strategies, project management, waste management, etc.);
- cost structure and estimations and the variation with time (updating);
- factors most influencing the cost estimations;
- coverage of uncertainties for cost estimations;
- lessons learnt.

Information provided in the case studies was extracted and used for the drafting of this report, in particular to support the analysis of the cost estimations in Section 3.3 above and as direct input for Section 3.6.

### 3.6. Variation of decommissioning cost estimates over time

Out of the six case studies that have been reported, three are providing some quantitative information on the variation of decommissioning costs (estimations) over time. Two are related to immediate dismantlement (Finland, Loviisa NPP and Switzerland, all NPPs), and one is related to deferred dismantlement (United Kingdom, NDA for the Magnox fleet). In the paragraphs below, the focus is specifically on the way the estimations are regularly revised and updated, and the trends and reasons of their evolution.

**For Loviisa**, the decommissioning costs are revised each five to six years, since 1983. The latest update was done in 2012. The total costs figures below are given without and with a contingency (arbitrarily fixed at 10%), and are provided in 2012 values to allow effective comparison of the estimations (see Table 3.16). The methodology to convert the figures in 2012 values is based on the combined index of define salaries (50%) and construction costs (50%) in Finland.

**Table 3.16: Decommissioning cost estimations between 1987-2012 for Loviisa, Finland**

	In "2012 EUR" without contingency	In "2012 EUR" with 10% contingency
1987	EUR 278 793 k	EUR 306 672 k
1993	EUR 261 752 k	EUR 287 928 k
1998	EUR 258 801 k	EUR 284 681 k
2003	EUR 263 131 k	EUR 289 444 k
2008	EUR 312 424 k	EUR 343 666 k
2012	EUR 326 437 k	EUR 359 081 k

Source: Finland case study.

First, there was a slight decrease of the cost estimations, followed by roughly 20% increase between 2003 and 2008, then a small increase in 2012.

The decision to consider an increase of the operational lifetime of the plant from 30 to 45 years, which occurred between the estimations of 1993 and 1998, had no major impact. The lifetime was further increased to 50 years for the estimation of 2003. The change in the free release limits late 2000s (factor 100 decrease from 10 to 0.1 kBq/kg) made the major difference in the 2008 calculation, by increasing the cost estimations for dismantlement and waste management. The increase in 2012 was coming from the updated costs for the expansion of the waste repository (the on-site operational waste repository expected to become the final ILW and LLW repository, including for main primary components after decontamination). The knowledge gained from the real cost of excavation for the extension of the (operational) waste repository served as the basis for the update of the cost estimations.

**In Switzerland**, cost estimation for decommissioning and dismantling of nuclear installations and disposing the waste arising from these activities are revised every five years. The calculation of the contributions to the decommissioning and waste disposal funds is based on a comprehensive estimate of the decommissioning and waste disposal cost carried out every five years.

The costs of the so-called post-operational phase (still under the umbrella of the active operation's licence) are reassessed together with the updating of the decommissioning and waste disposal cost studies; these are paid for directly by the operator via provisions also set aside for this purpose. The basis for the cost estimation assumes an operational lifetime of 50 years for the nuclear plants.

The Nuclear Energy Act and the Nuclear Energy Ordinance require updating of decommissioning plans for nuclear facilities on a regular basis (ten-year cycle) and, as necessary, taking account of changes made to the facilities, changes in the regulations and technological development. The Ordinance on the Decommissioning and Waste Management Funds requires a periodical update of the decommissioning cost estimate (five-year cycle), to take into account the uncertainty associated with the calculation, and making best possible use of current scientific-technical know-how and are based on costs/prices applying at the time of the calculation. To allow comparison, the costs/prices are escalated using an inflation rate of 3% per year, as per the Funds Ordinance.

The operators of the NPPs have elaborated detailed decommissioning studies for their facilities that are based on the decommissioning plans.

The last full revision of the decommissioning cost study was in 2001. The study was updated in 2006 but not recalculated. To take into account knowledge and experience from ongoing decommissioning projects in Germany and the current conditions in Switzerland, swissnuclear requested the NIS Engineering Group (NIS Ingenieurgesellschaft mbH – called NIS) to prepare new decommissioning studies for the Swiss nuclear power plants and the interim storage facility.

The results of the 2011 estimate of the decommissioning costs are compared in Table 3.17 below with the estimate for 2001, updated in 2006. To allow a direct comparison, the costs estimated in 2006 are projected from the 2006 price basis to the 2011 price basis using an inflation rate of 3% per year that is anchored in the Funds Ordinance and taken into account in the provisions model. These studies were revised in 2011. The decommissioning plans have been reviewed and approved by the authorities from a technical and financial point of view in 2012. A new revision of the decommissioning studies will be submitted by the end of 2016.

The variation of the cost estimations (in CHF million) for the “post-operational” phase for the diverse Swiss NPPs between the two last estimations (2006 and 2011 – both given in 2011 values) are given below (Table 3.17).

**Table 3.17: Variation of “post-operational phase” cost estimations, in CHF million**

Post-operational costs	PWR1	BWR1	PWR2	BWR2	Total
Cost Study 2011, price basis 2011 (estimation 2011/value 2011)	475	319	455	460	1 709
Cost Study 2006, price basis 2011 (estimation 2006/value 2011)	462	250	481	486	1 678
Absolute difference	13	69	-26	-26	31
Difference (%)	3%	28%	-5%	-5%	2%

Source: Swiss case study.

The variation of costs estimations (in CHF million) for the “decommissioning” phase for the diverse Swiss NPPs between 2006 and 2011 are given in Table 3.18.

**Table 3.18: Variation of “decommissioning phase” cost estimations, in CHF million**

Decommissioning costs	PWR1	BWR1	PWR2	BWR2	(Temporary H//LLW storage)	Total
Cost Study 2011, price basis 2011	809	487	663	920	95	2 974
Cost Study 2006, price basis 2011	631	440	605	835	31	2 541
Difference absolute	178	47	59	86	64	433
Difference (%)	28%	11%	10%	10%	204%	17%

Source: Swiss case study.

Corrected for inflation, the global decommissioning costs for 2011 are around 17% higher than the 2001 study (including the 2006 update). A significant contribution to the increase in costs is due to operational activities that continue to be required during dismantling (so-called operations during dismantling), the scope and duration of which has been expanded based on information from ongoing decommissioning studies. The above-average increase in the case of PWR1 is largely due to the sequential dismantling of the two reactor units on the same site. For the first time, the new decommissioning study for the central interim waste treatment and storage facility was carried out on the same basis as the NPP studies. This means that the 2006 and 2011 studies for the central interim waste treatment and storage facility are difficult to compare, but this is also due to a significant cost element (operations during dismantling) for Zwiilag being allocated to the decommissioning costs rather than the waste disposal costs.

A detailed comparison is given (see Table 3.19) for PWR2, in CHF million and percentage, based on the changes in the costs structure between the 2001/2006 and 2011 estimations.



**Table 3.19: Evolution of cost estimates over time**  
(CHF million and %)

NPP decommissioning cost study 2001, updated 2006			NPP decommissioning cost study 2011			Delta	
Work package (WP) Cost study/price basis	A 06/2011* CHF million	B (A/total A)	Work package	C 11/2011 CHF million	D (C/total C)**	E (A-C) CHF million	F (E/C) Per WP
Planning and preparing documentation	25.6	4%	Decommissioning project and order	21.3	3%	-8.2	-28%
Review and licensing	3.9	1%					
Preparing the plant for dismantling	41.7	7%	Preparatory measures	44.0	7%	2.2	5%
Dismantling contaminated components	30.6	5%	Dismantling installations of controlled zone	24.2	4%	-6.4	-21%
Dismantling activated components (RPV and RPV internals)	34.3	6%	Dismantling RPV and RPV internals	39.5	6%	5.2	15%
Dismantling of bioshield	1.8	0% **	Dismantling of bioshield and drywell components	3.9	1%	2.1	115%
Dismantling of remaining components	8.9	1%	Remaining dismantling of installations of controlled zone	12.9	2%	4.0	45%
Building decontamination and clearance of building surfaces	40.2	7%	Decontamination and release of buildings	36.9	6%	-3.4	-8%
Decontamination	***	***					
Radiological and worker protection	***	***					
Conditioning and disposal	111.1	18%	Material treatment and disposal	112.8	17%	1.7	2%
Emptying buildings and demolition	108.0	18%	Dismantling installations of conventional area and conventional demolition	52.8	8%	-55.2	-51%
Project monitoring by authorities	198.3	33%	Operations during dismantling	314.9	47%	116.6	59%
Construction site operation and property protection							
Project and construction management							
Totals	604.5	100%		663.1	100%	58.5	10%

\* Escalation according to Funds Ordinance (3%/year).

\*\* 0% implies that the value is less than 0.5%.

\*\*\* The costs of these two work packages have been distributed among the others for the 2011 calculations. To ease comparison with the 2006 values, these have been reallocated also following Table 3.20 below.

Source: Swiss case study.

**Table 3.20: Reallocation of costs over time**

Work package	[CHF <sub>01/2001</sub> million] – 2006	Percentage distribution
<b>Decontamination</b>	<b>39.87</b>	
Preparing the plant for dismantling	5.65	14%
Dismantling of contaminated components	1.77	4%
Dismantling of activated components (RPV internals and RPV)	0.62	2%
Dismantling bioshield and drywell components	0.09	0%
Dismantling of remaining components	0.68	2%
Building decontamination and clearance of building surfaces		0%
Conditioning and disposal	22.20	56%
Construction site operation and property protection; project and construction management	8.87	22%
<b>Radiological and worker protection</b>	<b>34.87</b>	
Preparing the plant for dismantling		0%
Dismantling of contaminated components	3.03	9%
Dismantling of activated components (RPV internals and RPV)	1.27	4%
Dismantling bioshield and drywell components	0.16	0%
Dismantling of remaining components	0.38	1%
Building decontamination and clearance of building surfaces	2.92	8%
Conditioning and disposal	8.70	25%
Construction site operation and property protection; project and construction management	18.41	53%

Source: Swiss case study.

While the difference in the total cost estimations between 2006 and 2011 is only 10% for PWR2, the differences at the level of the individual work package vary much more, some positively, some negatively.

The higher costs for the work package “preparatory measures” are due to the reassessment (almost triple) of the required manpower. The higher costs in the work packages “dismantling of RPV internals and RPV” and “dismantling bioshield” result from a reassessment of the required manpower and the costs of the tools to be used. The higher costs for the work package “remaining dismantling of installations of the controlled zone” result on the one hand from moving the dismantling effort from the work package “dismantling the installations of the controlled zone” into this work package and, on the other hand, from reassessment of the work effort involved. The costs of these two work packages together give a slightly lower amount than the sum of the costs for the 2006 study (column A). Moving the measures between the work packages was due to the new time sequence for dismantling. In the present decommissioning study, dismantling of the activated components (RPV internals, RPV, bioshield, etc.) is assumed to take place earlier than in the 2006 study. The dismantling of the contaminated components therefore occurs later and is considered in the work package “remaining dismantling of installations of the controlled zone”. The higher allocable repository costs have an effect on the work package “material treatment and disposal”.

The fact that the total costs for the 2011 study are still around 10% higher than the inflation-adjusted costs for the 2006 study is mainly due to the work package “Operations

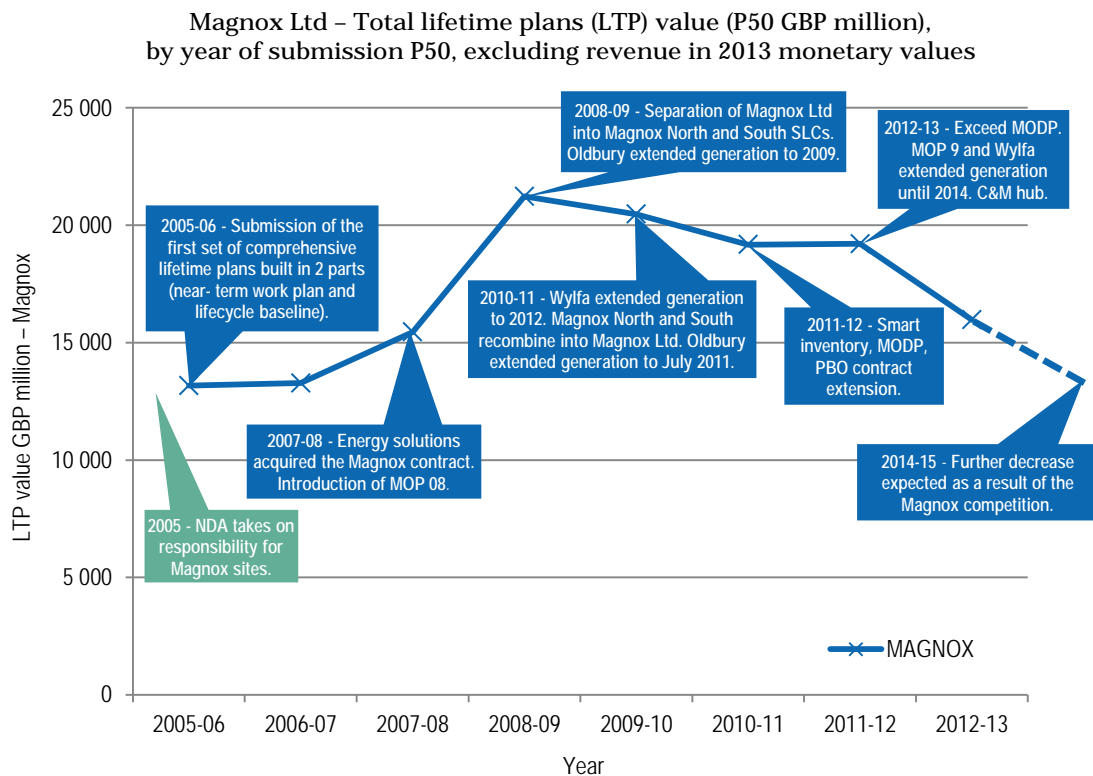
during dismantling”. This work package comprises all measures that ensure the operation of the construction site.

**In the United Kingdom**, deferred decommissioning is the selected option for the Magnox reactor fleet. By 2028 ten Magnox sites are scheduled to be in the care and maintenance (C&M) phase. This is when all required decommissioning preparations have been completed. The sites will then remain in a safe and secure state until they reach the commencement of final site clearance some 85 years after cessation of power generation.

The current schedule for the Magnox sites incorporates lessons learnt over the first five years of the NDA’s operations since 2005. In 2011, a revised schedule to C&M was drawn up for ten Magnox sites, this was termed the Magnox optimised decommissioning plan (MODP). The MODP introduced cost reductions of more than GBP 1.3 billion into the Magnox lifetime plans and reduced the total time required to place the 10 Magnox sites into C&M by 34 years.

The benefits of the MODP were achieved through a combination of new technical solutions and different working arrangements with the introduction of strategic programmes, in addition to extended generation at the remaining operating site, Wylfa. Further to the major schedule and tactical changes, there has been the introduction of the C&M Hub providing further Lifetime Plan cost reductions of approximately GBP 0.5 billion. Below the major headline changes, every single project had a scope, schedule and cost produced to underpin the MODP. The culmination of these changes is the schedule to deliver work more efficiently, bringing forward C&M entry dates at Bradwell and Trawsfynydd and progressing decommissioning work at other Magnox sites. The evolution over time of the overall cost estimates (lifetime plan maturity curve) is given in Figure 3.4 below.

**Figure 3.4: Evolution implied of the overall cost estimates (lifetime plan maturity curve)**



In 2005, the submission represented the first set of comprehensive plans built in two parts. The Near Term Work Plan (NTWP) included three years of more detailed information and the life cycle baseline included the remaining life cycle cost.

Since 2005 when the NDA took on responsibility for the Magnox sites, a Lifetime Plan was submitted on an annual basis by the site licence companies (SLCs). The graph demonstrates the Maturity Curve of Lifetime Plan by year of submission for Magnox Limited, and is overlaid with key events which contributed to the changing profile of Lifetime Plan cost. Further detail on the key events is outlined below.

Energy Solutions acquired the Magnox contract in 2007. The main driver for increase in the 2007/08 submission was the impact of revising the Magnox operating programme (MOP 8), extending the time frame over which Magnox stations are defueled, which increased the overall schedules to C&M entry. As a result, the revised MOP 8 affected the decommissioning and clean-up liability at a large proportion of Magnox sites. In addition, the introduction of Magnox North and South as two independent SLCs, resulted in movements of support and overhead costs to the two centralised functions and although there were some efficiencies, additional resources were required to provide discrete technical support to the two separate bodies.

The Lifetime Plan cost peaked in 2008/09 to incorporate extended generation for Oldbury and the full extent of changes, as a result of MOP 8 were included. In addition to this, the focus on higher hazards in the near term reduced the annual expenditure levels at some sites and therefore re-phased decommissioning expenditures to later years. This increased the lifetime costs as site support expenditures (overheads) had to be maintained for longer. In 2008, the Magnox SLC's final site clearance costs including reactor dismantling and site landscaping were insufficiently developed and underpinned for inclusion in the 2007/2008 accounts. As a result of a remodelling exercise and review during 2008/2009, the associated cost of realigning the final site clearance and care and maintenance costs were identified as approximately GBP 1 billion.

In 2010, Magnox North and South recombined to form Magnox Limited, which drove a reduction in costs particularly in overheads and support areas. The MODP baseline changes were implemented over a number of months. Both Oldbury and Wylfa further extended generation were included at this time resulting in an increase in the early year costs for operations and a consequential rescheduling of the subsequent phases.

In 2011, the "SMART" Inventory demonstrated a level of maturity and understanding of the full scope. This was the systematic review of the waste inventory of sites, getting more accurate waste volumes and increased characterisation resulting in a reduction in this area of the plan.

Further changes have occurred from 2012/13 with the balance between additional costs following further generation extension at Wylfa and the cost reductions introduced through the centralised "hub" for the management and maintenance of the sites during the C&M period.

A further decrease to the Magnox baseline estimate is expected once the preferred bidder, resulting from the Magnox Competition, has taken over the Magnox contract.

In summary, a downward trend from 2009-2010 of decreasing Lifetime Plan value is demonstrated for Magnox once a level of maturity had been reached for the decommissioning plans and Magnox had developed an understanding of the full scope. The implementation of MODP was a contributor, drawing on actual experience through lead and learn and the benefits from approaching multiple sites in a systematic way.

**Out of these three cases studies** related to the evolution and revisions of cost estimates in time, the following recommendations may be drawn:

- The revision and update of the decommissioning cost estimations should be done on a regular basis. Five years seems a preferred period. A specific revision may be done in the case where there is a major change in the scope, duration, process of decommissioning or a change in the regulatory basis (for example, a change in clearance level). In the United Kingdom, since the creation of NDA in 2005 as the responsible entity, estimations have been revised each year, and in line with major changes in the approaches for decommissioning, based on the return of experience of their lead and learn process and the desire to benefit from the multiple sites effect.
- Integration of the latest knowledge available and return of experience of ongoing and finalised decommissioning projects greatly helps improving the estimation of costs and reinforces the validity of “best estimate” costs (defined as expenses based on detailed technical and scientific concepts, in accordance with the latest knowledge available and a clear planning of activities).
- Comparison and explanation of differences between successive cost estimations, are only possible if the scope, duration, process stay compatible. Changes in cost structure and allocation may, in particular, render the comparison difficult. For sure, comparison is also only possible if costs are all expressed in monetary value for the same given reference year. The methodology used to make the cost and price conversion must be clearly explained.
- The Swiss experience shows that the total costs of decommissioning the nuclear plants in Switzerland can be kept, provided that planning is optimised and that lessons already learnt are incorporated. The total costs determined in each case are therefore within the bandwidths to be expected, as compared with international decommissioning projects. It is anticipated that the actual decommissioning costs will be within the usual industrial cost range of -15% to +30% as compared to the cost studies. This level of accuracy is adequate for the current status of planning.
- According to a subsequent revision of the Ordinance on the Decommissioning and Waste Management Funds for Nuclear Facilities in Switzerland, a contingency of 30% of the overall overnight costs should be taken into account for determining the provisions for the decommissioning and waste management funds in the future.
- In the case of a decommissioning programme developed for a fleet, such as for the UK Magnox case, changes in the overall management structure with specific attention to planning and sharing the use of resources, in particular overheads, may greatly affect the overall cost estimations.

### **3.7. Lessons learnt and potential challenges**

This section summarises some of the lessons learnt through the experience of different countries, both regarding their understanding of factors affecting the costs of decommissioning, as well as in terms of good practices and optimisation processes identified. For future decommissioning projects, some challenges have been identified through the process of periodic review of cost calculations.

#### **3.7.1. Resource needs and management**

- Decommissioning as any industrial projects have budgets and time constraints. Therefore sound and professional project management is necessary. Detailed

planning and its continuous monitoring are fundamental to anticipate deviations and establish corrective actions in time. Due to the long time frames applicable to decommissioning projects, the multiple tasks to organise and realise, and the uncertainties affecting the process, project management must be dynamic and flexible. Not having this in place might lead to cost increases.

- Decommissioning is a labour intensive process and labour costs dominate the decommissioning costs. The selection of the suitable manpower strategy can be a key differentiator (for example make/buy decisions, using specialist contractors versus incumbent workforce). Estimation of the labour needed for different tasks, as well as the total duration of the decommissioning works is crucial in the development of cost estimates and major uncertainties are related to this assessment. An additional challenge may arise where there is parallel operation and decommissioning at different units on the same site.
- One of the major challenges is dealing with the necessary transition of personnel: from an organisation that was created to support the safe operation of a nuclear plant to one that is more project-oriented with a focus on safe dismantlement of a nuclear facility. To a large extent the number of people and their needed skills vary for these two very different missions and the organisation of the transition must be conducted under strict regulatory requirements and in a relatively short time frame. The Human Resource process for the transition needs to be well thought out and undertaken.
- Several issues related to the performance of suppliers and contractors involved in the decommissioning activities can have considerable impact on the schedules and costs:
  - For contractors who might not be familiar with work in the nuclear sector or with nuclear standards, problems can arise, including, for instance in the preparation of suitable documentation, with supplementary control and support required by the site organisation.
  - Disruptions can arise from interferences between the different contractors working at the same time.
  - Management of interfaces and logistics at combined sites with either existing generation or new build NPPs is key.
- Impacts of management changes during the execution of the project can be very significant in terms of delays in the activities and escalation of costs.
- Monitoring of the decommissioning schedule is essential for project cost control, which is very sensitive to programme delays.

### **3.7.2. Contamination characterisation and waste inventory**

- The extent of characterisation required to determine accurately the amounts of waste corresponding to different available waste disposition routes is an important cost factor. Accurate characterisation is central to achieving reliable cost estimates.
- The amount of contamination in the reactor and auxiliary buildings, as well as in the secondary side of the plant can be a great factor of uncertainty.
- Similar uncertainties extend to site restoration activities, when these are included in the scope. Increased levels of contamination may lead to higher waste volumes and manpower needs in dismantling, potential delays in the overall schedule and escalating costs.

- Importantly, waste inventories are also inherently dependent on the clean-up levels and clearance criteria applied in each case. More stringent regulatory requirements can lead to much greater volumes of waste to be handled and managed as radioactive. Changes in regulatory free release limits have had an impact on the evolution of cost estimation with time. It might contradict one of the expected benefits of deferred decommissioning. Going beyond the strict regulatory limits, in some cases, the scrap industry is not prepared to accept cleared material, even below the free release limits. This then induces more expensive waste management processes than strictly required.

### **3.7.3. Waste management**

- The availability of a clear waste management route is a great advantage for the decommissioning planning and for cost estimation and control. Actual experience, as well as cost projections, show that waste management costs are very sensitive to the management strategies and solutions selected or assumed, and their related costs. In addition, the accessibility of waste management routes can even determine the decommissioning strategy of the reactor.
- The availability of a defined waste management route is also important because the costs of interim storage can increase over time. Moreover, in the absence of disposal facilities, the costs of final disposal of decommissioning waste remain uncertain.
- The fact that the low- and intermediate-level radioactive waste (LILW) disposal facility is owned and operated by the plant operator makes it possible for optimisation of the whole waste management route from dismantling works to the final disposal.
- Although fuel management costs are not covered in this analysis, the timely availability of fuel management routes is also critical in the selection of decommissioning strategies, sequencing, timing, and hence costs. Unknowns related to the deployment of SNF disposal facilities and the changing regulatory environment contributes to increasing the uncertainties on decommissioning. Extended SNF/high-level waste (HLW) on-site storage has become a reality in several cases, with emerging issues related e.g. to ageing management and canister relicensing.

### **3.7.4. Policy and regulatory framework**

- Lack of clarity in and/or changes to the policy and regulatory framework create uncertainties about the conduct of decommissioning activities and the associated costs.
- Safety requirements from the regulatory authority applied during the operational phase may remain during decommissioning, even if, after defueling, associated hazards and risks may change in magnitude and nature. The application of these regulatory requirements for decommissioning activities may impact the associated cost estimates.
- Experience in the process for compliance demonstration with licence release criteria (licence termination), after decommissioning work has been completed and the waste has been disposed of, is currently limited. As such, there are inherent uncertainties associated with these cost estimates.

### **3.7.5. Execution of operations**

- Processes that represent precursor activities to decommissioning can also be the root of external influences. For example, defueling delays and extensions can

significantly affect the timeline and hence costs of decommissioning because there is limited work that can be completed during the intervening period.

- Cost estimations are based on assumptions and approaches, which may be adopted in time due to experiences made in other ongoing decommissioning projects and have a great impact on costs. Lack in preparatory work can lead to unexpected increases of cost elements.
- First time technical activities may be a very challenging endeavour, requiring great effort, well in excess of that originally estimated, with extended time frames and a significantly increased radiation levels.
- From a technical point of view, the segmentation of the internals and reactor vessel is a challenging activity. It involves several disciplines of different nature as engineering, licensing, health physics, cutting techniques or radioactive waste management, requiring a multidisciplinary approach. These complex operations are part of the critical path of the project and require exhaustive planning and control to prevent delays and cost deviations.
- Preparation for a safe enclosure may present enhanced challenges in the selected de-planting of systems that retained no functions, with only certain parts of the installation taken out of service. Due to the many (electrical and plumbing) cross-links this operation may prove very complex and very time-consuming.

#### **3.7.6. Increased understanding**

- Current ongoing decommissioning projects are often undertaken as first-of-a-kind. On the basis of greater experience in the future, the possibility will exist for optimisation in some areas, e.g. material treatment and disposal (melting, and packaging), use of replacement systems (maintenance and repair measures) or planning the timing of dismantling activities (time optimisation).
- In addition, new approaches in cost calculations (more complete modelling of some cost elements) may also be responsible for the increase in the estimates.

#### **3.7.7. Some additional factors influencing costs**

- Stakeholder issues: Early and continued interaction with stakeholders will facilitate decommissioning. However, it might also impact the cost as it becomes necessary to cover some particular expectations/interests that were not considered at the time of cost estimation. Good and early understanding of the views of stakeholders as well as appropriate explanations about the goal and scope of the decommissioning project should limit the risk.
- Fleet effect: The following approaches and practices might benefit licensees co-ordinating multi-unit or multi-site decommissioning (as it appeared in particular from the case study for the UK NDA Magnox fleet):
  - Centralisation of functions and resources for support activities can reduce on overhead/fixed cost burden.
  - Resource planning across a fleet allows strategy optimisation through series effects, enabling effective use, training and succession arrangements as the activities move from operations to decommissioning and sharing of best practices and spreading of lessons learnt.
  - A systematic approach recognising that across sites there are differences but also that some core decommissioning challenges will be common across projects, allowing similar solutions to be implemented and providing delivery benefits.



### 3.8. Conclusions

Collecting sufficient useful data from the questionnaire to ensure an in-depth analysis and assessment of the costs of decommissioning, from both actual figures coming from completed projects and estimates for future projects, has not been possible. Among other factors, issues of confidentiality still emerge, refraining some organisation from disclosing their experience and cost data with enough details, in particular when private companies have developed proprietary technologies or practices.

The COSTSDEC and the NEA have nevertheless agreed to release distributions of the main cost categories within the overall decommissioning cost estimates, according to an aggregation of categories of the ISDC. These distributions are presented in two sets, one from the numbers collected via the questionnaire, and one from the PNNL study for the United States. A conversion of the US estimates into the ISDC format was performed to verify how far this aggregation process allows the same approach for both data sets. Most of the PNNL data are cost estimates are established using the same methodology, which leads to some kind of standardisation and explains why the US data may appear more consistent. The PNNL data also contain actual cost data for four completed decommissioning projects in the United States. These are the only actual completed decommissioning projects for which cost data has been made available for this report. They show wide differences between them.

Some analysis of differences and similarities in approaches and assumptions has also been performed to, partially at least, explain the diverse figures. Out of this, some lessons and challenges could be drawn in terms of the factors influencing estimates of decommissioning costs.

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## Appendix 3.A1. International Structure for Decommissioning Costing (ISDC)

**Table 3.A1.1: ISDC disaggregated decommissioning cost items**

Cost item	Labour		Capital	Expenses	Contingency	Total
	Hours	NCU	NCU			NCU
<b>01 Pre-decommissioning</b>						
01.0100 Decommissioning planning						
01.0200 Facility characterisation						
01.0300 Safety, security and environmental studies						
01.0400 Waste management planning						
01.0500 Authorisation						
01.0600 Preparing management group and contracting						
<b>02 Facility shutdown activities</b>						
02.0100 Plant shutdown and inspection						
02.0200 Drainage and drying of systems						
02.0300 Decontamination of closed systems for dose reduction						
02.0400 Radiological inventory characterisation to support detailed planning						
02.0500 Removal of system fluids, operational waste and redundant material						
<b>03 Additional activities for safe enclosure or entombment</b>						
03.0100 Preparation for safe enclosure						
03.0200 Site boundary reconfiguration, isolating and securing structures						
03.0300 Facility entombment						
<b>04 Dismantling activities within the controlled area</b>						
04.0100 Procurement of equipment for decontamination and dismantling						
04.0200 Preparations and support for dismantling						
04.0300 Pre-dismantling decontamination						
04.0400 Removal of materials requiring specific procedures						
04.0500 Dismantling of main process systems, structures and components						
04.0600 Dismantling of other systems and components						
04.0700 Removal of contamination from building structures						
04.0800 Removal of contamination from areas outside buildings						
04.0900 Final radioactivity survey for release of buildings						

**Table 3.A1.1: ISDC disaggregated decommissioning cost items (cont'd)**

Cost item	Labour		Capital	Expenses	Contingency	Total
	Hours	NCU	NCU			NCU
<b>05 Waste processing, storage and disposal</b>						
05.0100 Waste management system						
05.0200 Management of historical/legacy high-level waste						
05.0300 Management of historical/legacy intermediate-level waste						
05.0400 Management of historical/legacy low-level waste						
05.0500 Management of historical/legacy very low-level waste						
05.0600 Management of historical/legacy exempt waste and materials						
05.0700 Management of decommissioning high-level waste						
05.0800 Management of decommissioning intermediate-level waste						
05.0900 Management of decommissioning low-level waste						
05.1000 Management of decommissioning very low-level waste						
05.1100 Management of decommissioning very short-lived waste						
05.1200 Management of decommissioning exempt waste and materials						
05.1300 Management of decommissioning waste and materials generated outside controlled areas						
<b>06 Site infrastructure and operation</b>						
06.0100 Site security and surveillance						
06.0200 Site operation and maintenance						
06.0300 Operation of support systems						
06.0400 Radiation and environmental safety monitoring						
<b>07 Conventional dismantling, demolition and site restoration</b>						
07.0100 Procurement of equipment for conventional dismantling and demolition						
07.0200 Dismantling of systems and building components outside the controlled area						
07.0300 Demolition of buildings and structures						
07.0400 Final clean-up, landscaping and refurbishment						
07.0500 Final radioactivity survey of site						
07.0600 Perpetuity funding/surveillance for limited or restricted release of property						

**Table 3.A1.1: ISDC disaggregated decommissioning cost items (cont'd)**

Cost item	Labour		Capital	Expenses	Contingency	Total
	Hours	NCU	NCU			NCU
<b>08 Project management, engineering and site support</b>						
08.0100 Mobilisation and preparatory work						
08.0200 Project management						
08.0300 Support services						
08.0400 Health and safety						
08.0500 Demobilisation						
08.0600 Mobilisation and preparatory work by contractors (if needed)						
08.0700 Project management by contractors (if needed)						
08.0800 Support services by contractors (if needed)						
08.0900 Health and safety by contractors (if needed)						
08.1000 Demobilisation by contractors (if needed)						
<b>09 Research and development</b>						
09.0200 Research and development of equipment, techniques and procedures						
09.0200 Simulation of complicated works						
<b>10 Fuel and nuclear material</b>						
10.0100 Removal of fuel or nuclear material from facility to be decommissioned						
10.0200 Dedicated buffer storage for fuel and/or nuclear material						
10.0300 Decommissioning of buffer storage						
<b>11 Miscellaneous expenditures</b>						
11.0100 Owner costs						
11.0200 Taxes						
11.0300 Insurances						
11.0400 Asset recovery						

NCU = National currency unit.



## **Appendix 3.A2. Conversion of United States decommissioning cost data (PNNL Study 2011) into ISDC format**

The decommissioning cost estimation data presented in the PNNL report (PNNL, 2011) are based on the work breakdown structure (WBS). This is true for data provided by two different companies, Thomas LaGuardia (TLG) and Energy Solutions (ES). This WBS cost structure is completely different from the International Structure for Decommissioning Costing (ISDC) (NEA, 2012a). But even more, the TLG and Energy Solutions WBS's differs from each other both for the structure of WBS items and also for the cost categories presented for individual WBS items.

To allow at least a kind of comparison between the data collected via the questionnaire, and the US PNNL data, a consultant was hired (Mr Vladimir Daniska) to analyse the potential conversion of US WBS (TLG and energy solutions) data into the ISDC format. The procedure to perform this task was to review the cost elements of TLG and Energy Solutions cost structures at the lowest level available to understand the meaning of cost elements, to allocate relevant ISDC numbers to the cost item under review, to retrieve systematically the ISDC cost items with the same ISDC numbers and to develop the ISDC format at the ISDC Level 2 and ISDC Level 1. This was done for a limited number of cases, covering many possible combinations: TLG and Energy Solutions, PWR and BWR, immediate and deferred dismantling (called DECON and SAFSTOR in the United States).

Converted ISDC data were then used for developing general percentage distributions of TLG and Energy Solutions decommissioning cost estimation data across individual ISDC Level 1 items. These general percentage distributions can further be used for different conversion purposes. One being the conversion into the ISDC format of actual cost data for accomplished projects as presented in the PNNL report for four cases (Haddam Neck, Trojan, Main Yankee and Rancho Seco).

This full exercise was done by the contractor and the results are reported succinctly below.

### **Structure of TLG data**

TLG decommissioning cost data is a matrix of:

- WBS items organised according to the phases of the decommissioning project: 12 phases are presented in the analysed TLG documents for the DECON option and 13 phases for the SAFSTOR option.
- Cost categories specifically used for TLG cost estimates, contingency and the total cost for individual WBS items.

As example, WBS items used by TLG are the following for the DECON 12 phases:

- Period 1a – Shutdown through transition;
- Period 1b – Decommissioning preparations;
- Period 2a – Large component removal;

- Period 2b – Site decontamination;
- Period 2c – Decontamination following wet fuel storage;
- Period 2d – Delay before licence termination;
- Period 2e – Licence termination;
- Period 3b – Site restoration;
- Period 3c – Fuel storage operations/shipping;
- Period 3d – Greater than done waste (GTCC) shipping;
- Period 3e – Independent spend fuel storage installation (ISFSI) decontamination;
- Period 3f – ISFSI site restoration.

TLG cost estimates breakdown includes following cost categories:

- DECON cost;
- removal cost;
- packaging cost;
- transport cost;
- off-site processing cost;
- LLRW disposal cost;
- other cost;
- contingency;
- total cost.

Spent fuel management cost data are presented separately.

TLG cost data were analysed for the following cases:

- LaSalle BWR unit 1; DECON and SAFSTOR;
- LaSalle BWR unit 2; DECON and SAFSTOR;
- Comanche Peak PWR unit 1; DECON and SAFSTOR;
- Comanche Peak PWR unit 2; DECON and SAFSTOR.

### **Structure of Energy Solutions data**

Energy Solutions decommissioning cost data is a matrix of:

- WBS items organised in phases of the decommissioning project;
- cost categories specifically used for ES cost estimates, contingency and the total cost for individual WBS items.

Cost breakdown has three principal phases as following:

- licence termination;
- spent fuel;
- greenfield.



The phases include two types of cost items:

- distributed, which include cost items specific for individual phases;
- undistributed, which include cost items with the same meaning for all phases, however only costs items relevant for the given phases are included in the data.

Examples of undistributed cost items are the following:

- utility staff;
- utility staff office supplies;
- security guard force;
- insurance;
- property taxes;
- US NRC decommissioning fees;
- materials and services;
- dry active waste disposal;
- energy;
- decommissioning general contractor staff;
- office supplies.

Cost categories in the Energy Solutions cost estimates are following:

- labour;
- equipment;
- disposal;
- other;
- subtotal (only in the case for Kewaunee DECON option);
- contingency;
- total.

Following Energy Solutions cost data were analysed:

- Duane Arnold NPP, single BWR unit; DECON and SAFSTOR;
- Kewaunee NPP, single PWR unit; DECON and SAFSTOR.

### **Principles of data conversions**

Conversion of the TLG and ES cost data is based on individual WBS items for TLG and ES costs structures and for DECON and SAFSTOR options. Conversion is performed at the lowest level of the WBS structure for individual items of cost categories; this approach keeps the transparency of data conversion. Proper understanding of ISDC cost items at the ISDC Level 2 and ISDC Level 3 is needed for developing the conversion relations. The target structure is the ISDC Level 2 (see Appendix 3.A1).

Items at the lowest levels of the WBS structure may include one or several ISDC cost items. This level, i.e. one item of the cost category as defined for WBS individual items is understood as the elementary cost item for conversion. The conversion for elementary TLG and Energy Solutions WBS cost items is performed by using two basic approaches:

- **One-to-one allocation:** One relevant item in ISDC is identified which match with the content of the given WBS item cost category at the lowest level. Conversion is performed by allocation of the proper ISDC number to the elementary cost item of the TLG and ES cost structures. The elementary cost data of TLG and ES structures labelled by ISDC numbers are then retrieved and summed according to the allocated ISDC numbers to the ISDC cost formats at the ISDC Level 2.
- **One-to-N allocation:** In these cases the individual elementary items of the WBS correspond to more than one ISDC items. Specific ISDC conversion sub-matrixes were developed for splitting one WBS cost categories item into several ISDC items. Specific sub-conversion matrixes use the percentage distributions of WBS cost categories to identified ISDC items. The data split according to the ISDC conversion sub-matrixes are then retrieved and summed according to the ISDC cost formats at the ISDC Level 2.

### **Determination of ranges of percentage of individual ISDC items on total costs, resulting from the conversion of WBS data**

Additionally, based on converted ISDC data at Level 2, a determination of ranges of percentage of individual ISDC Level 2 and ISDC Level 1 items on total decommissioning costs was performed. These ranges of percentages of individual ISDC Level 2 and ISDC Level 1 items on total decommissioning costs enable further use of the converted data for general conversion of WBS decommissioning costs data into the ISDC format. Results at ISDC Level 1 ranges of percentage are presented in Table 3.A2.1.

**Table 3.A2.1: Percentage distribution of ISDC Level 1 items for decommissioning costs**

ISDC	Percentage of ISDC items on decommissioning costs	DECON			SAFSTOR		
		TLG	ES	Mean	TLG	ES	Mean
01	Pre-decommissioning actions	2.2	2.2	2.2	2.4	3.0	2.7
02	Facility shutdown activities	3.3	8.4	5.9	1.5	6.5	4.0
03	Additional activities for safe enclosure or entombment	0.0	0.0	0.0	1.9	0.8	1.4
04	Dismantling activities within the controlled area	15.3	14.8	15.1	10.3	14.5	12.4
05	Waste processing, storage and disposal	22.6	19.5	21.0	13.3	13.2	13.3
06	Site infrastructure and operation	18.0	26.3	22.1	27.8	25.1	26.4
07	Conventional dismantling, demolition and site restoration	8.5	3.8	6.2	7.6	3.5	5.6
08	Project management, engineering and support	27.6	19.0	23.3	26.5	24.3	25.4
09	Research and development	0.0	0.0	0.0	0.0	0.0	0.0
10	Fuel and nuclear material	0.0	0.0	0.0	0.0	0.0	0.0
11	Miscellaneous expenditures	2.6	5.9	4.2	8.6	9.1	8.9

## Reformatting of actual decommissioning cost data for completed projects into the ISDC format

The data ranges of percentage of individual ISDC Level 2 items on total costs were used for reconstruction of decommissioning cost data for the following completed decommissioning:

- Haddam Neck NPP.
- Main Yankee NPP.
- Trojan NPP.
- Rancho Seco NPP.

Actual costs data of these completed decommissioning projects were presented in the document PNNL report (2011). The structure of the presented cost data is limited to some costs items, typically approx. ten items or less. To convert the data to the ISDC Level 2, the percentage distribution at ISDC Level 2 as derived from the TLG and ES conversions was used for further breakdown of cost data of completed projects to the ISDC Level 2. The general procedure is the following:

- Based on the description of presented cost items and on an understanding of these presented cost items from the point of view of ISDC definitions, the involvement of individual ISDC Level 1 items into the presented cost items was proposed based on expert opinion.
- The summary of relevant ISDC items for individual cost projects was evaluated to check the total value.
- For relevant ISDC Level 1 items, the percentage distribution at ISDC Level 2 was calculated.
- The percentage of relevant ISDC items was multiplied by the relevant cost items, which gives the numerical value of ISDC items at the Level 2.
- Average values of TLG and ES were used.

## Results of data conversion

Results of cost estimation data conversion at ISDC Level 1 for DECON TLG and ES options and results of ISDC Level 1 data reformatting for completed projects are presented in Table 3.A2.2. The Haddam Neck NPP data are presented twice; the second case (HNP-R, i.e. reduced) is the attempt for reconstruction of actual cost data which were escalated to 82% more during the project. The NPPs in Tables 3.A2.2 and 3.A2.3 are as follows:

- LS U1 La Salle unit 1, DECON.
- LS U2 La Salle unit 2, DECON.
- CP U1 Comanche Peak unit 1, DECON.
- CP U2 Comanche Peak unit 2, DECON.
- DA Duane Arnold, DECON.
- KW Kewaunee, DECON.
- HNP Haddam Neck Plant, DECON.
- MY Main Yankee, DECON.
- TNP Trojan NPP, DECON.
- RS Rancho Seco NPP, DECON.

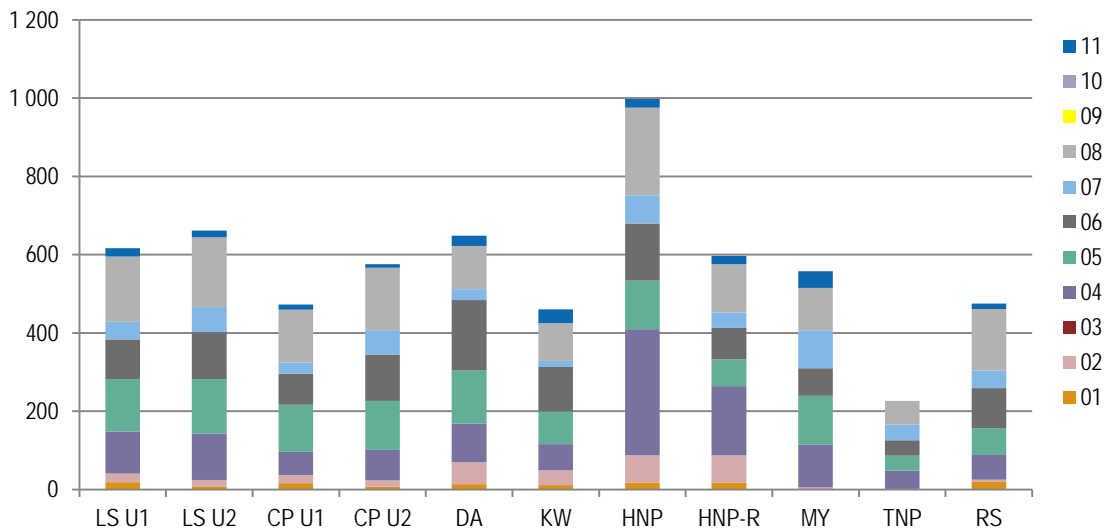
**Table 3.A2.2: Results for ISDC data conversions for DECON TLG and ES options and results of ISDC data reformatting for completed projects**

	DECON options (USD thousand) Mwe	LS U1	LS U2	CP U1	CP U2	DA	KW	HNP	HNP-R*	MY	TNP	RS
		BWR 1138	BWR 1150	PWR 1084	PWR 1124	BWR 581	PWR 556	PWR 619	PWR 619	PWR 900	PWE 1130	PWR 913
ISDC	Decommissioning costs (2013)	617	662	472	575	649	460	997	597	558	259	475
01	Pre-decommissioning actions	18.9	7.9	16.1	6.9	13.9	10.8	18.0	18.0	0.0	0.0	19.3
02	Facility shutdown activities	21.3	16.3	20.4	16.6	56.0	38.0	69.0	69.0	5.1	1.7	6.0
03	Additional activities for safe enclosure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
04	Dismantling activities within the controlled area	107.4	118.3	59.7	77.3	97.9	67.2	322.5	177.2	109.0	53.4	62.7
05	Waste processing, storage and disposal	134.4	139.7	120.5	125.3	136.2	82.9	124.6	68.5	125.1	44.3	69.1
06	Site infrastructure and operation	101.6	119.9	79.3	117.7	179.5	114.4	145.4	79.9	70.5	44.7	102.2
07	Conventional dismantling, demolition and site restoration	44.7	63.9	28.4	63.2	28.2	15.3	72.1	39.6	96.6	46.4	44.3
08	Project management, engineering and support	167.1	178.1	135.3	159.8	110.4	96.4	223.6	122.9	108.5	68.8	157.1
09	Research and development	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Fuel and nuclear material	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	Miscellaneous expenditures	21.3	17.6	12.3	8.7	26.5	35.3	22.0	22.0	42.7	0.0	14.5
	Spent fuel management costs (2013)	110.1	116.6	105.9	103.0	191.9	161.7	148.6		152.5	274.6	98.3

\* In the case of Haddam Neck, major organisational changes associated with changes in responsibilities, have led to major increases in cost. The HNP-R column is a reconstitution to eliminate this artificial over cost to allow comparison with the other cases.

Results of data conversion into ISDC Level 1 format for DECON options and ISDC data reformatting for completed projects in graphical form are presented in Figure 3.A2.1.

**Figure 3.A2.1: Results of data conversion at ISDC Level 1 format for DECON options and ISDC data reformatting for completed projects**



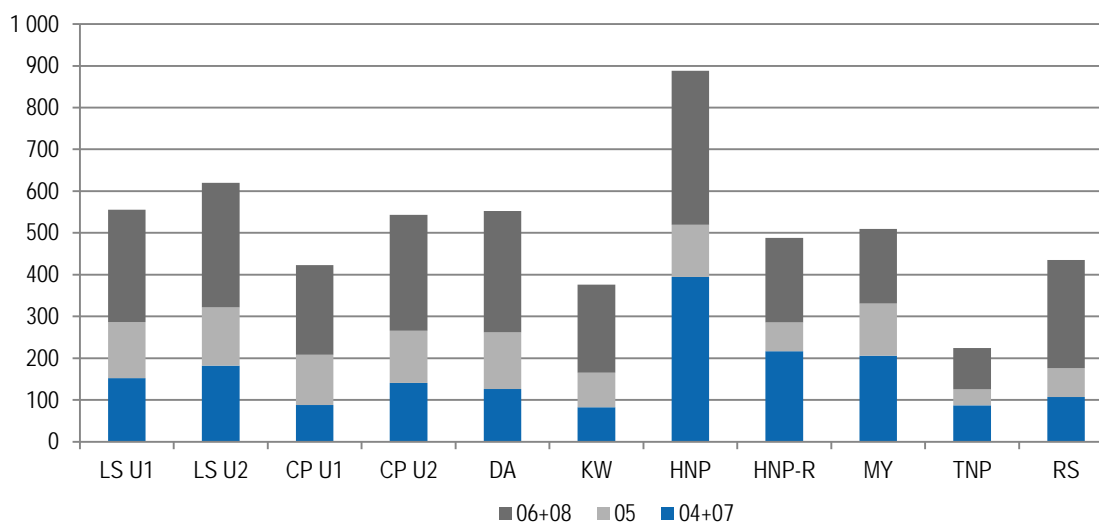
To be able to compare the cost data for selected ISDC items for converted cost estimate data and reformatted data for completed projects in the same style as used in Chapter 3, the main ISDC cost data for ISDC 04+07, ISDC 05 and ISDC 06+08 are presented in Table 3.A2.3.

**Table 3.A2.3: ISDC 04+07, ISDC 05 and ISDC 06+08 data for converted data and reformatted data for completed projects**

	DECON options (USD <sub>2013</sub> thousand)	LS U1	LS U2	CP U1	CP U2	DA	KW	HNP	HNP-R	MY	TNP	RS
		BWR 1138	BWR 1150	PWR 1084	PWR11 24	BWR 581	PWR 556	PWR 619	PWR 619	PWR 900	PWE 1130	PWR 913
ISDC	Decommissioning costs (2013)	617	662	472	575	649	460	997	597	558	259	475
04+07	Decontamination, dismantling, demolition, site restoration	152.1	182.2	88.1	140.5	126.1	82.6	394.6	216.8	205.6	99.8	107.0
05	Waste processing, storage and disposal	134.4	139.7	120.5	125.3	136.2	82.9	124.6	68.5	125.1	44.3	69.1
06+08	Site infrastructure, operation; Project management, engineering, support	268.7	298.0	214.6	277.5	289.9	210.7	369.0	202.8	179.0	113.5	259.3

The ISDC cost data for ISDC 04+07, ISDC 05 and ISDC 06+08 are also presented in graphical form in Figure 3.A2.2.

**Figure 3.A2.2: ISDC 04+07, ISDC 05 and ISDC 06+08 data for converted data and reformatted data for accomplished projects**

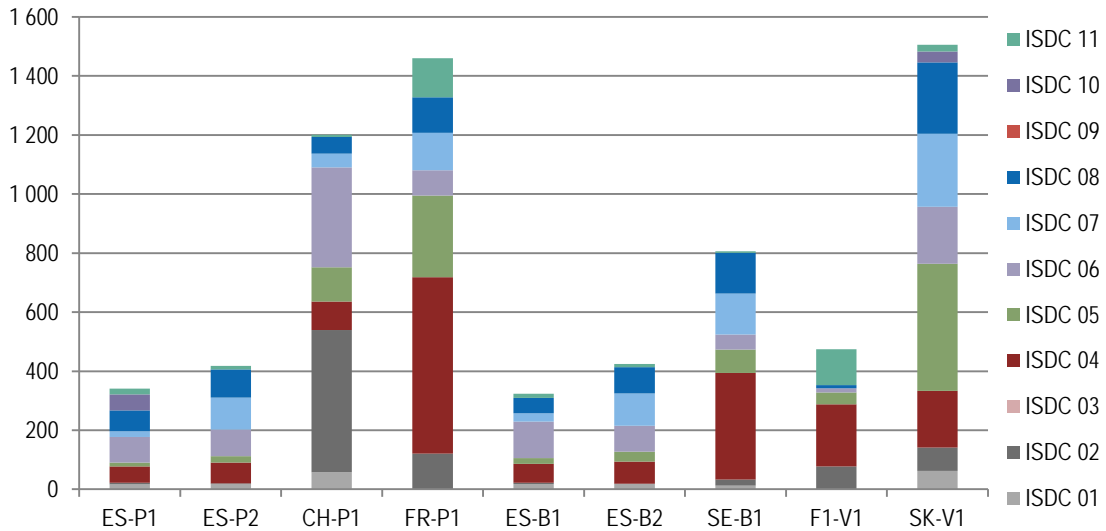


A further comparative analysis of the numbers of Table 3.A2.3 above with Tables 3.13 and 3.14 of Chapter 3 provides some insights on the value and limits of the conversion exercise.

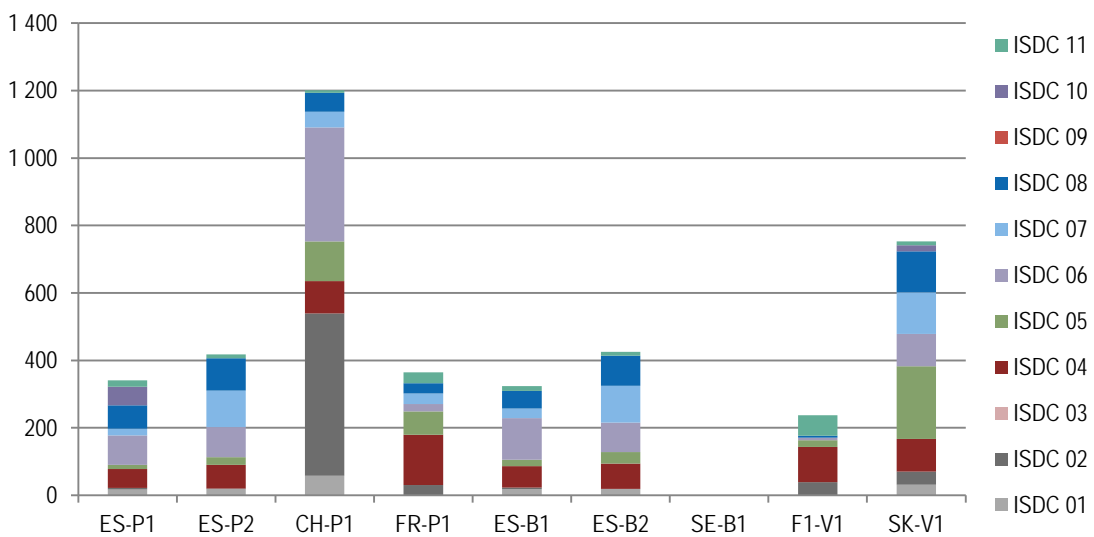


### Appendix 3.A3. Collected data presentation in graphs

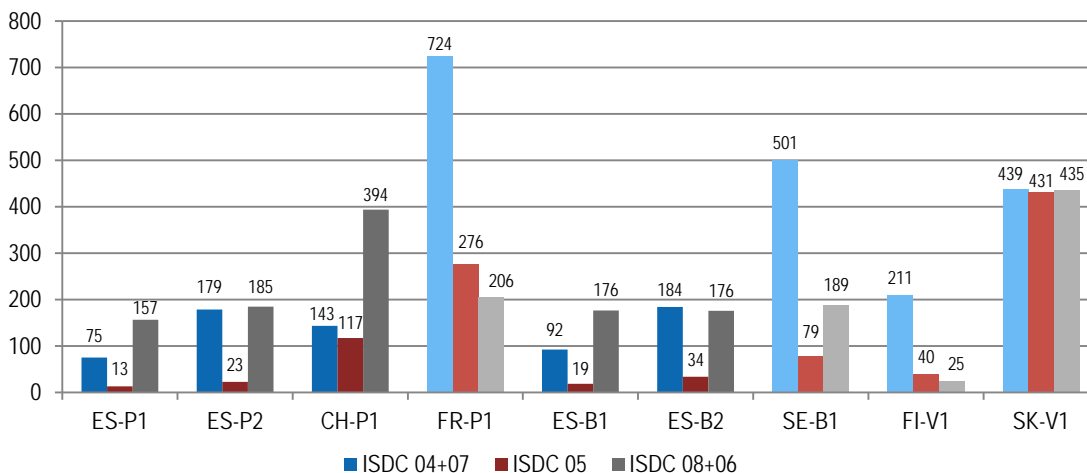
**Figure 3.A3.1: ISDC Level 1 cost items reported per site in USD<sub>2013</sub> million**



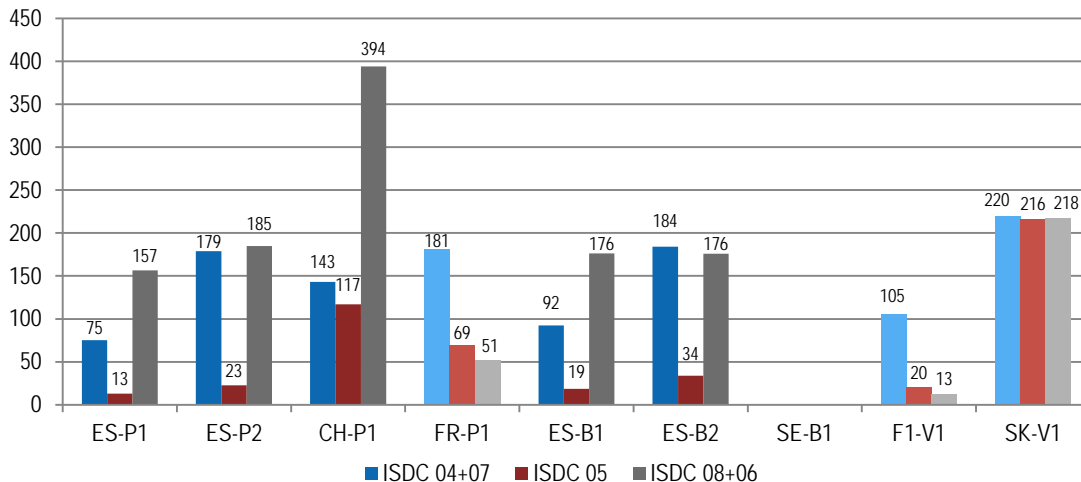
**Figure 3.A3.2: ISDC Level 1 cost items reported per unit in USD<sub>2013</sub> million**



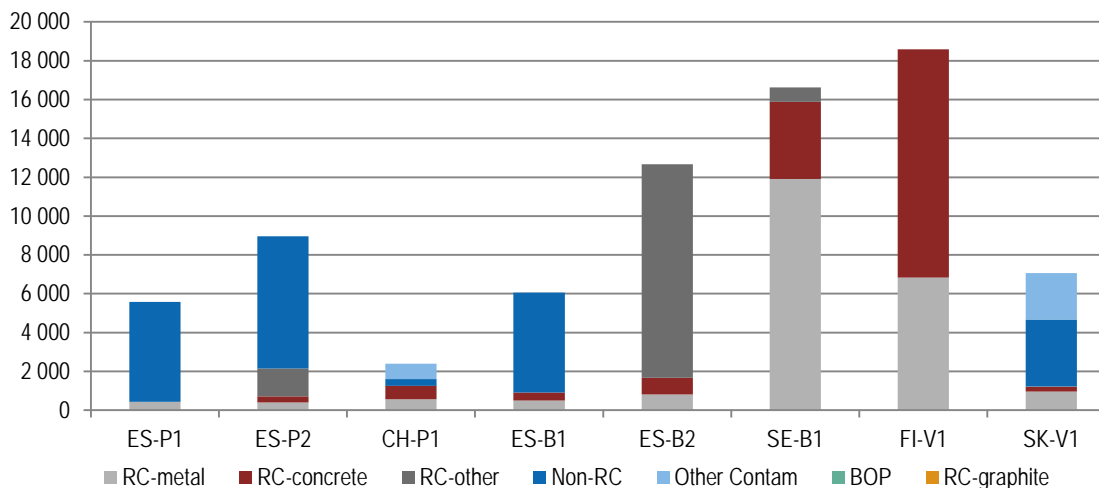
**Figure 3.A3.3: Costs related to aggregated categories in USD<sub>2013</sub> million - for the site**



**Figure 3.A3.4: Costs related to aggregated categories in USD<sub>2013</sub> million - for the unit**

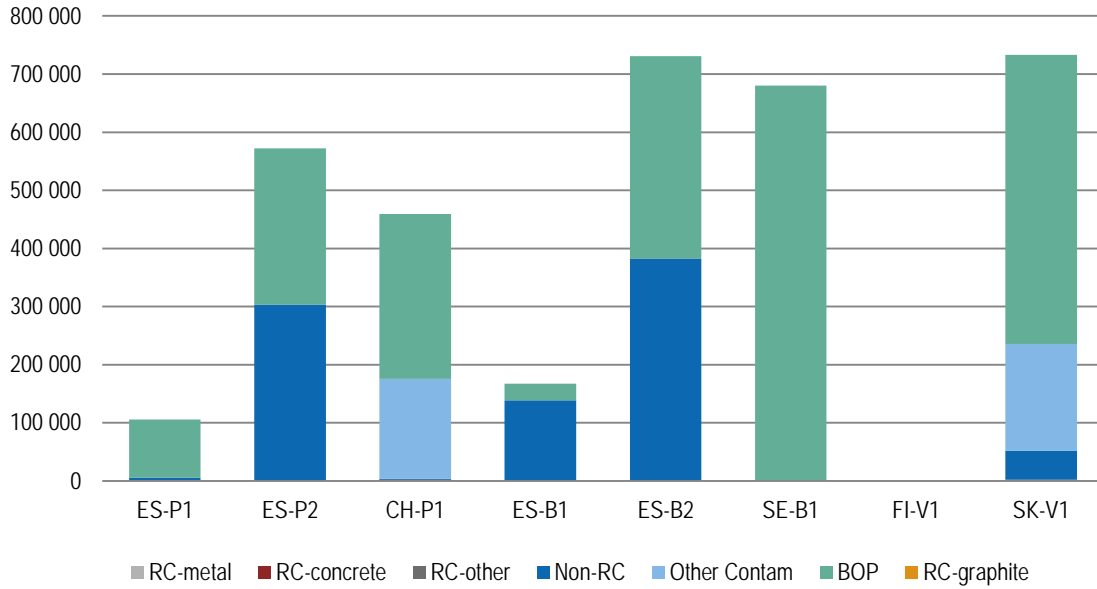


**Figure 3.A3.5: Radioactive waste - tonnes**

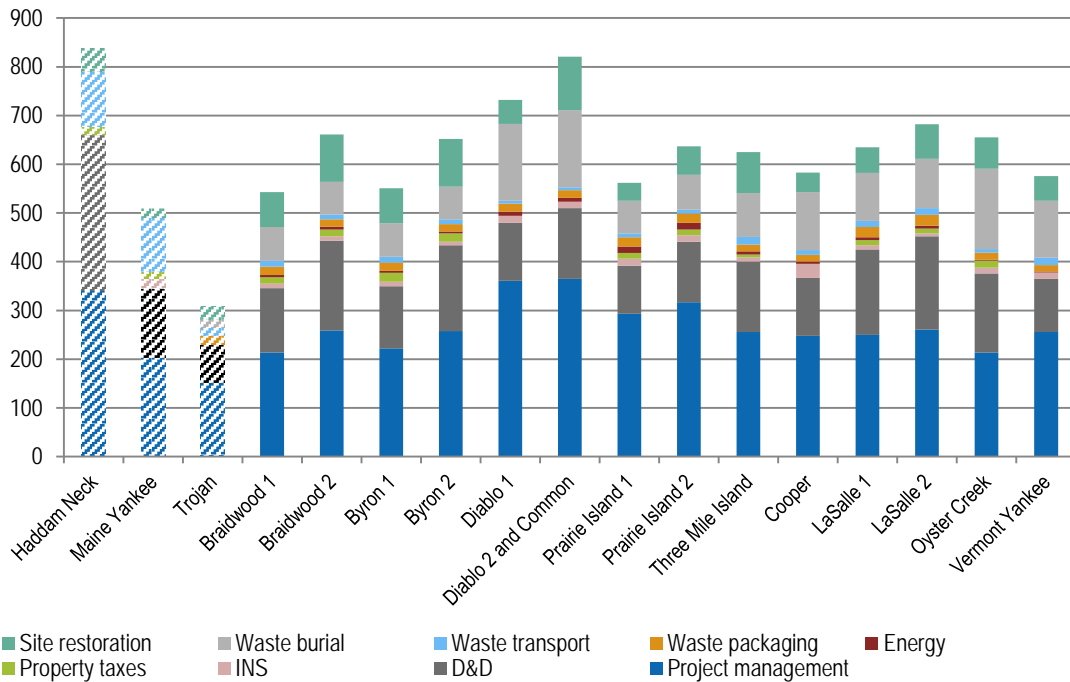




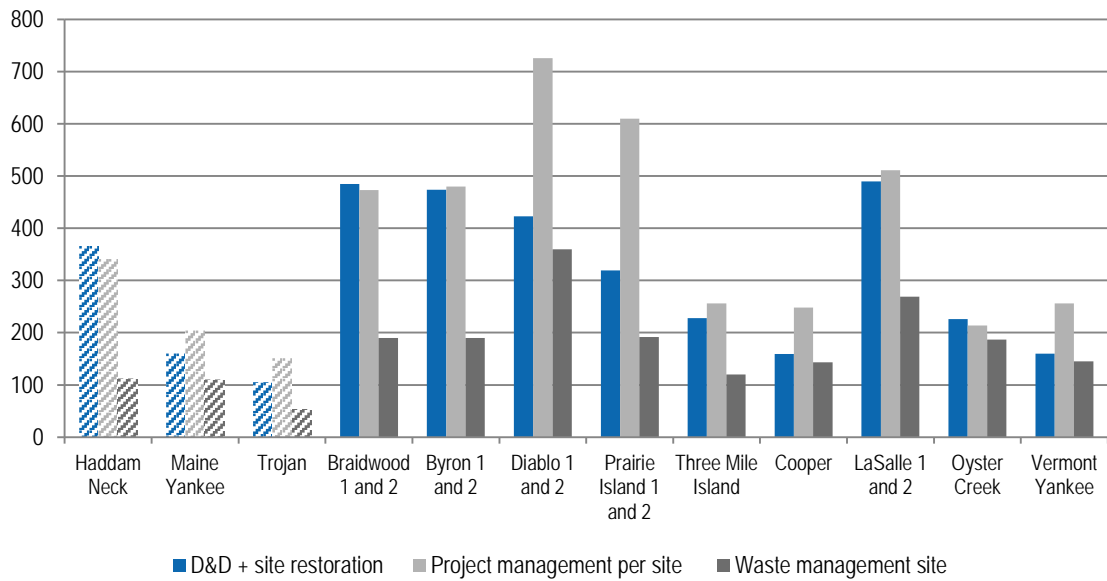
**Figure 3.A3.6: Residual materials – tonnes**



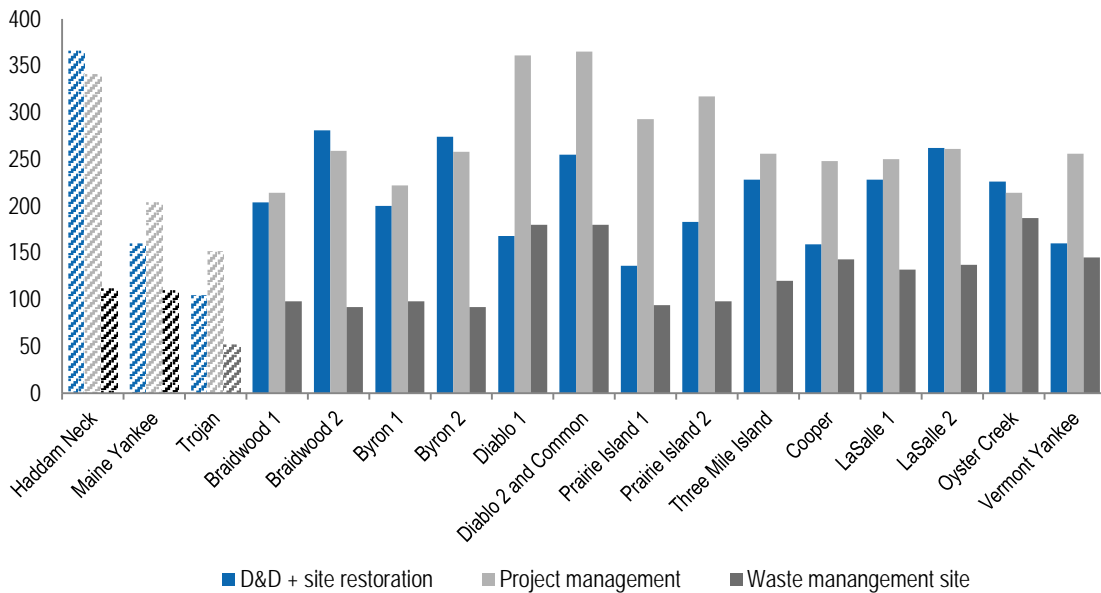
**Figure 3.A3.7: PNNL cost data reported per unit in USD<sub>2013</sub> million**



**Figure 3.A3.8: Costs related to aggregated categories per site in USD<sub>2013</sub> million**



**Figure 3.A3.9: Costs related to aggregated categories per unit in USD<sub>2013</sub> million**



### Appendix 3.A4. Considerations on waste volumes and specific costs for United States cases<sup>1</sup>

Figure 3.A4.1 provides a bar chart of waste volumes actually generated from the decommissioning of US PWR units, grouped by categories: Class A, B/C and processed waste. This classification, adopted in the United States, pertains waste for near-surface disposal and it is based on considerations related to the concentration of individual long-lived and shorter-lived radionuclides; the magnitude of the potential dose limits; and the required precautions, as institutional controls, improved waste form, etc.

Definitions are provided by NRC:

- Class A waste is waste that is usually segregated from other waste classes at the disposal site. The physical form and characteristics of Class A waste must meet minimum set requirements. If Class A waste also meets the stability requirements, it is not necessary to segregate the waste for disposal.
- Class B waste is waste that must meet more rigorous requirements on waste form to ensure stability after disposal.
- Class C waste is waste that not only must meet more rigorous requirements on waste form to ensure stability but also requires additional measures at the disposal facility to protect against inadvertent intrusion.
- GCC “Greater than Category C” waste, that is not generally acceptable for near-surface disposal is waste for which form and disposal methods must be different, and in general more stringent, than those specified for Class C waste. In the absence of specific requirements in this part, such waste must be disposed of in a geologic repository unless proposals for disposal of such waste in a disposal site licensed pursuant to this part are approved by the commission.

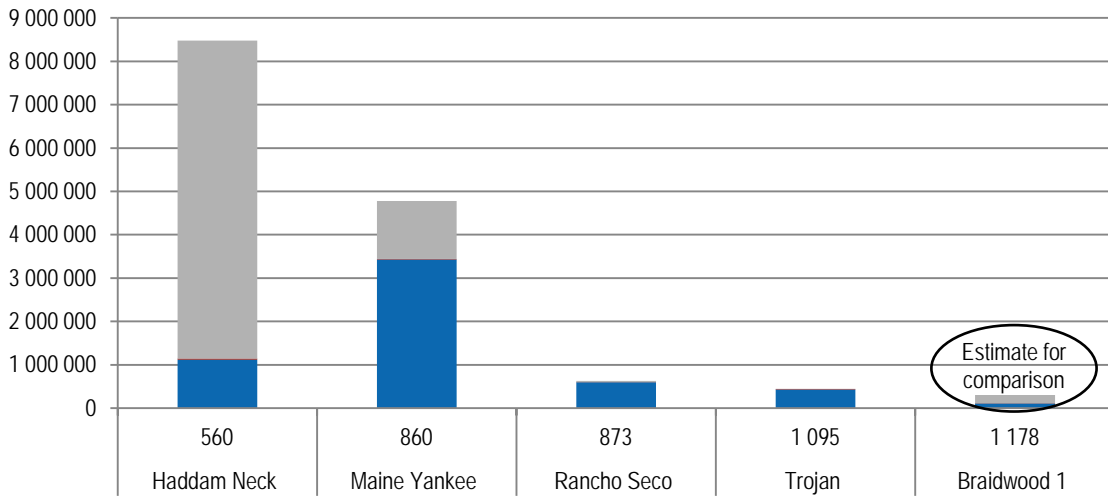
Details on specific requirements are provided in USNRC website: [www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html](http://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html).

Much of the waste generated during decommissioning consists of material that is likely to be uncontaminated (e.g. concrete). Such waste can be analysed on-site or shipped off-site to licensed facilities for further analysis, processing and conditioning. This waste is referred to as processed waste (PNNL, 2011). The waste volume estimates for a “typical” PWR future project (Braidwood 1) is also reported for comparative purposes. Figure 3.A4.2 provides available projections of waste volumes assumed to be generated from the future decommissioning of US PWR units, also grouped by categories: Class A, B/C and processed waste. Similarly, for BWRs, estimates of decommissioning waste volumes are given in Figure 3.A4.3 by the same waste categories. The information reported in these graphs can provide further insight in understanding the costs reported in Figures 3.A3.8 and 3.A3.9.

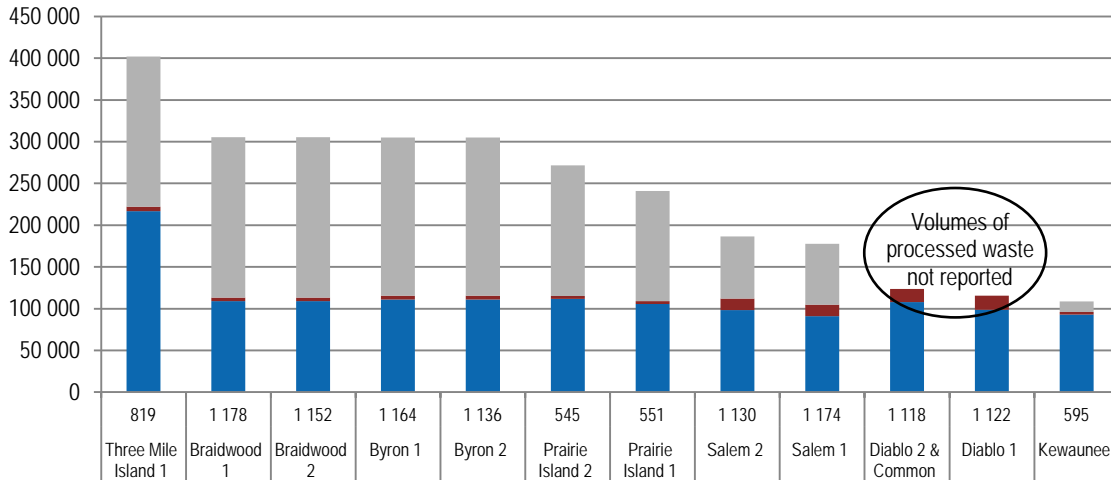
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1. 1 ft<sup>3</sup> = 0.0283 m<sup>3</sup>.

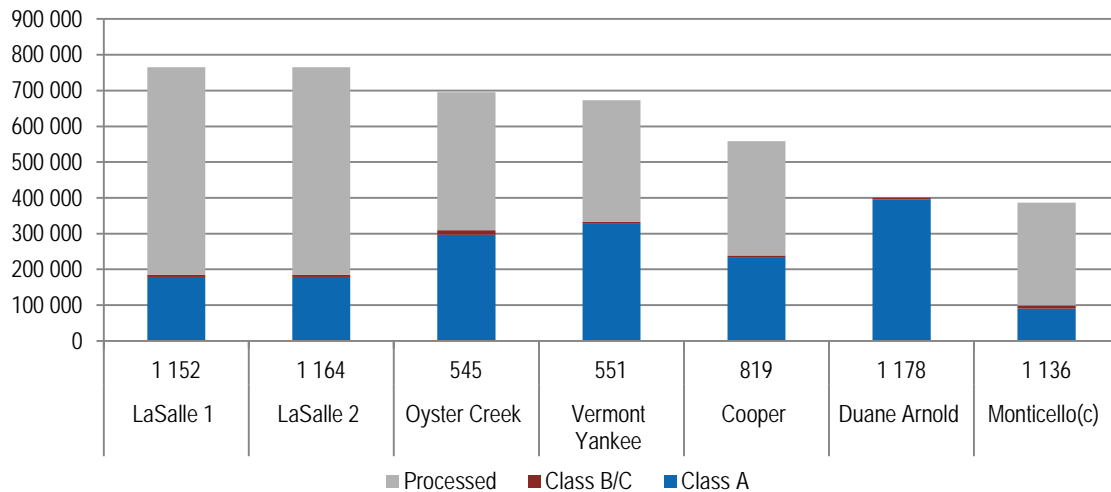
**Figure 3.A4.1: Waste volumes generated from the decommissioning of US PWR units, in ft<sup>3</sup>**



**Figure 3.A4.2: Projections of decommissioning waste volumes for US PWR units, in ft<sup>3</sup>**



**Figure 3.A4.3: Projections of waste volumes from the decommissioning of US BWR units, in ft<sup>3</sup>**



A first consideration is that there is no apparent proportionality of waste volumes to plant capacity, with amounts from plants of smaller capacity sometime greater than those reported for larger plants. For PWRs, waste volume estimates (Figure 3.A4.2) vary between approximately 180 000 ft<sup>3</sup> and 400 000 ft<sup>3</sup>. Looking at costs for completed projects in Figure 3.A3.8 and Figure 3.A3.9, in conjunction with the volumes generated, reported in Figure 3.A4.1, the comparatively high waste management costs incurred for the decommissioning HNP can be partly explained by the amounts of waste produced, substantially greater than those observed in all other completed cases. These are mostly attributable to the very stringent release criteria and clean-up levels adopted by the State of Connecticut. The PNNL study reports that “regulation of HNP decommissioning by multiple government agencies complicated the process for obtaining approval of site release criteria”. Such limits are significantly more restrictive than those established by the NRC (PNNL, 2011) and entailed, *inter alia*, the requirement to remove above-grade portions of site buildings and structures and to demolish structures, systems, and components to 4 feet below grade. Most notably, the groundwater beneath the Haddam Neck site was classified for residential use, requiring the need for a very rigorous subsurface soil remediation and the consequent removal of substantially more soil than would have been necessary to meet the NRC requirements for the site licence termination. Soils not meeting the applicable limits were removed and disposed of as radioactive waste. Hence very large quantities of waste were produced during the decommissioning of Haddam Neck. The packing, transport, and disposal of such vast waste volumes were major undertakings, generating a large fraction of the overall decommissioning cost.

Enhanced state clean-up standards were applied for the decommissioning of Maine Yankee, by the State of Maine, which also required the out-of-state disposal of decommissioning concrete waste. In addition, demolition of all buildings to an elevation equivalent to (at least) 3 feet below grade was undertaken. Volumes generated for the decommissioning of Rancho Seco and Trojan were significantly lower; the case of Trojan, in particular, will be discussed below.

Alongside the actual waste volumes from decommissioned plants, volumes assumed in one of the “typical estimates” (for Braidwood 1) are reported in Figure 3.A4.1 for comparative purposes. The assumed volumes are considerably lower than what was experienced in all of the completed projects (by an order of magnitude when compared to Haddam Neck and Maine Yankee, and by nearly 50% when compared to Trojan).

Estimates of waste volumes for US PWRs are reported in Figure 3.A4.2. The assumptions on waste inventories and management for Prairie Island 1 and 2, Braidwood 1 and 2, Byron 1 and 2 are fairly homogeneous. Braidwood 1 and 2, Byron 1 and 2 have similar capacities, and operational lives of 60 years postulated in the estimates, which essentially leads to analogous waste volumes and categories, and thus equal costs. For Three Miles Island, and Prairie Island 1 and 2, despite their lower capacities (and, for Prairie Island, also a shorter operational life assumed – of 40 years), similar or even greater radwaste inventories are projected. In particular, for Three Miles Island, both Class A and Class B/C inventories are substantially greater than for the other units. Due to insufficient details on the bases of such assumptions, further understanding of differences and similarities cannot be achieved. Waste volumes assumed for Salem 1 and 2 are, conversely, on the low end, but their waste management costs are comparatively high (see also discussion below). Volumes for Diablo 1 and 2 do not include processed waste.

Figure 3.A4.3 reports estimates of decommissioning waste volumes for US BWR units. Waste volumes range from about 400 000 ft<sup>3</sup> to about 700 000 ft<sup>3</sup>, larger than those projected for PWRs, as expected. For PWRs, data on total waste volumes generated from decommissioning suggest no clear relationship with plant capacity. Furthermore, looking at the available cost data for waste management, costs vary congruously with the relative waste volumes. Waste costs appear to be more sensitive to the management strategies

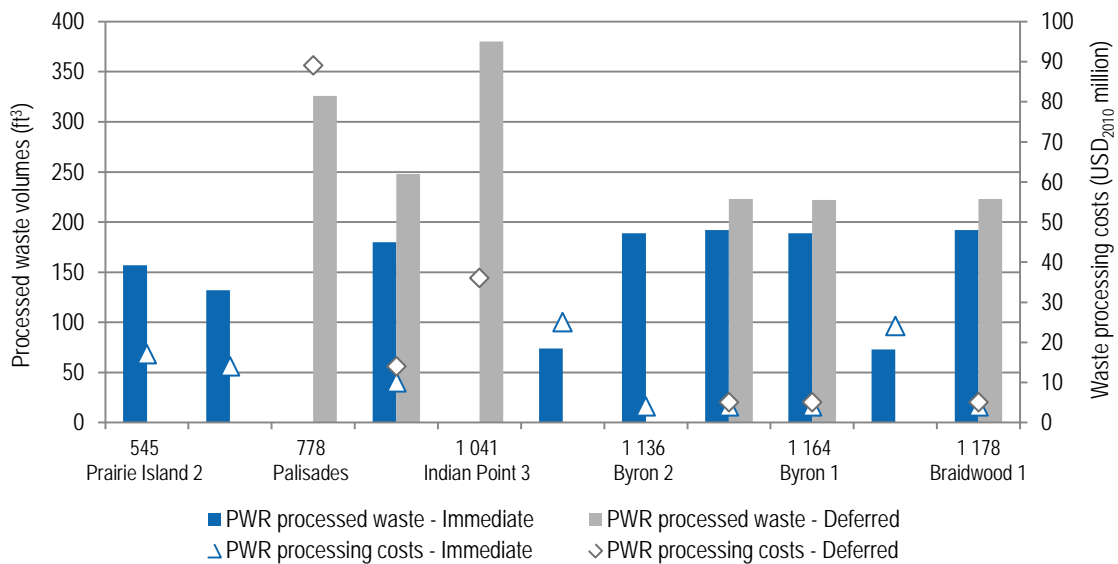
and solutions selected or assumed, for the specific plant, and the related unit costs individually applied. The accessibility of waste management routes can even determine the way the decommissioning of the reactor is undertaken. For example, one piece removal can be favoured if an adequate repository is available for its disposal. This, in turn, can have considerable bearing on the time frames involved and the costs incurred, not only for the management of waste, but also other decommissioning cost categories. The importance of selected waste management routes is emphasised in the PNNL study. For the US estimates, it is assumed that two burial sites are available for radwaste disposal: a generic LLW site (at Barnwell, South Carolina), and Energy Solutions (at Clive, Utah), which accepts only Class A waste at significantly lower costs, and the US Ecology disposal facility, a full-service facility (in Washington State), currently available only to very few units (in the Northwest and Rocky Mountain compact states). For this reason, and since Class A waste volume greatly exceeds Class B and C volumes, the relative amounts of Class A waste sent to each site is an important driver in determining radwaste disposal costs in US plants. In this respect, the actual waste management costs incurred for the decommissioning of Trojan are indicative. For the decommissioning of Trojan, essentially 100% of the total volume of LLW was shipped and directly disposed of at the US Ecology facility. The charges incurred from this process were comparatively low, and were limited by annual revenue constraints applied at the time to that disposal facility (PNNL, 2011). Importantly, owing to the access to this waste management route, the reactor vessel was removed as a “package”, with intact internals, and transported by barge for disposal, with the steam generators and the pressuriser. This approach presented a number of advantages, including decreased waste volumes; reduced personnel exposure; and much fewer radioactive shipments, which, in turn, yielded significant savings. The most challenging aspect of the project was obtaining several state and federal approvals needed for this disposal option. Without state regulatory changes, the option to dispose of the reactor pressure vessel and internals in a single package will not be open to other commercial NPP decommissioning projects in the United States. In this respect conditions experienced at Trojan for waste management, both in terms of approach, as well as specific charges applied, are unique. Also, Trojan reactor controlled area structures were released intact, which lowered waste volumes.

On the other hand, for both the Diablo Canyon and Salem estimates, all (or most) waste is assumed to be directly disposed (not processed) into a future, full-service disposal facility, with high specific costs (estimates for these two stations, are however quite old – 2002 – and this assumption should be reviewed). This escalates the total cost of waste management, despite the relatively low waste volumes assumed in their estimates. In the PNNL study it is argued that the assumed disposal in the LLW full-service facility might also justify the significantly higher transport cost in the estimates reported in the PNNL study for Salem and Diablo Canyon, perhaps implying that shipments are predominantly made by truck, a more expensive means than rail transport. For this reason, for Diablo Canyon, the implementation of an extensive programme to minimise the amount of material requiring disposal as LLW is also considered (PNNL, 2011).

Conversely, looking at estimates for Byron 1 and 2, and Braidwood 1 and 2, despite the greater waste volumes projected (Figure 3.A4.2), waste management costs are lower. For these units, about 45% of waste is processed, and the assumed unit costs for its processing appear to be fairly small. This is shown in Figure 3.A4.4 where volumes of processed waste and the relative waste processing costs are plotted for selected PWRs for both immediate and deferred dismantling options. A similar graph is shown in Figure 3.A4.5 for US BWR units. Figure 3.A4.4 and Figure 3.A4.5 show that the amount of processed waste is not the most important factor in the determination of the final processing costs, which change widely depending on the unit costs assumed for processing. In fact, specific costs for PWR waste processing vary by an order of magnitude across the sample. In some cases, volume discounts have been negotiated by sites with high waste volumes, leading to reduced unit costs. Among BWRs estimates, processed

waste volumes are greatest for La Salle 1 and 2; but processed waste costs are significantly lower than those forecasted for other plants, even of smaller capacities; this is due to the low unit costs assumed for processing, similarly to PWR plants: Byron 1 and 2, and Braidwood 1 and 2. Conversely, the high specific cost assumed for waste processing is certainly an important factor driving the costs of LLW management in Oyster Creek estimates. In addition, the estimates for Oyster Creek, assume some portion of Class A LLW going to a costly full-service LLW disposal facility, which would yield higher costs also for the portion of Class A waste not going to be processed (the estimate for Oyster Creek is dated – 2003).

**Figure 3.A4.4: Processed waste volumes relating to immediate and deferred dismantling of US PWRs**



**Figure 3.A4.5: Processed waste volumes relating to immediate and deferred dismantling of US BWRs**

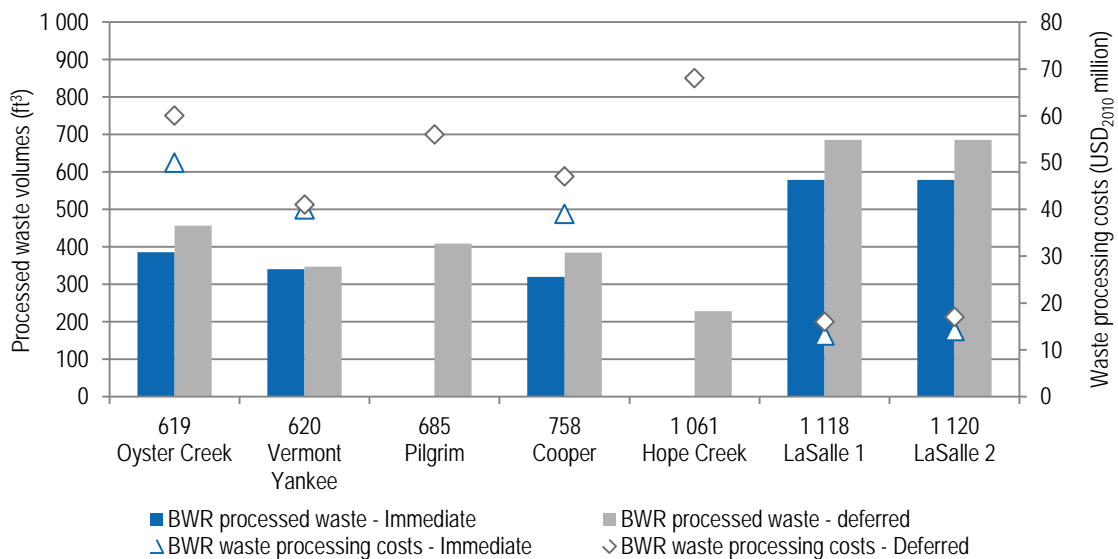


Figure 3.A4.4 and Figure 3.A4.5 provide data for immediate and as well as deferred dismantling. But, neither from the country survey (at least for light water reactors) nor from the PNNL study, detailed data on cost estimates assuming deferred dismantling are available. The only data reported in the PNNL study for which immediate dismantling costs can be compared with corresponding estimates based on the deferred dismantling option are those related to the volumes of assumed processed waste, illustrated in Figure 3.A4.4 and Figure 3.A4.5 for PWR and BWR plants respectively.



## Chapter 4. Decommissioning funds

### 4.1. Introduction

The purpose of this chapter is to discuss various financial aspects related to the accrual and management of funds for decommissioning nuclear power plants. The first part of the chapter focuses on the systems for accumulating resources in decommissioning funds in OECD member countries. The second part of the chapter focuses on the management and control of such funds.

Unless otherwise indicated, the country specific information provided in this chapter is drawn from the data provided in the responses to the questionnaire developed by the NEA Ad Hoc Expert Group on Costs of Decommissioning (COSTSDEC). In some cases, the questionnaire responses were supplemented with more in-depth information on particular examples. This chapter also builds upon and complements work and analysis by the European Commission (EC) and its Decommissioning Funding Group (DFG) (EC, 2013a, 2013b, 2009, 2007).

Ultimately, the availability of adequate funds for decommissioning is linked to the safety and protection of current and future generations (NEA, 2006). Sound financial provisions need to be built up in good time to warrant that all decommissioning costs are covered and to reduce the potential risk for residual unfunded liabilities and burden on future generations, while ensuring environmental protection.

It is now effectively a universal requirement that a preliminary decommissioning plan be developed early in the licensing process (IAEA, 2014; NEA, 2010). Key considerations from the outset therefore include identification of the provision of funds for the decommissioning project as well as requirements for financial assurance concerning the adequacy and timely availability of resources for safe decommissioning (IAEA, 2014). In some countries, such prerequisites prevent operators from proceeding with operation unless they have approved decommissioning fund arrangements or guarantees (NEA, 2012).

Legal and/or regulatory frameworks are required and have been put in place in most countries for the creation of decommissioning funds and to warrant that they will not be diverted for other purposes (NEA, 2006). These measures are needed to ensure:

- Contributions to the fund are made by facilities using radioactive material during their operation to ensure sufficient funds are available at the time of final shutdown to cover all decommissioning and waste management expenses.
- Contributions are in line with the estimated service life, defined time schedule, and chosen strategy, to cover decommissioning of the facility.
- The funds are managed and reviewed periodically in a manner ensuring liquidity compatible with the timetable for the decommissioning obligations and their costs.
- The funds are used only to cover the costs of the decommissioning obligations in line with the decommissioning strategy.

- Legal and administrative remedies are available and enforceable in the event of non-compliance with the above.

These aspects are considered further in the body of this chapter.

## **4.2. Funding mechanisms**

The focus in this section is on the development of decommissioning funds and the accumulation of resources within them. At the outset it should be recognised that, in addition to the variations in funding mechanisms and oversight described in this chapter, even the scope of funding may differ quite fundamentally in different countries. For example, in some cases one fund is intended to cover both the financing of the costs of decommissioning, as well as waste and spent fuel management and disposal; whereas in others, separate funds are raised to cover decommissioning and waste activities. Other variants outside these basic cases also exist (Laraia, 2012; IAEA, 2005). In some cases there may be a need to make special decommissioning funding arrangements for so-called “legacy” facilities that are no longer in operation and for which there was insufficient provision made for future decommissioning during their operation. In addition, some countries also have separate financing arrangements for government funded facilities. In such cases, there may be more than one system of decommissioning funding in operation at the same time in a particular country. Understanding exactly which activities and liabilities are to be covered is an essential step in analysing decommissioning funding and the financing requirements which are put in place in a particular country or situation.

### **4.2.1. Collection of decommissioning funds**

#### *4.2.1.1. Responsibility for funding decommissioning*

The way decommissioning funds are accumulated varies from country to country. In general, in the case of a nuclear power plant, funds for decommissioning are set aside from the revenue obtained from the sale of electricity generated by the plant during its operating phase, or through a levy on sales of electricity of any origin. A levy may also be applied to the net profits that the operator may make from other goods and services provided (NEA, 2006). In some cases for nuclear power stations with multiple units, collection of funds may be organised on a site-wide basis or, if the owner has several sites, it may be pursued on a fleet basis. In other cases, funds cannot be transferred to other units. Premature permanent shutdown for decommissioning raises potential issues of depletion of the fund where a fleet concept is being used (IAEA, 2005).

In Belgium, Canada, the Czech Republic, Finland, France, Korea, the Netherlands, the Slovak Republic, Spain, Sweden, Switzerland, and the United States, operators of nuclear facilities are fully responsible for paying all the costs of decommissioning.

In the case of the Slovak Republic, although operators of nuclear power plants are required to contribute to the National Nuclear Fund to finance future decommissioning, there is additionally a general levy on the price of electricity to cover the period prior to the establishment of the fund. In addition, the European Union (EU) has established the Bohunice International Decommissioning Support Fund (BIDSF) in order to finance some specific decommissioning activities and help mitigate negative economic impacts of the early closure of the nuclear power plants (units 1 and 2) at Bohunice, as a part of the accession of the country to the EU.

Two exceptions to operator-funded decommissioning are found in Italy and the United Kingdom. Italy had a fund to which the operator contributed until 1987. However, since then decommissioning costs are covered by a levy on the sales of electricity under the management of the Italian Regulatory Authority for Electricity and Gas (AEEG). In the United Kingdom, decommissioning costs for older nuclear reactors for which the Nuclear

Decommissioning Authority (NDA) is responsible, are covered by government funds. However, decommissioning costs for the newer reactors in the United Kingdom are to be covered by the Nuclear Liabilities Fund (NLF), which is funded by payments made by the nuclear power plant operators.

#### 4.2.1.2. Timeline for building up the funds

In most cases the fund is built up year by year, either over the entire expected lifetime of the facility or over a shorter period, and is based on the calculated decommissioning cost. The funds may be collected over a shorter period to reduce the risk associated with unplanned, premature shutdown (e.g. Canada). Where a fund is also intended to cover the costs of spent fuel management as well as decommissioning, the collection period for the management and disposal of spent fuel component is typically distributed throughout the entire life cycle of the facility, because the spent fuel is being produced continuously during operation. Most countries indicated that the total funding required for decommissioning must be provided “by shutdown”, while the remainder of the questionnaire responses indicated “other”, with these indicating a range of different approaches in their responses (see Table 4.1). Each of these options has specific advantages and disadvantages. In general, a collection over the entire expected life cycle will lead to lower annual amounts to be transferred to the fund, but a collection over a shorter period or through prepayments will reduce the risks associated with premature shutdown (IAEA, 2005). In other cases, there may be collection as a prepayment to the fund before start-up, i.e. the operator is expected to make an endowment as a condition for obtaining the operating licence (Laraia, 2012). Combinations of these mechanisms are also possible. In all cases, these mechanisms are intended to balance the need for affordability with the need to reduce risks associated with possible premature shutdown of a facility or unfunded decommissioning liabilities.

**Table 4.1: Timing of the provision of decommissioning funds**

By shutdown	Other	Not applicable/no answer
Belgium, Canada, Korea, Netherlands, Slovak Republic, Spain, Sweden, Switzerland, United States	Finland, France, Italy, United Kingdom	Czech Republic

Note: No country responses indicated either of the other two categories proposed in the questionnaire: “*Within x years of commissioning plant*” or “*Within x years of plant shutdown*”.

Finland indicated that, in principle, throughout operation there should always be sufficient resources paid into the waste fund to cover the future costs of the management of the accumulated radioactive waste. There the requirement is that the fund target for each calendar year shall be equal to the assessed liability at the end of the previous calendar year. In practice, the fund target during the first years of operation of a new nuclear facility may be lower than the assessed liability. In addition, correcting for major increases in assessed liability may be distributed over five years.

France indicated that the nuclear operators set up internal restricted funds covered by dedicated assets managed under separate account. These funds are required to account for all future costs related to decommissioning as well as waste management and are to be established from the beginning of operations of each given nuclear installation.

The Netherlands indicated that a licensee is required to have a financial provision to cover the costs of decommissioning and that a financial guarantee is to be given before the start of construction. However, the exact arrangements are for each operator to determine, subject to approval by the competent authorities.

The United States indicated that an operator may take credit for earnings to the accumulated decommissioning funds after shutdown.

#### 4.2.1.3. Estimation of the contributions to the fund and review mechanisms

Estimating the contributions to be paid in the fund is a crucial part of fund management (IAEA, 2005). Calculations are based on both the estimated decommissioning costs and on the various assumptions made, including the time when the costs will arise, inflation, and the anticipated nominal interest rate on the accumulated capital. While aspects relating to the funds themselves are addressed here, aspects primarily related to decommissioning costs and cost calculations are addressed in detail in Chapter 3.

Korea indicated that the decommissioning funds should be managed as provision and the funding per one unit shall be managed by the operator within a separate account to resolve the concerns that the funds may not be available when needed.

Countries indicated that decommissioning cost estimates are reviewed, although the exact mechanisms vary considerably from country to country, as does the frequency for these (see Table 4.2).

**Table 4.2: Mechanisms for the review of decommissioning cost estimates**

Review mechanism by	Country
Utility or decommissioning entity	Belgium, Italy, United Kingdom
Both the utility/decommissioning entity and the government or nuclear regulator	Canada, Finland*, France, Netherlands, Spain
Administrative body for the fund, on the basis of estimates produced by the operator	Slovak Republic, Switzerland
National nuclear regulator	Sweden, United States

\* In Finland, the government ministry responsible sends the estimates for external review.

Similarly, all countries indicated that there is a review of the financial resources in comparison to the assessed liability, with the exact frequency and mechanisms varying considerably from country to country. These tended to be conducted either on the same frequency as the reviews of the decommissioning cost estimates, although in some countries the intervals were shorter (Belgium, the Czech Republic, Finland, and Korea), see Table 4.3.

**Table 4.3: Mechanisms for the review of decommissioning funds**

Review frequency	Country
Annual	France, Italy, Spain, United States
2 years	Korea
3 years	Belgium, Sweden
5 years	Canada, Czech Republic, Switzerland
6 years	Finland
Other*	United Kingdom

\* In the United Kingdom, for NDA liabilities, the methodology for calculating the decommissioning liabilities is reviewed and updated if and when required. However, NDA does assess the decommissioning costs and update these on an annual basis for the impact of inflation. For non-NDA liabilities (i.e. those principally relating to EDF Energy's existing reactor fleet), a review is performed annually by the NDA. In addition, the NDA *i)* approves decommissioning plans submitted by EDF Energy every five years or three years before station closure, whichever is sooner; and *ii)* approves near term work plans which are submitted annually on a rolling three-year basis.

Finland and the Netherlands indicated that there was no external review of the methodology by which the decommissioning cost liability is established. Belgium, Canada, the Czech Republic, France, Korea, the Slovak Republic, Sweden, Switzerland, the United Kingdom, and the United States all indicated that they conducted such reviews, with the frequency and mechanisms for these broadly following those indicated for the above reviews of the decommissioning cost estimates themselves. In Spain, the methodology is proposed by Empresa Nacional de Residuos Radioactivos S.A. (Enresa) and approved by Ministry for Industry, Energy and Tourism (MINETUR), being reviewed by the official bodies (i.e. Court of Auditors) responsible for the tracking of fund performance.

#### 4.2.1.4. Mechanisms to feed the fund

Countries indicated that a “charge included in the electricity price”, a “compulsory government charge”, and “other” were the common mechanisms by which funds are raised to cover the costs of decommissioning, however no one specific mechanism was clearly favoured over others. Some countries indicated that more than one approach was used in their country. No respondent indicated a tax was used to fund decommissioning in their country.

France and Italy both indicated that there was a charge included in the price of electricity. In the case of France, the level of this charge was determined by the operator; whereas in Italy this is determined by the electricity market regulator.

Spain and Switzerland indicated that there was a compulsory government charge applied.

The responses from the Slovak Republic, Sweden and the United States indicated that in their respective countries both charges included in the electricity price and compulsory charges were applied. In the case of the Slovak Republic, the annual fee consists of fixed part and floating part. The fixed fee is calculated based on the installed power generating capacity of the nuclear power plant whereas the floating part consists of a fee based on the annual income from the electricity sold. In addition, a special levy at the amount of EUR 3 for each 1 MW of sold electricity has been applied to cover the historical shortfall in decommissioning funding. In the case of Sweden, the primary mechanism for reactors in operation is a charge per kWh of nuclear electricity, with the specific amounts varying between the site operators. For the Swedish operators, the fee is differentiated for each one and is calculated so that the total fees to be paid by each operator should provide sufficient income into the fund to cover that particular operator’s future costs. However, for Swedish reactors that are shut down and therefore no longer producing electricity, a fixed annual amount is charged, based on a calculation of the additional contribution to the fund required from the operator finance the remaining costs for which they are responsible.

Belgium, the Czech Republic, Finland, Korea, and the United Kingdom indicated “other” in their responses. Belgium indicated that operators are required to ensure that the resources available for decommissioning are adequate, and pay additional contributions for the funding where necessary to the legal entity (Synatom) responsible for the management of the decommissioning fund. The response from the Czech Republic indicated that contributions are made based on the cost estimation by the Radioactive Waste Repository Authority (RAWRA). In Finland, annual payments are made by the operators to the national nuclear waste fund. In Korea, provisions for decommissioning are made by the operator and managed within the operators own assets. The response from the United Kingdom indicates that decommissioning funds for the older reactors under the responsibility of the NDA come largely from direct government funding, and that there is no segregated decommissioning fund for NDA sites. Government funding is supplemented by income from some NDA facilities still in commercial operation. However, for the case of the decommissioning liabilities for newer reactors in the United Kingdom where EDF Energy is the operator, there is a segregated

fund financed by operator payments. This is also the model for any new UK nuclear development.

Both Canada and the Netherlands indicated that there were “no specific requirements” in their respective countries. In the case of Canada, the required decommissioning fund is accumulated by making annual contributions over the entire planned lifetime of the facility. However, funds can also be collected over a shorter period to reduce the risk of insufficient funding that is associated with premature shutdown of the facility. In the case of the Netherlands, the response indicates that the licensee is in principle free to choose the form of the financial provision and have it approved by the competent authority.

#### 4.2.1.5. Beyond the “pure costs of decommissioning” – adding the costs of financing

The specific amounts to be collected to cover the costs of decommissioning are influenced not only by the estimate of the decommissioning liability, but also by the investment strategy and expected rates of return on investment of fund assets. A risk-balancing is required: those making the payments will want to see a sufficient return on investment so as to reduce the size of their contributions, whereas those having responsibility for the overall funds or exercising regulatory oversight, may require an investment strategy yielding a lower rate of return vis-à-vis a higher degree of security over the accumulated funds. Irrespective of the management approach followed, mechanisms are needed to address risks ranging from errors in the assumptions about inflation, the discount rates and rates of return used for the estimation of the funds required, to a simple loss in value of the assets held by the fund. Some of these risks are further discussed in Section 4.3, and specific protective measures described in subsequent subsections.

#### 4.2.2. Approaches to the management of decommissioning funds

Any management strategy of decommissioning funds should aim to match the full decommissioning cost and to ensure its availability at the time when it is needed, under the control of the national body (EU, 2013a). The protection and security of the funds are of top priority, recognising the unpredictable performance of investments in the stock and bond markets. Different management strategies are adopted in different countries, and fund ownership or control also may be differently attributed. Table 4.4 below summarises the different approaches taken towards control over decommissioning funds.

**Table 4.4: Control over decommissioning funds**

Government	Utility/operator*	Another body	No specific requirement
Finland	Czech Republic, France, Korea, Spain	Belgium, Italy, Slovak Republic, Sweden, Switzerland, United Kingdom, United States	Canada, Netherlands

\* Distinction may have to be done between utility (as paying to the fund) and operator (as decommissioning implementer, it may pay or only execute).

In some countries, the licensee/owners (operators) are allowed to accumulate and manage their own decommissioning funds that remain in their own accounts. In this type of approach, referred to as internal management of the funds, or accruals (see below), the operators have full responsibility for the respective investment and any potential losses, for which they would have to compensate (NEA, 2006). In other countries, the funds are collected from the operators or via the electricity market system, and are managed by separate, independent bodies. Through this approach, referred to as external management, or trusts (see below), the organisation responsible for the fund needs to manage and control the assets in such a way as to ensure that the fund at least retains its value and is not disbursed on anything other than its identified purpose. In the case of

external management, compensation for any losses may need to be addressed in the legal and regulatory framework (NEA, 2006); in addition to measures necessary to address the risk of fund loss due, for example, to bankruptcy of the owner of the facility.

Both management approaches have the same goal: namely to cover the expected costs of decommissioning and to have the finances available at the time the costs are incurred. To make this possible, calculations of future costs are expected to meet high accuracy standards and are subjected to regular and frequent review. The funds themselves need to be managed in such a way to ensure that they retain their value, and it is important that the real value of assets in the fund is safeguarded against periods of high inflation. The management of the accumulated assets of the fund may be entrusted to a variety of custodian banks or asset managers for the purpose of investing them. The options for asset management include investment in national currency bonds, international currency bonds, national equities and international equities or investment in real estate. The range of options available in any given instance, however, may be restricted as a matter of national or fund policies, and/or fund investment strategy.

In some countries there are specific features relating to access or use of the decommissioning funds that may not be directly related to actual decommissioning. For example, in Belgium and Finland, facility operators contributing to the fund are entitled to borrow back a percentage (up to 75%) of the capital of the fund, against provision of full securities and at a defined government-fixed rate. Such access may trigger competition concerns, particularly where there are deregulated electricity markets, for example within the European Union. In addition to such arrangements, in some countries the state may have the right to borrow the capital of the fund (IAEA, 2005).

A range of specific management models exist for decommissioning funds. These can be categorised in a variety of ways, however for the purposes of this, the following main groups are identified and discussed below. More than one category of funding may be found in some countries. The categories considered here are funds run:

- as external segregated funds;
- by the utility/operator within its own assets;
- by the utility/operator within a separated account or segregated fund.

In addition to those models listed above, there are other examples of nuclear power plant decommissioning funding models, such as direct funding from government, particularly for older reactors.

Other classification could have been used also, such as by the European Commission:

- internal funds;
- external funds:
  - managed by the utility/operator within a separate account;
  - managed by a different entity.

#### 4.2.2.1. External segregated fund management

In the “external segregated fund model”, the funds are managed externally, by a dedicated independent body that may be a private or state-owned entity. Such funds may be centralised, for the entire industry, or decentralised, with as many funds as there are operators. It is argued that the advantages with this model include increased transparency, enhanced insolvency protection and improved public confidence that the required funds will be available when needed.

Finland, the Slovak Republic, Spain, Sweden, Switzerland and the United States indicated that there were external segregated funds in their countries. Switzerland indicated that there are two national funds, one for decommissioning and one for waste,

each having their own legal personality and subject to the supervision of the Swiss Confederation.

#### 4.2.2.2. Funds managed by the utility/operator within its own assets

In the “internal own assets fund model”, the funds are managed within operating organisations, and held within their accounts in the form of reserves. Historically, this model was common within the OECD (NEA, 2006), but it is becoming increasingly less common now. It is argued that the advantages with this model include flexible access to funds, and combined technical and financial responsibility. However, this approach creates concerns that the funds may not be available when needed. Special control measures may be required to verify that the fund meets basic principles of sufficiency, availability, transparency, and assurance that they are used only for the intended purpose (Laraia, 2012). Korea indicated that the decommissioning funds are managed by the utility/operator within its own assets.

#### 4.2.2.3. Funds managed by the utility/operator within a separate account

In the “internal separate account fund model”, the funds are still managed internally but are accounted for separately from other assets and liabilities. This is intended to give a greater degree of transparency over the funds and facilitate oversight of their use.

A variation of this approach is one where the fund is actually segregated from regular utility accounts. There are a range of possibilities here as well, but typically the operators are required to contribute to an external funding source (bank or treasury account) subject to specific rules protecting the fund from misuse and financial risks. Alternatively the operator can pay into an external fund managed by an independent body. The segregation is intended to limit the flexibility of access to the funds and facilitate oversight of their use, thereby enhancing further assurance that the funds will be available for their intended use.

Both the Czech Republic and France indicated that the decommissioning funds are managed by the utility/operator within a separate account. (For the Czech Republic, “blocked account” can be classified as internally managed segregated funds with all assets being earmarked for decommissioning purposes.)

#### 4.2.2.4. Government funded

In this model, the state provides the funding for decommissioning liabilities. However this is less common, and is typically associated with the older generation nuclear plants. Government intervention in providing funding for decommissioning of commercial nuclear power plants still in operation might be considered problematic from a competition perspective within the energy producing sector, nationally and internationally, for example within the European Union. The United Kingdom indicated that decommissioning funds for the NDA’s reactor decommissioning liabilities primarily come from direct government funding.

#### 4.2.2.5. Other examples, excluding direct government funding

In addition to the United Kingdom, Belgium, Italy, and the Netherlands also indicated “other” in their responses on how the decommissioning funds are managed.

- In Belgium, the funds are managed by Synatom, which is a private company for the management of the fuel contracts and the decommissioning fund, fully owned by the utility/operator (with a golden share of the Belgian State).
- In the Netherlands, the licensee is in principle free to choose the form of the financial provision, subject to approval by the competent authority. The authorities assess whether the financial provision offers sufficient security that the decommissioning costs will be covered at the moment of decommissioning.



- Canada indicated that the form of control over the funds is largely up to the utilities themselves to choose. The administration of financial guarantees should be accomplished by clearly defined and legally enforceable arrangements acceptable to the Canadian Nuclear Safety Commission (CNSC), the Canadian nuclear regulator. These arrangements should be structured so as to ensure that the funds or securities provided by the applicant or licensee to guarantee funding for an approved decommissioning plan are separated from its other assets.

### **4.3. Control and oversight of funds; protective measures and performance of risk management funds**

The level of financial resources available for decommissioning activities should be sufficient to cover all relevant activities in an approved decommissioning plan at the time such resources are needed. If aspects of the total decommissioning programme are to be covered by sources other than a separate, designated fund (e.g. from public funding), these funds need to be identified and subject to a legally enforceable requirement. Earlier than expected permanent plant closure or the failure of a fund to reach a sufficient level of financing to cover the full costs of decommissioning prior to plant closure may mean the postponement of decommissioning activities or the need to draw on financing from other sources.

All fund management models face a common challenge, namely the risk of not being sufficient or available for the decommissioning obligations and for covering their costs, owing, for instance, to premature shut down and decommissioning, escalation of costs, underperformance of funds, financial difficulties or bankruptcy of the operating company, or as the result of a change of ownership.

Recently a number of facilities in the United States and in Europe have faced premature shutdown, for reasons that may be technical (where performance of the facility does not meet safety criteria); operational (where reliability has been poor); financial (where the economics of operation of the nuclear facility in a competitive electricity market has not been favourable); or, political (where the government/parliament initiates a nuclear phase-out). Often more than one of these factors may be involved in an early closure decision. In any event, early shutdown of the facility may interrupt contribution to decommissioning funds before the liabilities are fully financed (IAEA, 2005).

Longer operating times currently envisaged for power plants could affect the time frame for the build-up of funds; and protracted financial crises and changes in the expected returns from investment funds could hamper the sufficiency or availability of funds. There is political risk, in that a government may take measures to allow the use of funds accumulated for future decommissioning for purposes other than those originally intended. Criminal misuse of funds is also a possibility and cannot be ruled out. Warfare could lead to a total loss of funds (NEA, 2006).

Some management models for decommissioning funds might be more vulnerable to certain risks than others. For instance, with internal reserves, in particular in cases where separate accounts are not established, there may be a greater risk that funds are not available when needed, and special measures may be required to get assurance that they are used only for the purpose for which they were set aside (IAEA, 2005). The funding mechanism itself may have particular risks associated with it. For example, when fund accrual relies on a system of fees per unit of electricity, the determinant of how much is expected to be paid into the fund is a function of the level of the fee and the prognosis of electricity to be delivered. Clearly, in such cases, where the actual volume of electricity varies from that anticipated in setting the fees, the income to the fund will be affected. In the event of prolonged outage of nuclear generation units that is not factored into the

fee-setting calculations, there is a risk for a shortfall of income to the fund against what was expected.

Decommissioning liabilities themselves can be volatile, with increases or decreases in the cost of decommissioning. Furthermore, the payment stream needs to be responsive to changes in the general economy and fund performance. In addition to having adequate financial resources and disbursements restricted to pre-identified objectives, nuclear decommissioning funds need to be designed to permit sufficient flexibility such that sufficient financial resources are available to cover all relevant activities in an approved decommissioning plan at the time such resources are needed. As discussed in Chapter 3, variations in costs are sensitive *inter alia* to changes in regulations, waste disposal policy, politics and plant conditions as the generating facility ages. All these underlying assumptions can be a source of risk.

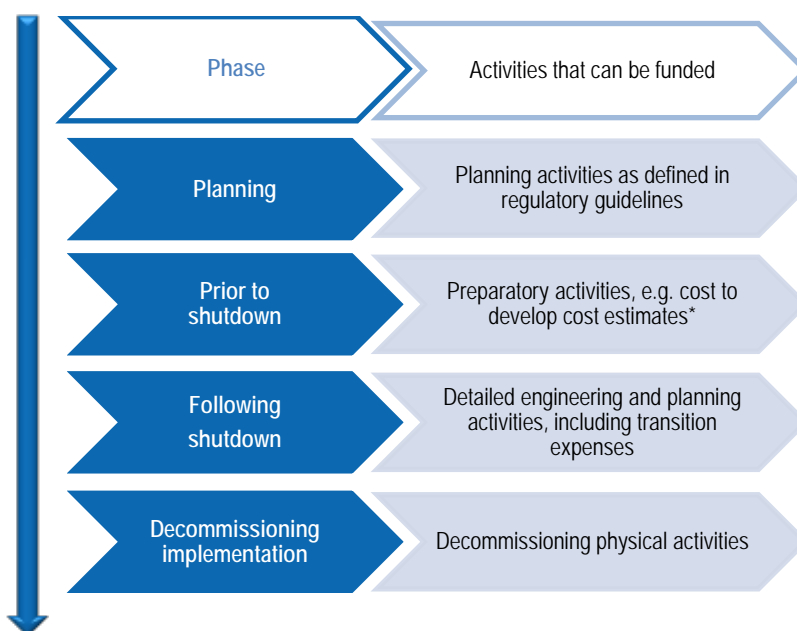
Even if arrangements for decommissioning funds are well established, it is not always clear how well funds are protected against risks, uncertainties and unknowns (NEA, 2008). In this section, the focus is on the control, oversight and protection of the decommissioning funds from the perspective of assuring their sufficiency and availability, as well as the implementation of possible measures aimed at averting, reducing and addressing the risks.

#### **4.3.1. Control and oversight of decommissioning funds**

The liabilities that remain following the closure of a nuclear facility need to be managed safely, even though this may be over a period that ranges from a few years to possibly more than 100 years. The future implementation of the decommissioning project, depending on the strategy chosen, will require specific timetables for decommissioning liabilities and for related disbursements. It is vitally important that the financial resources for the safe management of these costs can be guaranteed over the full period and in a manner ensuring liquidity compatible with the timetable for the decommissioning obligations and their costs. In this regard, and as discussed earlier, availability of funds is a particularly pertinent principle, as it affirms that the necessary funds are to be available at the appropriate time. This in turn depends on the growth of the funds, something that is affected by considerable uncertainties, as a result of the chosen investment strategy, the management of the fund or inflation rates. Moreover, the funds should not be spent on anything other than their identified purpose, as diversion of resources for non-intended purposes will deplete the level of the funds available for actual decommissioning. It is also necessary that the funding system complies with national tax laws (NEA, 2006).

The management of funds should be transparent to the respective national authorities and other relevant stakeholders as regards the accumulation of money, the expenses and the financial management.

National legislative and regulatory frameworks have established rigorous rules to control the access to decommissioning funds and the timing as to when they could be withdrawn (IAEA, 2005). These rules typically define the types of expenditures that may be made at different stages during the phased approach to decommissioning project management: from pre-shutdown engineering and planning, post-shutdown project initiation, and full project implementation. (In some countries, there may also be limits to the actual amounts that may be drawn down from decommissioning funds during particular phases.) This ensures that specific limitations are imposed in terms of the types of activities that may be reimbursed from the fund at each stage of the project, and that this is subject to a corresponding oversight. Spending limits and release of the funds may be tied to specific milestones of the project, in which case there may be a requirement of documented evidence to support authorisation of expenditure (IAEA, 2005). Decommissioning project phases are shown schematically in Figure 4.1.

**Figure 4.1: Decommissioning project phases**

\* In general, physical changes to the facility, removal of equipment, or purchase of dismantling or demolition equipment are not included in this phase.

In the case of an external account or trust fund, the modalities for reimbursement can vary considerably, mainly according to the assignment of responsibilities for decommissioning and the specific procedures for disbursements from the fund. In such a situation, care needs to be taken to manage the risk of mismatch between the asset and the liability since these are being dealt with by two separate bodies.

There are a variety of national systems in place for reviewing the financing and operation of the funds. While the details vary considerably between countries, in all cases these arrangements constitute a system of checks and evaluations, with a differentiation of powers and responsibilities from those more closely related to the operational issues, where oversight is typically of a more technical, expert nature; to policy considerations, where there is typically a role for a state authority or government.

#### 4.3.2. Protective measures

In circumstances causing insufficiency or unavailability of decommissioning funds, missing financial resources must be covered by other sources. As already noted, mechanisms based on the fund collection over a period shorter than the expected lifetime of the plant or obliging the operator to make a down payment for all future costs as a condition for obtaining an operational licence reduce the risks associated of premature shutdown of the facility (IAEA, 2005).

Changing the decommissioning strategy by delaying or prolonging decommissioning can be sometimes used to address a lack of liquidity, by extending the period of return of investments and accrual of the fund. However, concern has been raised that such an approach is vulnerable where rates of return are low and where the costs of maintaining a facility in a safe condition may draw on the decommissioning funds.

A way to insure against these types of problems is to plan for an alternative financing system at an early stage (NEA, 2006). Insurance policies or bank guarantees, where these are available, could cover some contingencies should they occur. An obligation to pay additional contributions can also be imposed on a parent company, for example, or even

on other operators by defining a joint liability. However, there may be legal limits to such approaches in particular countries or legal systems.

As a precaution against insolvency in the case of privately owned facilities, the part of the assessed liability that is not covered by the fund assets may be covered with securities furnished by the operator. These securities can be given to the fund or to the state. Mortgages on a nuclear facility itself cannot be accepted as securities, and other restrictions as to acceptable securities may be imposed. Typically each security is required to be separately accepted by a regulatory body or is subject to requirements set out in the legislation or regulations governing decommissioning financing.

When funding mechanisms are adopted that are based on fees raised per unit of delivered electricity, income to the fund can be insufficient. In such situations, states should take steps to monitor possible variations between the prognosis of electricity to be delivered used when setting the fees, and the actual electricity delivered. A number of corrective measures could be envisaged. These might include retrospective measures such as requiring additional in-payments to make up deficits, or an increase in the fee for the next payment period. It might be possible to reduce the need for retrospective measures by implementing controls on what electricity prognosis is used when calculating the required fees, for example by using a prognosis produced by an independent, respected source (e.g. an electricity market regulator). Alternatively, a risk factor might be applied when setting the fees, based on an analysis of the historic variation between the prognosis and the actual delivered electricity.

In the case of a unique external national fund for several nuclear operators, each operator can be said to have its own “account” in the fund, and the state authorities regularly establish the required balance for each operators account. In some cases, where one operator can no longer take care of its obligation for financial provisions, the state may take over the account and the securities furnished by that operator to guarantee that the fund as a whole can return monies in a timely manner (IAEA, 2005). If it turns out that a reactor owner cannot pay, and fund assets and guarantees are insufficient, the state – and thereby the taxpayers – will in the end have to contribute the necessary funds. As one example, in recognition of this possibility, as of 1 January 2008 the Swedish state is entitled to charge the nuclear power companies a risk fee for this risk, although to date it has not exercised this possibility.

In the case where decommissioning liabilities are to be met with direct government funding, funding may be constrained to the extent the government places annual or other limits on the amount of funds available to perform the decommissioning activities. In the event funds are not being collected either because of financial stress (bankruptcy, inadequate cash flow, or simple delinquency), or lack of legal structure to require collections, it may be necessary to impose enforcement actions against the licensee (IAEA, 2005).

The change of owner or operator of a nuclear facility constitutes a potential risk to the adequacy of decommissioning funds and there is a range of approaches to this scenario. Several countries indicated that some form of evaluation would be done: Belgium, on a case-by-case basis; Spain, the new owner must provide evidence of sufficient legal, technical and economic-financial capacity to carry on the activities; the United States, review of the licence transfer application under the applicable Code of Federal Regulations. Finland, France and Switzerland indicated that the liabilities would be transferred to the new owner or operator, who would also assume responsibilities for any future liabilities. The Slovak Republic indicated that the decommissioning funds are earmarked for individual nuclear facilities and managed separately by the national fund, and thus would be available for the facility’s decommissioning regardless of any change in the owner/operator. In some countries respondents indicated that this scenario is not applicable, for example because the facilities are state-owned (Korea) or state-controlled (Czech Republic), or the facilities have been transferred to a state entity for

decommissioning (Italy). Where there is a change of owner in the case of the United Kingdom, financial liability will be specific to the commercial contract, and will depend on whether the sale is leasehold or freehold. In addition, the Energy Act 2004 (HMG, 2004) limits the extent to which liabilities can be transferred to a third party.

#### **4.3.3. Funds' performance risk management**

Beside the risks, discussed earlier, that can jeopardise the sufficiency and availability of decommissioning funds, the capital that is managed to provide a positive return is exposed to different financial risks, such as inflation risk, market risks – with varying interest rates on the accumulated capital, credit risks, liquidity risks, currency risk and administrative risks. These types of financial risks are the same for all kinds of capital management. Economic stability is necessary for a sound long-term funding system. Variations in decommissioning costs and payment streams are also recurrent. Consequently, a funding plan developed for decommissioning a facility needs to be adaptive.

The growth of the fund is dependent on the investment strategy, i.e. how aggressively or conservatively the funds are invested, thereby determining the amounts to be collected. It is reasonable that the owners who are depositing monies into the funds will want to see the greatest possible return on the investment such that they will, in the long run, deposit less money. On the other hand, governments tend to have a more conservative approach and want to protect the capital in the fund. To achieve this, they are willing to accept a lower rate of return. For the optimal performance of the fund a balance is required between these two perspectives, and the expected return on capital invested needs to be weighed against the acceptability of risks taken to obtain that return (IAEA, 2005). This balance will generally establish the kind of assets into which the fund capital may be invested. For a secure risk profile, low-risk assets should be preferred while not excluding high-risk assets but with constraints on the risk exposure (EU, 2013a). The responsibility to establish risk acceptability limits normally rests with governments (NEA, 2006), although it may be delegated to national bodies having fund oversight.

Implications of these considerations for the investment concept are a long-term saving process with a lengthy investment horizon, a sustainable nature of investment income, and sometimes individual goals for each facility (IAEA, 2005).

Specific guidelines may be defined, such as:

- only low-risk investments are permitted;
- investments in companies associated with the legally obliged contributors to the funds are prohibited;
- investments in companies that have invested the majority of their assets in nuclear facilities are prohibited;
- investments into domestic or international money markets are permitted.

Different asset management possibilities exist. The range of options available in any given instance, however, may be restricted as a matter of national or fund policies, and/or fund investment strategy, such as:

- investment in national currency bonds;
- investment in international currency bonds;
- national equities and international equities (indexed and active);
- investment in real estate.

As reported in a recent communication from the EU (2013a), funds are required to be invested to a high degree in government bonds in many EU countries. However, owing to the recent events in financial markets, which have put serious doubts on the absolute safety of government bonds, the commission considers advisable that the implicit assumptions underlying the existing relevant legislation are revisited (EU, 2013a). This circumstances laid out with revision of the investing criteria in several cases i.e. Spain.

In some countries where concern for the liquidity of the fund and its security against poor investment performance has favoured investment of funds in low risk, low return securities, funds have been given favourable tax treatment to offset the low return on investment. They are generally called qualified funds, as they qualify for this favourable tax treatment. Investment in a higher risk, higher return security such as equities (stock) might provide a greater return to the fund and require a smaller collection from ratepayers. These are called nonqualified funds. The tax treatment on nonqualified funds is usually at the higher corporate tax rate. The return on these nonqualified investments is hoped to be great enough to cover the corporate tax rate and still return a greater contribution to the fund than qualified funds. The tax treatment of decommissioning funds is a key consideration in developing strategies for the collection and/or management of decommissioning funds in some countries or some conditions (e.g. new reactor projects in the United Kingdom).

As already noted, the management of the fund itself can be entrusted to a variety of custodian banks and asset managers with the task of investing the funds' assets. These investment policies and their compliance with specified guidelines can be monitored by submitting regular reports from a specific investment committee or external experts.

#### 4.3.3.1. Asset constitution of the decommissioning fund – Some specific examples

There is considerable variation on the nature of, or policy relating to, the asset constitution strategy of the funds. Some respondents provided details of the requirements in place or referred to specific regulations or guidelines that are applied, while other respondents referred more generally to the nature of the funds themselves. Some of the specific features of the arrangements described include:

- Belgium: Restrictions on use of funds: Up to 75% of the fund can be lent to operators depending on their solvency and credit rating. Up to 25% of the fund must be invested outside nuclear plants, with 10% to be invested in selected energy projects.
- Canada: The Canadian regulator can require the inclusion of terms restricting access to, or use of, monies realised from the fund or securities. Withdrawals from a fund, or access to monies realised from other security vehicles should only be permitted for approved purposes; in particular, to pay for approved decommissioning activities, or to refund excess monies to the licensee.
- Finland: The licensees are entitled to borrow money from the fund against securities. These loans may not exceed 75% of the confirmed fund holding of the loan-taker at a time. The state has a right to borrow the sum not borrowed by the contributors. The remaining funds are invested by the fund. No specific asset constitution strategy is determined in the legislation.
- France: In the case of EDF, the asset constitution plan is typically defined to match the regulatory target of funding 100% of the long-term liabilities by the prescribed date, assuming a constant yearly contribution in real terms. A government decree defines the categories of assets admissible for funding the liabilities, and the maximum authorised weights of each asset class. The strategic asset allocation is defined by the EDF Board of Directors. Since the inception of funding through dedicated assets in 1999, EDF has maintained a strategic allocation that is balanced between bonds and internationally diversified equities. Since 2010, EDF has

increased diversification into real assets, first by assigning half of RTE equity (the French regulated power transportation network operator, an EDF affiliate) at the end of 2010, then by reviewing in November 2012 the strategic allocation to incorporate infrastructure and real estate.

- The Slovak Republic: In addition to the fixed and floating charges described earlier, assets of the National Nuclear Fund are collected from a wide range of resources. These additional assets include: levies on the sale of electricity collected by distribution companies to cover historical shortfall; fines imposed by the Nuclear Regulatory Authority under special regulation; grants and possible contributions from the European Union and other international and financial institutions.
- Spain: Enresa, as national entity for radioactive waste management and decommissioning implementation, is also responsible for fund collection and management. The financial management of the fund is governed by the principles of security, profitability and liquidity and may be realised through assets specified by decree. Subject to specific restrictions, these include: fixed and variable transferable securities, government bonds, mortgage bonds and other financial assets and instruments; instruments deriving from structuring, transformation or coverage of investment operations as part of financial investment portfolios; deposits at financial institutions, credits and loans; property; foreign securities; other assets or investment instruments that are deemed appropriate by the Fund Monitoring and Control Commission.
- United States: The Code of Federal Regulations has simple guidelines such as using a “prudent investor” standard, prohibition on self-investing, and restrictions on foreign investments.
- Switzerland: Table 4.5 shows the asset classes, their target weights and boundaries, expected to ensure the return on investment.

**Table 4.5: Asset classes for decommissioning funds in Switzerland**

Asset classes	Policy	Lower value	Upper value
Cash	0%	0%	5%
Bonds (CHF)	25%	15%	35%
Bonds FX (hedged)	15%	10%	20%
Stocks	40%	30%	50%
Real estate	10%	7%	13%
Alternative investments	10%	7%	13%
<i>In foreign currency</i>	<i>48%</i>	<i>30%</i>	<i>70%</i>

#### 4.3.3.2. Review of fund performance and corrective measures – Some specific examples

It is important, that the fund be periodically reviewed and updated to respond to any changes as they occur. Early recognition and funding takes full advantage of the remaining period of operation for investment growth. This key control mechanism is adopted in most countries, with review of funds and contributions, as well as review of the cost estimates themselves, periodically undertaken (the arrangements vary from country to country, see Section 4.2.1). In addition, ad hoc reviews can also be conducted as necessary if a new situation occurred, or if a significant modification of costs is to be expected due to unforeseen circumstances. The annual contributions can also change if, as a result of developments in the financial markets, the accumulated capital deviates from the target level (IAEA, 2005).

In this respect, the annual review of the accumulated funds, as well as the review of the cost estimates by the national body, is of the utmost importance (EU, 2013a). All countries indicated that there is a review of the financial resources in comparison to the assessed liability, with the exact frequency and mechanisms varying considerably from country to country. These tended to be conducted either on the same frequency as for the reviews of the decommissioning cost estimates (Section 4.2.1), although in some countries the intervals were shorter – typically on a yearly basis (Belgium, Czech Republic, Finland, and Korea).

The identification of a shortfall between the value of the fund and the decommissioning liabilities should give rise to an immediate definition of corrective measures to be implemented. Belgium, the Czech Republic, France, Italy, Korea, and the Netherlands all indicated that potential fund underperformance for an external decommissioning fund was not a relevant scenario for their particular country because of specific features of their funding arrangements. For the remaining respondents, a range of responses were described:

- In Canada, in certain cases, a government guarantee (e.g. at federal or provincial level) can be used to cover the external fund's underperformance.
- In Finland, to provide for unforeseen costs, the government can decide on an extra security of up to 10% of the total liability.
- In the Slovak Republic, if a shortfall is identified during periodic reassessment of the national policy, the National Nuclear Fund can increase the fixed amount and/or the levy (variable amount) on the sale of electricity. The Slovak Republic also requested the EU to extend the existing nuclear decommissioning assistance programme to cover a shortfalls resulting from a political early closure decision.
- In Spain, the fund performance is reviewed quarterly by the Tracking and Control Committee of MINETUR who could advise and make proposals for better performance. Corrective measures could be established immediately by means of a royal decree.
- In the United States, a number of possibilities exist and the exact approach to be followed would depend on the specific circumstances of the underperformance. Licensees are required always to maintain a minimum amount of funds in the trust. Cash and non-cash options for such funds are outlined in the relevant Code of Federal Regulations.
- In the United Kingdom, for the facilities covered by the NLF, addressing such a shortfall would be a matter for the funds trustees possibly backed by a review of the liabilities cost base to see if savings can be achieved. In the case of nuclear new build the intention is to ensure that the fund is sufficiently endowed such that any shortfall during discharge of the liabilities would be remote and the sufficiency of the fund reviewed through its investment lifetime.
- In France, the operator is responsible for any underperformance of its fund and is therefore required to implement corrective measures under the supervision of the administrative authority.

The timing of corrective measures typically would be associated with the periodic review of the funds, and the various reporting mechanisms in place in the countries concerned. However, the time required for implementing the measures and the period during which the corrective measures are required to be effective in addressing the shortfall varies. There was considerable variation described in responses, e.g.:

- Finland: If the shortfalls are small they are adjusted annually through the payments of the utility. If there is a larger shortfall it may be adjusted within a five-year interval.



- France: To determine this delay, the administrative authority shall take account of economic and financial markets conditions; this delay cannot exceed three years.
- Italy: Any shortfall is typically addressed through the raising of the levy on the electricity bill. Such adjustments can be made every three months during the regular update of the electricity bill components.
- The Slovak Republic has an actual shortfall in the decommissioning funds. To address this, it has imposed a special levy on the price of sold electricity to create a systematic accumulation of funds to cover the decommissioning costs shortfall in the coming years.
- Switzerland: If the value of the fund is 15% or more below the reference value during two consecutive years, the Commission on the Decommissioning and Waste Management Funds decides on measures to close the gap in a reasonable time.

A similar pattern can be found concerning the specific instance of how a shortfall in the value of the fund's available assets during the decommissioning phase would be addressed and who is specifically responsible for the additional payments under such a scenario. The responses can be summarised as follows:

- Belgium, Canada, Finland, France, Korea, the Netherlands, and the United States all indicated that it is generally the operator's/licensees responsibility to make up such a shortfall during the decommissioning phase. In Canada, the licensee must inform the regulator of the shortfall. Expressed commitments from a government (either federal or provincial) to cover all otherwise unfunded aspects of decommissioning would be acceptable to the national regulator. In the Netherlands, the government serves as a final fall-back.
- Italy and the Slovak Republic: Any shortfall is typically addressed through raising of the levy on the electricity bill, as described for these countries in the preceding scenario. (In the Slovak Republic, the levy covers historical shortfall for non-operating nuclear power plants [NPPs] under decommissioning).
- Spain: At any moment, it is responsibility of the licensee to pay the stipulated fees during the operational phase of the plant. There are no payments during the decommissioning phase. In case of a shortfall during the decommissioning phase it would be full responsibility of the "decommissioning licensee", namely Enresa.
- Switzerland: Detailed provisions for additional contributions are set out in the Nuclear Energy Act. In the first instance, this obligation rests on the operator.
- United Kingdom: As noted earlier, NDA liabilities primarily are funded directly by government. For the facilities covered by the NLF, ultimately, any shortfall in funding would be met by the United Kingdom taxpayer as described in the preceding scenario. In the case of the NLF in the United Kingdom, according to the conditions that were agreed during the sale of British Energy, apart from specific reasons, there is no provision for any adjustment of payments from the current operator, EDF Energy, to the fund.
- The response from the Czech Republic indicated that such a scenario was not applicable.

#### 4.4. Conclusions

From the analysis of the replies to the survey, some conclusions can be derived as follows:

- Current systems and practices for funding decommissioning of nuclear power facilities aim to preserve safety and not to impose undue burdens on future generations.
- The requirements for nuclear power plant decommissioning financing are formally established according to the national legal systems, including regulations of the nuclear regulatory body. There are considerable variations between countries in the details of these formal legal requirements. In many cases, the systems currently in place have incorporated features intended to address deficiencies identified in earlier years, with countries introducing requirements for systematic reviews, and requirements on the various parties involved.
- Operators of nuclear power plants generally are responsible for financing the costs of decommissioning, with arrangements typically being based on the revenues earned from the sales of the electricity generated. The exact financing mechanisms vary from country to country. Exceptions to the general pattern include financing arrangements for some of the oldest facilities, or where there are deficits arising from historical arrangements.
- The completeness and accuracy of decommissioning cost estimates are important prerequisites for establishing adequate funds for future decommissioning.
- Ensuring availability of the necessary funds at the right time is one of the cornerstones of a decommissioning financing system. Accordingly, the identification of risks and uncertainties in funding arrangements, and implementation of appropriate measures to manage them, are essential elements of national decommissioning fund management and oversight. Nonetheless, decommissioning funding arrangements may still be vulnerable to earlier than expected plant shutdown or the failure of a fund to reach a sufficient level of financing to cover the full actual costs of decommissioning.
- States have put in place mechanisms to regularly review changes to calculated liabilities, fund growth and other changes to market conditions, and timing of decommissioning, to reduce the risks of inadequate decommissioning funding. The details of these national systems vary considerably, reflecting both current needs and the historical development of the systems.

The information provided for this analysis does not enable general conclusions to be drawn concerning the adequacy of current decommissioning financing arrangements. Reviewing the adequacy of decommissioning funding arrangements is currently hampered by the limited amount of reliable and comparable information on decommissioning costs. Enhancing transparency around such costs and putting in place better arrangements to collect and share such information would contribute greatly to such assessments in the future. Nonetheless, it is clear that the financing, review and oversight mechanisms described in this chapter rely on a combination of features that together aim to manage risks and ensure the adequacy of decommissioning funding.

National review and oversight systems typically need to address many important considerations, including:

- the provision and review of decommissioning cost estimates, including the evaluation of uncertainties in the estimate;
- the period during which funding is accumulated to achieve fund sufficiency;
- the variability in inflation and escalation rates during the collection time of the funds;

- the variability of interest rates on the accumulated capital;
- the disbursement planning, in relation to both fund growth and fund liquidity;
- the risk of premature shutdown of a plant and thereby the loss of revenue;
- the relationship between the estimate of future liabilities and the fund assets;
- the measures that can be applied if needed to address potential increases in the estimated liabilities, deficits in payments to the fund, shortfalls in fund growth, or changes to decommissioning activities and timing;
- the enforcement measures to ensure compliance with the requirements, including legal remedies;
- the need for periodic review and updating of the arrangements to take into account other changing circumstances and return of experience.

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## Appendix 4.A1. Decommissioning funding: Detailed country descriptions for Sweden, Switzerland and the United Kingdom

To illustrate and complement Chapter 4 of the report, this appendix provides insights on how the funding of decommissioning is organised and managed concretely in three countries.

### Sweden

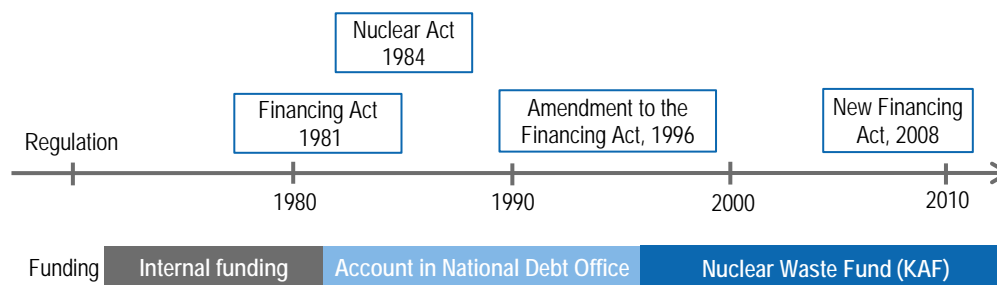
In Sweden a company that has a licence to operate a nuclear power plant is responsible for adopting whatever measures are needed for safe management and disposal of spent nuclear fuel and radioactive waste deriving from it and for decommissioning and dismantling of the reactors after they have been taken out of service. Provision for financial resources during decommissioning is provided by means of payments into a government-controlled fund.

The financing system for management of radioactive waste and decommissioning of nuclear power reactors in Sweden has now been in action since 1982.

Before 1982, the costs of radioactive waste management and decommissioning were accounted for on the balance sheets of the companies involved (i.e. internal funding). In the early 1980s, the Riksdag (Swedish parliament) devised a financing system to finance the costs of future management and disposal of nuclear fuel. Under this system, the holder of a licence to operate a nuclear facility that gives rise to waste products pays a special fee to the state. For the first 14 years the fees were deposited in interest-bearing accounts at the Riksbank (Swedish central bank). The current system was instituted in 1996, whereby the funds are managed by the Nuclear Waste Fund, which is a government authority. In Figure 4.A1.1, the timing of major changes to the regulatory framework are indicated.

While the financing system has been developed over time, many core features, such as the division of responsibilities, have essentially remained the same. However, the details of how to estimate the costs and the inherent uncertainties, as well as the management of the fund, have evolved over time.

**Figure 4.A1.1: Timing of major changes to the regulatory framework in Sweden**



Source: Carroll, 2014.

According to the present regulatory framework, the cost estimates and payments to the fund, as well as the calculation of the securities, are reviewed every third year.

### *The regulatory framework*

The system of nuclear waste fees and guarantees is regulated in the “Financing Act” of 2006 with its associated ordinance of 2008.

The purpose of the Financing Act is to ensure the financing of the general obligations imposed by the Swedish Act on Nuclear Activities. The obligations to ensure funding apply to all licensees of a nuclear facility. The primary purpose of the Swedish financing system is to secure the financing of the licensees’ costs for handling and disposing of residual products, decontamination and dismantling of nuclear facilities and carrying out needed research and development activities, but also minimising the government’s risk of being forced to bear the costs considered to be a licensee liability.

### *Obligation to pay the nuclear waste fee and provide guarantees*

The principle for the financing of the disposal of nuclear waste is that the nuclear power industry should be liable for the costs.

The licensee of a nuclear facility that generates or has generated residual products<sup>1</sup> must pay a nuclear waste fee. The fee is levied at a given rate per kWh of electricity delivered by the nuclear power plants. Since 2008, the fee can also be determined as an amount in kronor, to be paid for example by a fee-liable licensee who no longer delivers nuclear energy (for example, for a reactor following permanent closure, pending decommissioning).

Each nuclear power company and other fee-liable licensee is fully responsible for all its costs, even if the fees accumulated in the fund should not be sufficient. The party responsible for paying the nuclear waste fee must therefore provide a guarantee to the state for the costs the fee is intended to cover, but which are not covered by the paid-in and accumulated fees. The obligation to pay the nuclear waste fee and provide guarantees will end when the licensee has performed its obligations under the Act on Nuclear Activities or has been granted an exemption from them.

### *Administration of funds*

The financing system is based on payment by the licensees of nuclear waste fees to a state-administered fund (i.e. the Nuclear Waste Fund), primarily during the period the reactors are in operation, but also later if need be. The fund is intended to cover the estimated costs of both waste management (including spent fuel) and decommissioning. In addition to these fees, the licensees must pledge specific guarantees to the state. The Nuclear Waste Fund is an independent government authority that controls and administers this fund.

The state has the ultimate responsibility for long-term and safe management of spent fuel and radioactive waste. This responsibility also includes a financial obligation. Thus, if it turns out that a reactor owner cannot pay, and fund assets and guarantees are insufficient, the state – and thereby the taxpayers – will in the end have to contribute the necessary funds. As of 1 January 2008, the state is entitled to charge the nuclear power companies a risk fee for this risk.

The accumulated funds are to be used solely to reimburse the costs that the nuclear waste fee is intended to cover. If the Nuclear Waste Fund is proven inadequate, the guarantees shall be used to cover the costs. If fund assets remain for a fee-liable licensee

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1. “Residual product” is defined as: nuclear materials that will not be used again, nuclear waste which is not operational waste.

after all costs relating to that specific licensee have been paid, the excess of funds shall be repaid to the licensee or the payer. A licensee is obligated to submit cost estimates and other information which might be required to fulfil the purpose of the Financing Act.

#### *Guarantees*

In addition to paying a fee on nuclear energy generation to the Nuclear Waste Fund, the nuclear power reactor licensees must provide two types of guarantees. One guarantee is to cover the gap between the current level of funding and estimated liabilities, in the event of early plant closure. The second is to cover additional costs arising from unforeseen events.

#### *Management of assets*

The assets in the Nuclear Waste Fund will be managed to ensure a return and satisfactory liquidity. The Nuclear Waste Fund's assets are deposited in an interest-bearing account at the National Debt Office, in treasury bills issued by the state or in covered bonds. The return on the fund's assets shall be added to the principal.

#### *Disbursements to licensees*

The licensees are entitled to disbursements on a continuous basis for expenses that they have already incurred for measures to achieve the decommissioning, handling and disposal of spent nuclear fuel and nuclear waste, including the research needed for these activities. The remainder of the funds is accumulated for future needs.

#### *The fund*

The Nuclear Waste Fund is a government authority whose mission is to receive and manage the fees paid by the nuclear power companies and owners of other nuclear facilities in Sweden.

The authority is overseen by a Board of Governors appointed by the government. Two of the members are appointed at the suggestion of the fee-liable licensees.

The authority has no staff of its own. Its administration is handled by another authority: the Legal, Financial and Administrative Services Agency.

By the end of 2013 the total fund capital was SEK 51 366 million (NWF, 2014). From the start of National Waste Fund in its current form in 1996 until the end of 2012, the fund had an average real rate of return of about: 5% per annum. However, during 2013, the real rate of return was negative (-0.7%).

#### *Cost estimates*

This requires the licensees to every three years submit estimates of all future costs for management and disposal of spent nuclear fuel and nuclear waste, and decommissioning. The licensee of a nuclear power reactor shall base its cost estimates on 40 years of operation.

The cost estimates are submitted to the Swedish Radiation Safety Authority (SSM) for review. SSM will for each of the reactor licensees prepare a proposal for the nuclear waste fee that the reactor licensee is to pay over the following three calendar years.

SSM will prepare a proposal:

- based on the cost estimates submitted by industry, and SSM's analyses of these;
- taking into account the specified additional costs;
- so that all expected costs, after having taken into account previous payments, are expected to be covered by the fees that the reactor licensee will pay over the remaining operating period of the reactor.

If there are special reasons, SSM might order a licence holder to submit a cost estimate earlier than three years or to submit an additional cost estimate. If a supplementary cost estimate has been submitted or if there are special reasons for doing so, SSM might propose nuclear waste fees for a period of less than three years.

#### Supervision of the overall system

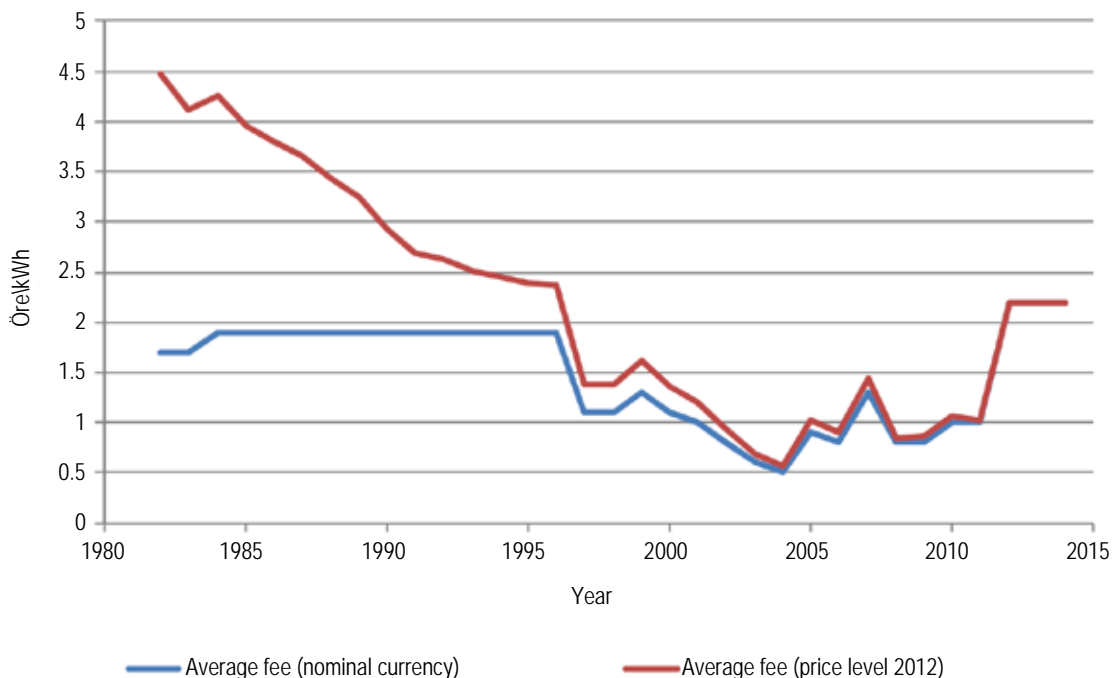
SSM reviews the cost estimates according to the Financing Act and then suggests the level of the nuclear waste fees and guarantees to the government. The government sets the fees and guarantees for the licensees of nuclear power reactors.

SSM decides on the disbursement of funds to the nuclear licensees. Furthermore, SSM has the responsibility to check that the nuclear utilities have made their payments to the fund and also to audit the disbursements.

#### Development of the waste and decommissioning fee

Figure 4.A1.2 below shows the historic development of the average annual fees to the Nuclear Waste Fund. The average fee is given in nominal currency and also adjusted for inflation to 2012 current value.

**Figure 4.A1.2: Historic development of the average annual fees to the Nuclear Waste Fund in Sweden**



Source: Holmberg et al, 2014.

In December 2014, the Swedish government agreed to proposals from the regulator that the fee be raised to an average rate of 4.0 öre per kilowatt hour (kWh) of nuclear power produced (approximately EUR 0.004/kWh) for the period 2015-2017. The reasons for the fee increase include:

- the increase in projected costs reported by the industry;
- the low rate return on the Nuclear Waste Fund assets;
- changes in the application of discount rates;



- the financing will be based on an underlying electricity production of 566 TWh instead of the 743 TWh used when the previous fee was calculated;
- the difference between the actual fee level imposed and that calculated by SSM;
- fund development and the effect of inflation.

In addition, many changes have been proposed to the financing system as the outcome of a recent review. These would, for example, change the basis for assessing liabilities and assets, allow a greater freedom for the fund to be able to invest its capital in a wider range of assets, such as equities, and make changes to some of the arrangements for government oversight of the financing system. At present, the government is considering the proposed changes and is expected to announce a decision in 2015, however for the time being the current system remains in place.

## Switzerland

The disposal of radioactive waste is based on the principle of “polluter pays”. Operators of nuclear power plants are responsible for the disposal of spent fuel elements and radioactive waste resulting from the operation of their plants, as well as from the later decommissioning and break-up of these facilities and the financing thereof.

The financing for decommissioning and disposal is secured by two independent funds, in which owners of nuclear installation are obliged to pay annual contributions. The aim of both funds is to secure the necessary financial resources for decommissioning and dismantling of retired nuclear installations, for the disposal of the resulting conventional waste (paid from the Decommissioning Fund) and for the disposal of radioactive waste and spent fuel elements after the installations have been decommissioned (paid from the Decommissioning Fund). Disposal costs that arise during operation, such as research and site selection for a deep geological repository, reprocessing of spent fuel, interim storage, purchase of transport and storage containers are not financed by the fund. They are paid continuously by the owners of nuclear installations. After the final shutdown of a nuclear installation, the outstanding cost items will be covered by the Disposal Fund. While the Decommissioning Fund exists since 1984, the Disposal Fund was established in 2000.

### *The legal basis*

The financing of the disposal of nuclear waste is regulated in the Swiss Federal Nuclear Energy Act, and the Ordinance on the Decommissioning Fund and the Waste Disposal Fund for Nuclear Installations (SEFV) regulates the specific details. Operators of nuclear power plants are responsible for the disposal of spent fuel elements and radioactive waste resulting from the operation of their plants as well as from decommissioning of these facilities. The obligation to manage and dispose of radioactive waste is met, if the radioactive waste has been transferred to a deep geological repository, the funding required for the monitoring period and the closure has been secured.

The entitlement of each owner to the two funds is equivalent to the amount paid, including capital earnings and after deduction of cost. In case the entitlement of the contributing party does not cover the cost, the concerned party has to cover the remaining cost from his own financial resources. If the financial resources are insufficient, the funds cover the remaining cost from its overall resource. Owners benefiting from this are obligated to pay additional contribution to the funds. If the beneficiary is unable to retribute, the other contributing parties and beneficiaries cover the difference through additional payments in proportion to their contributions. In case the additional payments are not economically bearable for the owners, the Federal Assembly decides if and to what extent the confederation will contribute. On the other

hand, if the funds are over financed, the party concerned may be entitled to a reimbursement under some conditions.

#### *The Ordinance*

The SEFV became legally effective in 2007. The ordinance regulates the details of the funds, such as:

- which costs are covered by the decommissioning fund and which by the waste disposal fund;
- the basis for the cost calculation/estimation;
- the obligation and duration of the contributions;
- the rates of return and inflation;
- organisation, tasks and supervision of the funds.

#### *Basis for the cost calculation/estimation*

Cost estimations are calculated and updated for each nuclear installation every five years. Before final shutdown of a nuclear installation or unforeseeable circumstances will lead to a significant change of cost, the cost estimations are also updated. The Swiss cost estimates are performed in what is known as “best estimates”. Best estimates costs are expenses based on a technical and scientific concept, in accordance with the latest knowledge available and a clear time progression of events. The estimations are also based on the Swiss Waste Management Program and, in case of the Decommissioning Fund, on an assumed lifetime of 50 years of the installations, according to the ordinance.

The amount of the contribution is based on cost estimation, the fund value at beginning of the assessment period and a mathematical model which takes into account the schedule of the working programme as well as the rate of inflation and of return.

At final shutdown of an installation, the financing for decommissioning should be secured by the Decommissioning Fund. To achieve this goal, owners of nuclear installations are obliged to pay annual contributions to the funds.

#### *Organisation, tasks and supervision of the funds*

The bodies of the funds and their tasks are described in the SEFV: the Administrative Board, the Management Board and the auditors. The Administrative Board controls and manages the funds. It decides about the Portfolio Strategy and fixes the annual contribution. The Administrative Board has established two committees for dealing with the various tasks: the Investment Committee and the Finance Committee. The duties of these committees are specified in a set of regulations issued by the Administrative Board. The task of the Management Board is to control the payment of the annual contributions and to manage the meetings of the Administrative Board and the committees.

The supervisory body is the Federal Council that appoints the members of the Administrative Board and the auditors. By approving the annual report, the Federal Council declares the discharge of the Administrative Board. The members of the Management Board and the committees are independent persons as well as operators of nuclear power plants, who are allowed maximally half of the board seats.

#### *Revision of the ordinance*

In the years 2013 and 2014, the ordinance was revised. The following main changes will come into force on 1 January 2015:

- Additional contingency:

In the last ten years, cost estimations showed a significant increase. Additionally, at the present stage of the project, there is an uncertainty of up to 30% regarding

the estimations. Therefore a contingency of 30% will be added to the cost of the estimations.

- Changes in the rates of return and inflation:

Taking into account the performance of the return rate in the past and the expected rates in the future, the new ordinance sets the rate of return to 3.5% and the rate of inflation to 1.5%. These numbers are used to calculate the nominal value of the fund at shutdown and the annual contributions. At the end of operation, the financing shall be available in the fund by the performed annual contributions. In addition, the contribution time will be extended to the end of the decommissioning activities.

#### Cost studies and contributions

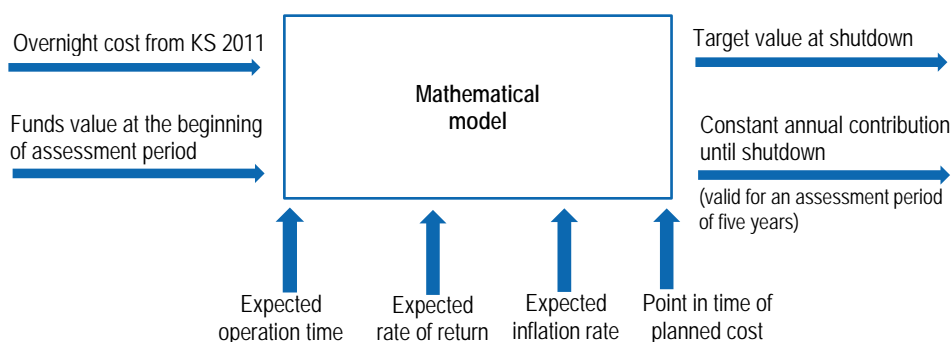
The Administrative Board assigned swissnuclear (nuclear energy section of swisselectric, the organisation of Swiss electricity grid operators) to elaborate the cost estimation for each nuclear installation based on their initial decommissioning plan. The cost studies are estimated realistically but without any additional safety reserves according to best expert understanding at current market prices (overnight costs). To calculate the annual contribution for an assessment period and the target value of the fund, a mathematical model is used taking into account (see Figure 4.A1.3):

- the overnight costs for D&D from the estimation;
- the fund value at beginning of assessment period;
- the expected operation time left with an assumed lifetime of 50 years;
- the expected rate of return and inflation rate;
- the point in time for a planned cost element.

The following example shows the contribution for one cost element. If a cost element is fixed in 2012 (i.e. to CHF 100 000) and will be incurred in 2032, this element will be CHF 180 611 ( $= 100\,000 \times 1.03^{20}$ ) due to inflation. The fund has an expected return value of 5%. At the end of operation time (2022 assumed), the funds need to have a value of CHF 110 879 ( $= 180\,611/1.05^{10}$ ) for this cost element.

The Swiss Federal Nuclear Safety Inspectorate (ENSI) reviews the decommissioning plans and the waste management programme, that are basis for the cost estimations and reports to the Management Board with recommendations for further studies. The financing aspects will be reviewed by other independent experts that are appointed by the Management Board.

**Figure 4.A1.3: Calculation of the annual contribution for an assessment period and the target value of the fund, a mathematical model is used**



Source: SFOE, 2014.

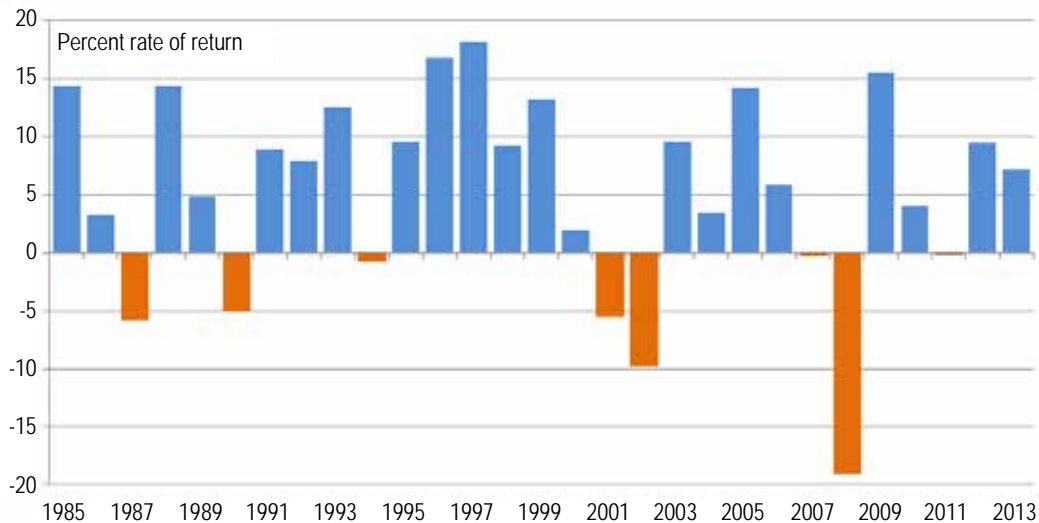
### The fund

The fund is supported by annual contributions and the rate of return. Table 4.A1.1 shows the asset classes, the policy and the lower and upper value for each asset class that is needed to ensure the return on investment. With these asset classes, the return of investment is quite volatile (Figure 4.A1.4).

**Table 4.A1.1: Asset classes, the policy and the lower and upper percentages for each asset class needed to ensure the return on investment**

Asset classes	Policy	Lower value	Upper value
Cash	0%	0%	5%
Bonds (CHF)	25%	15%	35%
Bonds FX (hedged)	15%	10%	20%
Stocks	40%	30%	50%
Real estate	10%	7%	13%
Alternative investments	10%	7%	13%
Foreign currency	48%	30%	70%

**Figure 4.A1.4: Return of investment**



Source: SFOE, 2013.

By the end of 2013, the decommissioning fund had a total value of CHF 1 697 billion. This corresponds to an excess of 1.65%.

### The United Kingdom

There are presently three financing systems for nuclear reactor decommissioning in the United Kingdom: one for older reactors (and other older facilities) owned by the Nuclear Decommissioning Authority (NDA); one for the newer reactors currently owned by EDF Energy; and one to be applied for any new nuclear reactors to be constructed in the United Kingdom.

### *Financing the decommissioning of Magnox reactors*

In 2005, ownership of all older civil nuclear facilities other than eight nuclear reactors owned by British Energy (see below), were transferred to the NDA, a government entity established under the Energy Act 2004 (HMG, 2004). Decommissioning of these facilities is being managed by NDA and will be undertaken by contractors. The decommissioning will be financed primarily through public funds.

Included in NDA's portfolio are the "Magnox" civil nuclear power stations. The Magnox stations were the first generation British nuclear power plant design, completed between 1962 and 1971, and these each comprise twin or quad units. Almost all of these reactors have been taken out of operation. At present, one unit at Wylfa, remains in service, and this unit is currently planned to continue in operation until December 2015. The total estimated lifetime cost of decommissioning the Magnox estate is currently GBP 15.4 billion (NDA, 2014).

The UK Department for Energy and Climate Change (DECC) and HM Treasury (the United Kingdom's economic and finance ministry) set the annual operational budget for NDA. The overall budget is a combination of government funding and income from NDA's commercial assets. Thus, the income from the commercial value of NDA's assets is used to offset some of the costs of the decommissioning programme. As its income-generating assets come to the end of their lives, NDA's reliance on public funds increases.

### *Financing the EDF Energy Nuclear Generation reactors*

The funding for decommissioning for the eight nuclear reactors owned by EDF Energy Nuclear Generation (EDFE) comes primarily from the Nuclear Liabilities Fund (NLF).

The NLF<sup>2</sup> was established by the UK government in 1996 to provide funding for the eventual decommissioning of the eight nuclear power stations then owned by British Energy<sup>3</sup> but currently owned by EDFE. The purpose of the fund is to provide funding to meet specific waste management costs of and the decommissioning liabilities of the eight reactors. To this end, the Nuclear Liabilities Fund has assets with a market value of GBP 8 782 million as of 31 March 2013, after deducting current liabilities (NLF, 2013). The UK government announced at the time of British Energy's restructuring in 2005 that it would fund the qualifying liabilities to the extent that they exceed all the assets of the fund.

The NLF is a company registered in Scotland and is owned by the Nuclear Trust which is a public trust established under Scottish law. The main purpose of the trust is "to protect and to preserve for the benefit of the nation the environment of the United Kingdom" by being a member of the NLF, a company with the principal object of providing "arrangements for funding the costs of decommissioning the stations" and paying for specific other uncontracted liabilities. The NLF is the trust's only asset and the purpose of the structure is to provide a secure and segregated pool of monies held for the specific purpose of decommissioning the nuclear stations. There are five trustees of the trust, of whom three are appointed by UK government and two by EDFE. They also act as the five directors of the NLF.

At its inception in 1996 the NLF<sup>4</sup> received an initial endowment from the UK government of GBP 228 million and thereafter British Energy was obliged to make quarterly contributions to the fund of initially GBP 4 million each. As a consequence of

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2. For a more detailed description of the NLF, see <http://nlf.uk.net/index.html> (accessed 22 August 2014).
  3. British Energy was created in 1996 when the more modern nuclear power plants were privatised. These included seven advanced gas-cooled reactor stations and one pressurised water reactor.
  4. Originally called the Nuclear Generation Decommissioning Fund.

the restructuring of British Energy in 2005, there were significant changes to the manner in which the decommissioning liabilities of the stations were to be funded and also for the funding of specific liabilities. Under current arrangements, EDFE makes small quarterly payments into the fund. However, the fund's growth is predominantly through its investments.

Payments from the fund to meet qualifying liabilities can only be made by application by EDFE to the NDA. The role of the NDA here is limited to that of an agent for the UK government/secretary of state. The NDA administers the Liabilities Management Agreements, including the approval of NLF payments for decommissioning, waste management, and the discharge of qualifying uncontracted liabilities. EDFE remains responsible for the decommissioning of the existing nuclear power station sites although there is provision for the decommissioning responsibility to transfer to the NDA at any point following end of generation at the discretion of government. A fund review may be initiated in January 2015 and at each five-year anniversary thereafter.

#### *Financing the decommissioning of new reactors*

A third type of arrangement will apply for financing of decommissioning of any new nuclear power stations to be built in the United Kingdom. Operators wishing to construct new nuclear reactors in the United Kingdom are required to establish secure financing arrangements to meet the full costs of decommissioning and their full share of waste management and disposal costs of these reactors. Operators of new nuclear power stations are required to have a Funded Decommissioning Programme (FDP) approved by the Secretary of State for Energy and Climate Change (Secretary of State) before construction of a new nuclear power station begins.

The Secretary of State has published guidance about the preparation, content, modification and implementation of an FDP (DECC, 2011). This guidance sets out principles that the Secretary of State will expect to see satisfied in the FDP, and information on ways in which an operator might satisfy those principles. The guidance includes a section concerning the arrangements for decommissioning the site and an associated prudent cost estimate, the so-called "Decommissioning and Waste Management Plan" (DWMP). It also includes a section addressing the financial arrangements for funding decommissioning, the so-called "Funding Arrangements Plan" (FAP). The FAP is that part of the FDP which addresses the financial arrangements for covering the costs of decommissioning and waste management, as required under the Energy Act 2008 (HMG, 2008). However, it is not intended that the guidance be unduly prescriptive as to the legal structure and administrative arrangements for the fund, nor does the guidance set out the relative advantages and disadvantages of possible vehicles that may be capable of discharging the various functions of the fund in achieving the objective of the FDP regime and meeting the guiding factors for approval.

#### *The objective of the FDP*

The objective of the FDP regime is to ensure that operators make prudent provision for:

- the full costs of decommissioning their installations;
- their full share of the costs of safely and securely managing and disposing of their waste;
- that in doing so the risk of recourse to public funds is remote (the objective).

The objective applies to the FDP regime as a whole.

#### *Approval of the FDP*

When considering whether to approve an FDP, the Secretary of State will consider whether it satisfies the following guiding factors, namely that the FDP:

- provides a transparent structure with clear divisions of roles and responsibilities;

- contains realistic, clearly defined and achievable plans for decommissioning, waste management and waste disposal (via the DWMP);
- contains robust cost estimates which take due account of risk and uncertainty (also via the DWMP);
- is a durable arrangement;
- sets out a fund structure that demonstrates: i) independence of the fund; ii) measures to ensure sufficiency of the fund; iii) restrictions on the use of fund assets; and iv) insolvency remoteness.

The guidelines state that the FAP should set out the operator's detailed arrangements for one or more funds to deliver sufficient assets to meet the estimated costs of carrying out the waste and decommissioning plans.<sup>5</sup> In doing so, the FAP should set out details for establishing, contributing to, maintaining, managing, administering, and winding up the fund and for making disbursements from it, together with all or any other forms of additional security to address risks such as the insufficiency of the fund.

Any structure proposed must ensure at all times the independence of the fund from the operator and protection from claims by the operator, other than where those claims are in accordance with the FDP. The fund entity and the fund assets must also be protected from the operator's creditors in the event of the operator's insolvency. Ensuring that the fund is a legally separate entity from the operator and that the fund does not owe any obligations directly to any creditors of the operator would assist in meeting this requirement.

An operator may decide to create a single fund, or establish separate funds for i) the operator's decommissioning and waste management costs and ii) the operator's waste disposal costs. In either case, there must be transparency, and separate accounting and reporting of the two sets of liabilities. A fund may be set up for each new nuclear power station or for a fleet of stations where they are under the same ownership. Where a fund is set up for a fleet of stations, separate and transparent accounting of the liabilities and the apportionment of assets for each site will be necessary.

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5. There is a specific definition of which costs must be covered.

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## Chapter 5. Conclusions and recommendations

With the average age of the worldwide nuclear power reactor fleet reaching 30 years in 2015, decommissioning activities are set to increase in the coming decades, giving rise to a considerable amount of work, and creating a sizeable and competitive market. According to a recent NEA study (2013a), the United States Department of Energy has nuclear liabilities of the order of USD 35 billion and has been spending around USD 6 billion per year on decommissioning. The current operating reactor fleet in the United States of 100 reactors represents a future liability of around USD 47 billion dollars if the average decommissioning cost per reactor is maintained at USD 470 million. France has combined future liabilities – from EDF, AREVA and the CEA – estimated at around USD 80 billion. The Nuclear Decommissioning Authority (NDA) in the United Kingdom has 2.2% discounted liabilities of USD 80 billion, covering a broad range of UK nuclear legacies, and it is spending around USD 5 billion per year on decommissioning. Future liabilities for the operating UK fleet are estimated at around USD 17 billion. A great deal of resources and capital will therefore be spent in the coming decades to safely decommission nuclear facilities, commercial nuclear power plants and other facilities.

In recent years, the subject of decommissioning costs and funding has been gaining attention, be it from industry, regulators, governments or the public. One issue of particular interest is whether cost estimates are realistic, embrace all the necessary aspects of decommissioning activities, and ensure that the necessary funds are set aside and available at the time of implementation. Cost estimates should begin to benefit from the return of experience of actual decommissioning activities in the future. Until now, only a limited number of power reactors have been fully decommissioned and most of these cases could be considered as first-of-a-kind. It is therefore essential that technologies and innovations are continuously developed and implemented so as to ensure that decommissioning is accomplished as safely, cost effectively and as expediently as possible (NEA, 2013a).

Heedful of this growing interest around decommissioning, the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) decided to launch a new study that would build upon former reports on the subject (NEA, 2003, 1991, 1986). The 2003 report in particular, *Decommissioning of Nuclear Power Plants: Policies, Strategies and Costs*, was the result of an effective data collection process, with 53 data points covering 24 countries and a broad range of nuclear reactor technologies. All data were cost estimates, performed on an ad hoc basis with different methodologies. Some ranges of costs were extracted from the survey for the different technologies, providing a tentative estimate of decommissioning costs, but with many unknowns and uncertainties due to the varying boundary conditions and estimation methodologies.

Although a limited number of nuclear power reactors have been effectively decommissioned since 2003, cost estimates have been and are being further developed for more operating reactors and a standardised method has been established to look at decommissioning costs – the International Structure for Decommissioning Costs (ISDC) (NEA, 2012). The analysis of decommissioning costs and funding was therefore included in the NEA 2013-2014 Programme of Work.

This report is the result of a two and a half years of activity by the Ad Hoc Expert Group on Costs of Decommissioning (COSTSDEC) set up in 2013. Members of COSTSDEC have brought their expertise on a wide range of issues in the field of decommissioning, including cost structure, cost estimation, financing mechanisms, national policies and other strategic aspects.

The principal objectives of this study were outlined in the “NDC Final Programme of Work for 2013-2014” (NEA, 2013b) as follows:

- To gather and assess available knowledge on completed decommissioning projects from different countries and, to the extent possible, to consider how related cost estimates have varied over time; how uncertainties were taken into account and what contingencies were built into the planning; and to determine the key factors driving costs.
- To review economic methodologies and related aspects for the management of nuclear power plant (NPP) decommissioning in NEA member countries, and if possible in selected other countries, to review funding mechanisms in place or under consideration and how these funds are managed, including the extent to which they have increased.
- To consider a selected set of decommissioning programmes, either ongoing or prospective, to perform a review of related cost estimates and to define, to the extent possible, cost categories and estimates for high-level processes with the aim of identifying broad cost ranges.

The work of COSTSDEC was to be performed in close collaboration with the Decommissioning Cost Estimation Group (DCEG) operating under the remit of the NEA Radioactive Waste Management Committee (RWMC). It was also to build upon and complement the work undertaken by the European Union Decommissioning Funding Group (EU-DFG), which has not met over the last two years.

Along the same lines as the previous report in 2003, an NEA questionnaire was developed, which more closely followed the ISDC format in this case. The questionnaire had three main parts:

- *Part I: National information*  
National decommissioning policies and strategies, regulatory and licensing issues and financial arrangements at the national level for the funding of decommissioning (e.g. the collection of funds, management of funds).
- *Part II: Reactor level information*  
Unit, site and/or fleet decommissioning strategies and data.
- *Part III: Decommissioning costs*  
Both actual decommissioning activities (real costs, if available), and cost estimates, using tables based on the two first levels of aggregation of the ISDC format.

The questionnaire was to be complemented by additional specific case studies provided by COSTSDEC members. The case studies would provide more insight into factors affecting the costs of decommissioning based on practical experiences of actual decommissioning activities or cost estimates – the evolution of cost estimates over time, for example, a comparison of real costs incurred with estimations or uncertainties and contingencies.

A total of 16 NEA member countries provided qualitative information in reply to Part I of the questionnaire. However, compared to the previous exercise (NEA, 2003), the collection of quantitative information via the Parts II and III has been limited. Indeed only ten usable observations were received (four PWRs, three BWRs, two VVERs, and the Magnox fleet), from seven member countries, despite repeated calls at the occasion of the COSTSDEC meetings. From these ten inputs, not all provided the full level of details

requested by the ISDC format tables. It should also be noted that no quantitative data was received from the United States and Germany, the two countries where decommissioning activity has already taken place, meaning that inputs received via the questionnaire focused essentially on cost estimates. There may be different reasons for such difficulties. For example, a real market for decommissioning activities is developing, with industrial players building their expertise and techniques. These players are seeking to develop their market shares in a more and more competitive environment. Getting detailed data beyond the limited national reporting requirements is therefore challenging.

A second reason may be associated with some tensions between utilities and their national authorities, which is not conducive to the transparent provision of financially sensitive information, in particular in countries where anticipated nuclear phase-out has been decided. Such a decision could have an influence on the financial aspects of such a legacy.

A third reason is related to the ISDC format itself. While most would recognise the value of having a common “template” to facilitate dialogue and exchanges, the ISDC has not (yet) been used for cost estimations per se. Cost estimations are still made using ad hoc (national or site-specific) methods, which means that the data provided via the questionnaire were the result of a time-consuming conversion effort by the respondents. This process of conversion explains some of the limitations when making comparisons, since what was understood under the ISDC items could differ somewhat from national or site-specific methods for cost estimations.

Six case studies were provided during the course of the project (Dutch Dodewaard, Finnish Loviisa, Slovak Bohunice V1, Spanish José Cabrera, Swiss fleet and generic PWR, UK Magnox fleet). With these case studies, lessons were drawn on the evolution of cost estimations, and factors underlying apparent differences or discrepancies between the corresponding data sets were revealed.

To partially overcome the lack of quantitative data, COSTSDEC decided to integrate additional information publicly available for a large number of US plants, more specifically from a Pacific Northwest National Laboratories (PNNL) report prepared in 2011 for the US Nuclear Regulatory Commission (NRC) (PNNL, 2011). While the objective of the PNNL report was mainly to verify the validity of the NRC decommissioning cost estimation formula, it contained quantitative data that was considered useful for the COSTSDEC report. There were nevertheless limitations.

The data were provided using a different format than the ISDC format (work breakdown structure - WBS). An NEA consultant converted the WBS data into the ISDC format and analysed how far aggregation into main cost categories using both methods was acceptable to ensure the proper integration of the PNNL data into the report.

In addition, US decommissioning cost estimates are based on the Thomas LaGuardia (TLG) methodology. While it may facilitate comparison on the US side, it could introduce a bias when combining the large quantity of US data with the very limited number of data collected via the NEA questionnaire, which were of diverse origin with diverse underlying methodologies.

A third reason is that most of the data in the PNNL report is for cost estimations. Only four (three usable for the purpose of this report) actual decommissioning projects are analysed, and there is no detailed analysis of how the actual costs evolved from the estimations when they were initially made for these reactors.

Keeping all these factors in mind - the scarcity of the data, the diversity of the decommissioning policies and strategies, the large scattering of reactor types/ratings/single vs multi-units, the non-consistent use of the ISDC structure leading to different interpretations of the elements reflecting national costing methods, the limits of the translation of US numbers into the ISDC format and their use - COSTSDEC decided to present the two data sets (from the NEA questionnaire and the PNNL report) in

separate sections of the report, while maintaining the same approach. It should be noted that the limited data on actual costs of decommissioning available today are, for the most part, of a “first-of-a-kind” nature and may not be representative of costs that will be incurred when the bulk of decommissioning activities will take place. Therefore, actual costs and cost estimations have to be examined separately. Many factors and uncertainties are at play that require this separation.

In spite of the aforementioned limitations, the project outcomes nevertheless contribute to a better understanding of the issues related to decommissioning costs and financing and the challenges associated with these issues. Some useful qualitative recommendations that may be drawn from these outcomes are listed below.

The cost of decommissioning is influenced by several factors or drivers, which must be carefully managed so as to avoid escalation and overruns. Useful recommendations on costs may be provided for each of these drivers.

- *Decommissioning policy and strategy*  
A global decommissioning policy and strategy should be defined as soon as possible, ideally when building a plant. This will allow for a sharing of responsibilities between the diverse actors and a streamlining the process of cost estimation and its revision. It should also define the legal framework and modes of operation for the collection and use of the decommissioning fund, ensuring that a legacy (in particular, costs) is not left on the shoulders of future generations.
- *Roles and duties of the diverse actors, and the regulatory framework*  
The regulatory framework needs to be established with clarity and anticipation. While changes in the regulatory framework may be necessary to reflect natural evolution, long-term consistency needs to be ensured so that actors can fulfil their roles and duties while taking full responsibility for the costs incurred.
- *Planning and preparation phase prior to decommissioning, and site characterisation*  
The costs of decommissioning will be influenced by the nature and level of radioactivity of materials being handled. It is therefore important to have a good understanding of these factors while making the cost estimate. Good site characterisation is also a vital precursor before actual decommissioning can start, and helps to avoid uncontrolled cost escalations during implementation.
- *Management of spent fuel and operational waste*  
The cost of spent fuel and operational waste management may not be seen as decommissioning costs per se and are thus often not included in decommissioning cost estimates. Clarity is needed in terms of what is included where and how all costs are covered.
- *Dismantling operations and related waste management*  
The effective planning and management of dismantling operations and corresponding waste management can have a major impact on actual costs. Waste management means and routes in particular can have a strong influence on these costs during the decommissioning phases. As the return of experience becomes more and more available, it should be used to the maximum possible extent. Project management needs to be flexible enough to integrate unexpected factors when they appear, while minimising costs.
- *Prospects for waste (final) disposal, including spent fuel*  
Final disposal of radioactive waste, in particular intermediate-level waste (ILW) and high-level waste (HLW) (including spent fuel in the case of open fuel cycles), is usually not perceived as part of decommissioning costs. It is therefore vital to ensure clarity in terms of how the ultimate radioactive waste will be handled, and how strategies and processes for the long-term funding of this legacy are defined.

For low-level waste (LLW), the clearance level is critical, and should to be clearly defined and thoroughly implemented.

- *Final stage of decommissioning, de-licensing, site restoration and reuse*  
Such factors can have an impact on the costs of decommissioning, in particular on what is included in these costs, and thus clarity is also needed in these areas.
- *Manpower management, contractors*  
The cost of manpower would appear to be the main contributor to decommissioning costs, whether for preparation activities, project management, implementation of decommissioning activities, or waste management and surveillance. A search for efficiency in this regard is therefore important, particularly in relation to the re-employment of former operations staff and/or recourse to contractors for specific activities. Lessons learnt from return experience will be useful.
- *Risks management, uncertainties and contingencies*  
Any industrial activity taking place over a period of years has a certain degree of uncertainty and requires risk management. It will be important in the future to have a much better understanding of the uncertainties affecting decommissioning activities and how to best take them into account in cost estimations. The ongoing NEA/IAEA project on this subject is expected to shed some light on this subject.

Beyond cost estimates and figures, ensuring that funding is available for the time when the actual decommissioning process takes place is a critical issue. This study demonstrates that a large diversity of approaches exists between countries and even within countries, although some general recommendations on funding can nonetheless be extracted.

- *Funding policy and strategy*  
The requirements for the financing of nuclear power plant decommissioning projects needs to be formally established according to the national legal system. There are considerable variations between countries in terms of the details of these formal legal requirements. In many cases, the systems currently in place have incorporated features intended to address deficiencies identified in earlier years, with countries introducing requirements for systematic reviews and for the various parties to be involved.
- *Roles and duties of the diverse actors, regulatory framework*  
Operators of nuclear power plants are generally responsible for financing the costs of decommissioning, with arrangements typically being based on the revenues earned from the sales of the electricity generated. Exact financing mechanisms vary from country to country but these must be clearly defined and associated with the regulatory framework. Exceptions to the general pattern include financing arrangements for some of the oldest facilities, or where there have been deficits arising from historical arrangements.
- *“During the plant operation” phase, prior to decommissioning activities: planning, collecting and securing the funding; updating the cost estimates; monitoring and adapting to financial conditions and financial risk management*  
The completeness, accuracy and regular updating of decommissioning cost estimates are important prerequisites for establishing adequate funds for future decommissioning.
- *“After the plant operation” phase, during decommissioning: disbursement and long-term management of the funds, and financial and technical risk management*  
Ensuring the availability of the necessary funds at the appropriate time is one of the cornerstones of a decommissioning financing system. Accordingly, the identification of risks and uncertainties in funding arrangements, and the

implementation of appropriate measures to manage them, are essential elements of national decommissioning fund management and oversight. Decommissioning funding arrangements may still be vulnerable to earlier than expected plant closure or to the failure of a fund to reach a sufficient level of financing to cover the actual costs of decommissioning.

- *What if the funds are not enough? Management of liabilities, evaluation of the risk and contingency planning*

States must put in place mechanisms to regularly review changes to calculated liabilities, fund growth and other changes to market conditions, as well as the timing of decommissioning in order to reduce the risks of inadequate decommissioning funding. The details of these national systems vary considerably, reflecting both current needs and the historical development of the systems. Special attention should be given to mechanisms mitigating the risks and uncertainties for projects which are “funded” years or even decades before their real implementation.

Work performed by COSTSDEC over the past two and half years of this study has led to the general conclusion that enhancing transparency around decommissioning costs and financing is fundamental to overcome difficulties in collecting enough detailed and reliable quantitative data, both in terms of actual data from real finished or ongoing decommissioning projects and data for cost estimates for future projects. The two sets of data should be treated separately, as lessons must be drawn from the finished projects to better understand cost drivers, which help define priority areas and uncertainties for cost estimates. In case the diversity of boundary conditions does not allow real benchmarking of decommissioning costs from one country to another, comparisons might nevertheless be possible for specific activity or project components.

As this study has shown, in order to improve data collection, it must occur in confidence when related to specific detailed data, but it also must be organised so as to draw lessons, and make conclusions and recommendations from the generic figures. The Information System for Occupational Exposure (ISOE) may be used as an example that could be adapted for the purpose of collecting sensitive information on decommissioning costs and funding. It will be vital that the standard ISDC format be used for the collection of this information, associated with additional detailed information on the boundary conditions for further analysis of the data.

Future studies could benefit from effective collaboration with the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) and the RWMC (in particular the DCEG) in identifying the critical data needed for such a study, and the assessment framework for conducting the analysis. A “virtual mean case” could be created from data assembled in this way. This mean case would be globally representative of the generic figures and information, and could ultimately lead to important conclusions and recommendations. Sensitivity analyses could be performed around this mean case to illustrate the impact of the main factors influencing costs, as derived from the study of cost drivers extracted from actual finished or ongoing decommissioning projects. Such a method is already used by the IAEA for the cost of decommissioning of research reactors (data analysis and collection for costing of research reactor decommissioning – DACCORD Project).

One of the recommendations of COSTSDEC is to investigate the launching of such a process within a timeframe of three years following the publication of this report, if indeed there is sufficient willingness on the side of the main actors to share information on decommissioning costs and funding (actual and estimates), and to proceed with a shared analysis. This willingness will be demonstrated by the number of participants who would be prepared to effectively engage in the process.

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## **PART II**

### **Case studies**

**Finland, the Netherlands, the Slovak Republic, Spain,  
Switzerland and the United Kingdom**

(as provided by COSTSDEC participants)



## **Chapter 6. Case study of Finland: Decommissioning of the Loviisa nuclear power plant**

### **6.1. Historical background**

The first unit of the Loviisa nuclear power plant (NPP), Loviisa 1 (LO1), was commissioned in 1977 and the second one, Loviisa 2 (LO2), in 1980. The originally designed technical life of the Loviisa power plant was 30 years. On the basis of the operating experience gathered at the plant, the preventive maintenance performed, and the modernisation and power upgrading project carried out in 1995-1998, the operational life has been extended to 50 years. Towards the end of the operational life it has to be assessed whether continued operation of the power plant will still be justifiable, considering the technical, safety and economic aspects, or whether the plant will be decommissioned. Decommissioning means that the systems, components and structures that contain radioactive substances will be dismantled and removed from the plant. Decommissioning plans have been made and updated regularly every five to six years since year 1983. The latest update was completed 2012.

### **6.2. Strategy**

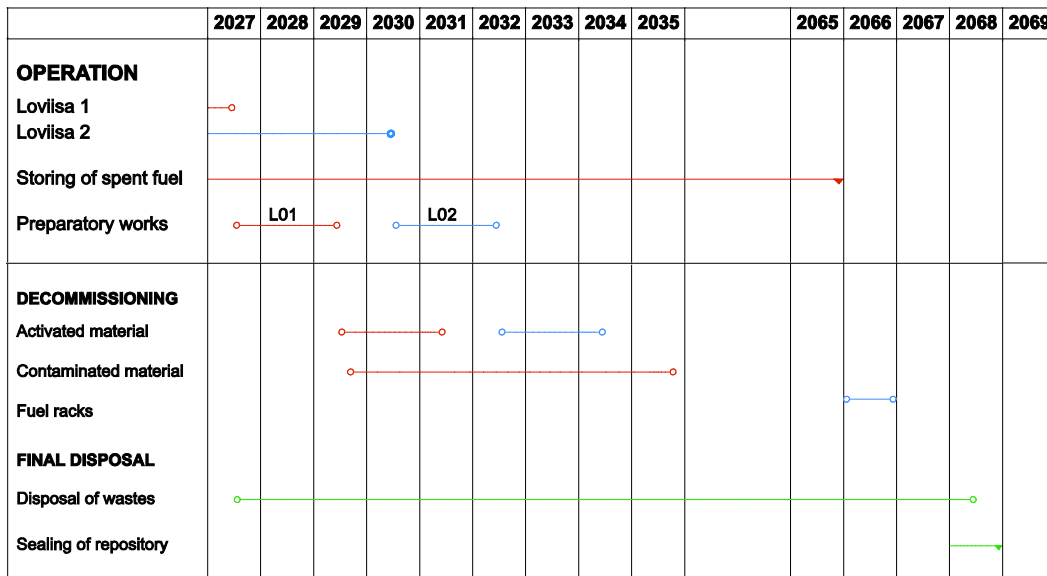
Current decommissioning plan is based on immediate dismantling after the shutdown of the power plant. The preparation of the power plant systems for dismantlement and the actual decommissioning work will be made under supervision of the experienced operating personnel of the plant. The only exceptions to immediate dismantling are the spent fuel storage, liquid waste storage and the solidification plant, which will be decommissioned after all the spent fuel has been transported away from the site.

### **6.3. Decommissioning schedule/issues and approaches**

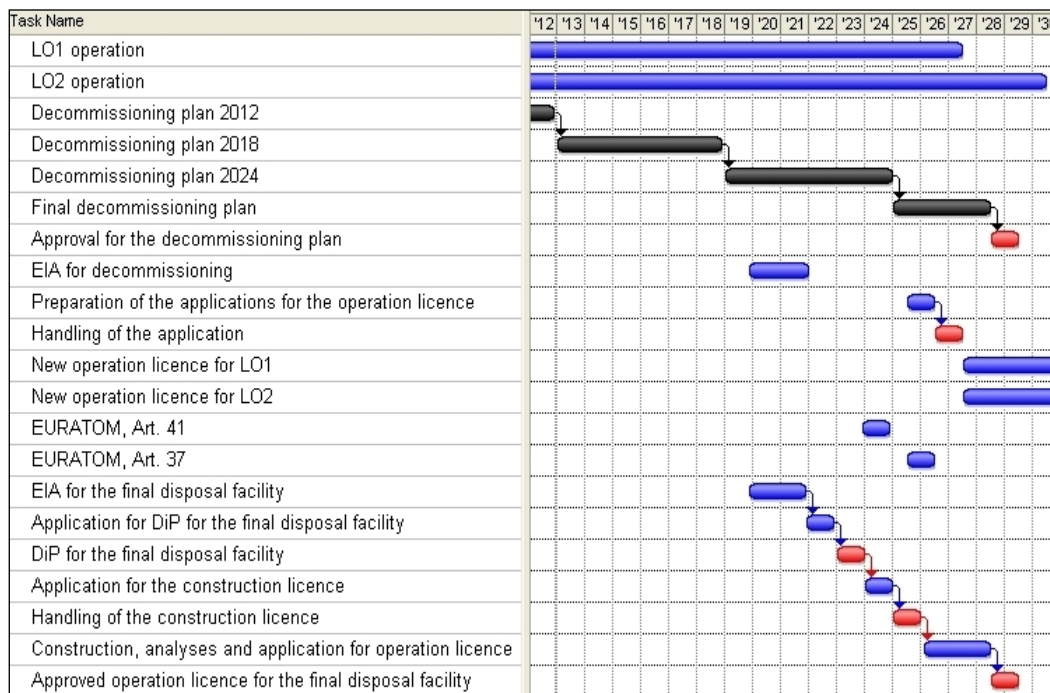
The overall schedule for the decommissioning is shown in Figure 6.1. It is based on a power plant unit operating period of 50 years. The shutdown of the power plant will be followed by a two-year preparatory phase before the actual dismantling work begins. The work to be carried out during the preparatory phase includes transfer of the spent fuel from the pools of the reactor building to the spent fuel storages, flushing and decontamination of the process systems (removal of radioactive deposits, etc. using a chemical solution) and construction of the necessary hauling openings for the transfer of large components.

The licensing process for decommissioning and extension of the low- and intermediate-level waste repository for decommissioning waste will start early 2020s (see Figure 6.2). The decommissioning work will begin in 2027 with a two-year long preparatory phase for plant unit 1. The preparatory phase for plant unit 2 is designed to start in 2030. Before that the repository for low- and intermediate-level waste at Loviisa site will be expanded for decommissioning waste. The dismantling work will begin in 2029 for plant unit 1 and 2032 for plant unit 2 with the reactor pressure vessel and other activated material and continue with the dismantling of the primary circuit and other contaminated systems. This phase will be finished in 2035.

**Figure 6.1: Overall schedule for the decommissioning of the Loviisa nuclear power plant**



**Figure 6.2: Licensing schedule for the decommissioning of the Loviisa nuclear power plant**



The last step will be to dismantle the spent fuel storage, the liquid waste storage and the liquid waste solidification plant, which have been made independent. Together with closure of the repository this last step will be done in 2066-2068.

The actual dismantling work takes about 11 years. The time period from 2036 to 2065 goes for the storage (and cooling) of spent fuel on the Loviisa site, before it is transferred to Olkiluoto site for final disposal, and this period is not regarded as part of the decommissioning plan.

## 6.4. Boundary conditions

In the decommissioning all radioactive material will be dismantled to the free clearance levels given by the authorities and disposed of. Later, the non-radioactive parts will be dismantled and the site will be released for industrial use, for example for power generation. Dismantling of these non-radioactive parts is, however, not a part of the decommissioning plan. The potential construction of a new nuclear power plant unit to Loviisa site has, however, not been taken into account in this plan.

The decommissioning plan of the Loviisa NPP is based on the following basic assumptions:

- commercial operation of the power plant units will last for 50 years;
- equilibrium load scheme with 4.37% enriched fuel;
- spent nuclear fuel will be stored at the power plant site for 35 years after the termination of the power plant's commercial operation;
- reactor pressure vessels with their internals will be removed in one piece and the pressure vessels will be used as a package for activated components;
- all the activated and contaminated material will be dismantled up to the nuclide specific activity concentrations defined by the Finnish nuclear regulatory authorities (clearance of nuclear waste and decommissioned nuclear facilities, Finnish Regulatory Guide YVL 8.2);
- essential decommissioning measures will be optimised with regard to radiological protection (the "as low as reasonably achievable" [ALARA] principle);
- decommissioning waste will be disposed of in the facilities to be built to the extension of the existing repository for operational waste (low- and intermediate-level radioactive waste [LILW] repository);
- dismantlement of the facilities to be made independent (spent fuel storages, liquid waste storage, the cementation-based solidification plant) and closure of the waste repository will be taken into account;
- technical and economic assessments are based on the technology employed and the procedures followed at present;
- potential construction of new power plant units at the Loviisa site have not been taken into account.

## 6.5. Radioactive waste features (e.g. volumes and activity) and management strategy

The decommissioning waste can be divided into two categories: activated and contaminated waste.

The reactor pressure vessels and their activated internals will be disposed of as such. The shielding elements will be put in the reactor pressure vessel in place of the fuel assemblies. The rest of activated material will be cut into pieces and packed into concrete and wooden containers of different types. Table 6.1 shows the weights and volumes of the packed activated decommissioning waste.

**Table 6.1: Amount of the activated decommissioning waste (LO1 and LO2)**

Component/construction	Weight without containers, tonnes	Volume when packed, m <sup>3</sup>
Reactor pressure vessel, internals and shielding elements	914	1 484
Control rod absorbers, intermediate rods, etc.	70	502
Thermal insulation plates, biological shield and activated floor in steam generator (SG) rooms	1 760	2 337
Total	2 744	4 323

The contaminated components of the primary circuit, the steam generators, pressurisers and bubblers will be disposed of as whole components without cutting or packaging them. With regard to the components of the auxiliary systems, the deaerators and evaporators will also be disposed of as whole components without being cut into small pieces. Other waste is packed into concrete and wooden containers. The packaging of all contaminated material will require 746 concrete containers, and 1 571 wooden boxes and 480 drums (200 litres). The weights and volumes of contaminated material are shown in Table 6.2.

**Table 6.2: Amount of the contaminated decommissioning waste (LO1 and LO2)**

Site	Weight without containers, tonnes	Volume when packed, m <sup>3</sup>
Reactor buildings		
Process systems	4 400	11 558
Constructions	9 834	7 363
Auxiliary buildings		
Process systems	960	2 688
Constructions	55	74
Spent fuel storages		
Process systems	346	1 200
Constructions	81	125
Waste buildings		
Process systems	148	443
Constructions	20	19
Laboratory		
Constructions	6	6
Total	15 850	23 476

During the power plant operation, similar maintenance waste and liquid waste to be solidified will also accumulate during the operation and maintenance measures linked with the decommissioning and the cleaning. The maintenance waste that accumulates during the decommissioning will be packed into steel drums of 200 litres each and the solidified waste into concrete drums (internal volume 1 m<sup>3</sup> and outer volume of the drum 1.73 m<sup>3</sup>). The volume of this waste (when packed) has been estimated at 2 080 m<sup>3</sup>.

The total activity and the main isotopes of the activated decommissioning waste are presented in Table 6.3. The most of the activity is in the reactor internals and shielding

elements. These components will be packed inside the reactor pressure vessel for disposal.

**Table 6.3: Total activities and main isotopes for activated waste items**

Waste items	Total activity (LO1 + LO2), TBq @ t = 2 a	Main isotopes
Reactor pressure vessels	560 + 560	Co-60, Ni-63, Ni-59, Fe-55, C-14
Reactor internals	33 085 + 33 085	
Shielding elements	61 800 + 61 800	
Control rod absorbers	115 + 115	
Dry silo (intermediate rods, core instruments, material samples etc.)	1 093 + 1 093	
Biological shields and thermal insulations	55 + 55	Co-60, Ni-63, Ni-59, Fe-55, C-14, Eu-152, H-3
Floors of the steam generator compartments	< 0.002 + 0.002	Eu-152, Co-60, Fe-55, H-3
Total	193 000	

## 6.6. Spent nuclear fuel management

At the Loviisa power plant, spent fuel management was previously based on the transport of spent fuel to the Soviet Union/Russia after storage of five years at the plant. Since the cessation of spent fuel exports from the Loviisa NPP, it is now stored at the power plant for 35 years after the shutdown to be disposed of in a disposal facility to be constructed in Olkiluoto, Finland.

Spent nuclear fuel management is not included in the decommissioning plan except the decommissioning of spent fuel storage. During decommissioning there is needed some work to make interim spent fuel storage independent of power plant processes. These costs are not part of costs in decommissioning plan.

## 6.7. Project management/organisation

The licensing process for decommissioning and decommissioning waste repository extension will be done by Fortum Company personnel with power plant's personnel involved in the work. Consultants and subcontractors will be used, for example, for the construction of the repository extension.

The general principle in the implementation of the decommissioning project is that the power plant's own personnel will be responsible for project administration linked with the decommissioning, the planning work, operation of the necessary processes and certain decommissioning tasks that require good knowledge of the plant and particular expertise. Other clearly definable tasks linked with the decommissioning will be contracted out separately to subcontractors.

As the decommissioning progresses, the operating organisation of the Loviisa power plant will change in stages to become purely responsible for decommissioning. When the preparatory phase of the decommissioning of Loviisa 1 begins, Loviisa 2 continues to be in full-scale production operation. The organisation of the Loviisa 1 preparatory phase will be mainly formed from the operating personnel of Loviisa 1. The organisation of the preparatory phase will be responsible for the following tasks among other things:

- operation and maintenance of the necessary process systems;
- treatment of the maintenance waste and treatment and solidification of the liquid waste;

- dismantling of the reactor internals and transfers of the spent fuel to the interim stores;
- decontamination of the primary circuit;
- clearance of the segment area;
- radiological protection;
- accounting and office services;
- accommodation services.

The strength of the organisation required for the preparatory phase has been estimated at 189 personnel. Some of the people will be in charge of tasks linked with both the operation of Loviisa 2 and preparations for the decommissioning of Loviisa 1.

In the preparatory phase, the most important contracts to be carried out by subcontractors will include the construction of the access ramp outside the reactor buildings, construction of the packaging and cutting station for the decommissioning waste, and construction of the repository.

When the actual decommissioning of Loviisa 1 begins, the organisation will be changed so as to meet the requirements set by the decommissioning process. The tasks of the power plant's own decommissioning organisation will include, for instance, the following:

- planning of the decommissioning measures;
- supervision of and guidance for the contractors concerning the detachment and treatment of activated and contaminated material;
- operation and maintenance of the necessary process systems;
- storage and transports of the spent fuel, and related safety arrangements;
- radiological protection;
- measurements for decommissioning and free releasing waste;
- transports and final disposal of the decommissioning wastes;
- accounting and office services;
- accommodation services.

The strength of the power plant's own personnel required for the decommissioning phase has been estimated at 156 people. In the beginning some of the people will be in charge of tasks linked with both the decommissioning of Loviisa 1 and the operation and subsequently the decommissioning of Loviisa 2.

In the decommissioning phase, the contracts to be carried out by subcontractors will include the dismantling, cutting and packaging of the process systems and constructions that contain radioactive substances, and the necessary cleaning.

Upon termination of the operation of Loviisa 2, the changing of the operating organisation into becoming the decommissioning organisation will be similar to the process at Loviisa 1. The guarding of the plant has been planned to be included in the decommissioning operations from the shutdown of Loviisa 2.

Table 6.4 shows the total strength of the decommissioning staff over the various years. The spent fuel will be stored at the plant site for 35 years after the shutdown of the power plant.



**Table 6.4: Total workload of the decommissioning staff in various years**

Years after the shutdown of Loviisa 1	Power plant's own organisation, man-years	Workload of the subcontractors, man-years
1	156	29
2	156	33
3	135	101
4	297	82
5	297	130
6	141	107
7	141	82
8	141	130
9	18	6
39	71	279
40	71	242
41	71	39
Total	1 695	1 260

The maximum strength of the decommissioning staff will be almost 430 people. Three distinct peaks can be recognised in the manpower demand. They will occur at the beginning of the preparatory phase of Loviisa 2, the launching of the actual decommissioning of Loviisa 2, and the dismantling of the contaminated auxiliary systems after all spent fuel has been taken away from the plant.

The amount of work required for the decommissioning of the Loviisa power plant will total about 2 955 person-years, of which the power plant's own personnel will account for about 1 695 man-years and the contractors for about 1 260 man-years.

After the first phase for decommissioning from 2027 to 2035, the time goes for cooling the spent nuclear fuel, maintenance for final repository and securing the area. The second phase for decommissioning is to dismantle the spent fuel storage and the waste solidification plant. Together with sealing of the repository this phase will be done in 2066-2068. The years between these two phases are not included in the decommissioning plan.

## 6.8. Site remediation

Site Remediation is not included in the decommissioning plan but in a separate non-radioactive parts demolition memo. The site is planned to be in industrial use after decommissioning.

## 6.9. Variation of cost estimates over time

Decommissioning cost estimates have been updated every five to six years since 1980s. Total costs in various updates (without 10% contingency) are presented below in nominal values both in Finnish marks and in euros (Table 6.5).

**Table 6.5: Development of decommissioning cost estimates for Loviisa NPP (two VVER-440 plant units) in nominal values**

1987	720 000 kmk / 5 946 =	EUR 121 090 k
1993	895 986 kmk / 5 946 =	EUR 150 687 k
1999	1 015 309 kmk / 5 946 =	EUR 170 755 k
2003		EUR 196 723 k
2008		EUR 283 335 k
2012		EUR 326 437 k

kmk = Finnish Devises: Kimmenem Markkaa.

The conversion is made using an index which is a combination of development of salaries (50%) and construction costs (50%) (Table 6.6).

**Table 6.6: Combined index of development of salaries (50%) and construction costs (50%) in Finland**

1987	5.8%
1988	7.8%
1989	8.4%
1990	8.1%
1991	4.3%
1992	0.1%
1993	0.5%
1994	1.8%
1995	3.0%
1996	1.7%
1997	2.3%
1998	2.9%
1999	2.1%
2000	3.5%
2001	3.8%
2002	2.4%
2003	3.0%
2004	3.2%
2005	3.8%
2006	3.4%
2007	4.4%
2008	4.9%
2009	1.8%
2010	2.0%
2011	3.0%
2012	3.1%

Decommissioning costs in 2012 year-end money (multiplied by above index) are presented below in Table 6.7.

**Table 6.7: Decommissioning costs in 2012 year-end money in various decommissioning plans, and same amounts with 10% contingencies**

	Without contingency	With 10% contingency
1987	EUR 278 793 k	EUR 306 672 k
1993	EUR 261 752 k	EUR 287 928 k
1998	EUR 258 801 k	EUR 284 681 k
2003	EUR 263 131 k	EUR 289 444 k
2008	EUR 312 424 k	EUR 343 666 k
2012	EUR 326 437 k	EUR 359 081 k

The first decommissioning cost estimates from 1987 and 1993 were based on 30 years operational lifetime of the Loviisa plant. Already in these plans dismantling large components in one piece was selected as a main option. The cost estimate in 1998 is based on 45 years operational lifetime of the plant. The decommissioning waste inventory was updated, as well as the work plan. For the 2003 decommissioning plan the operational lifetime was further increased to 50 years, but this had only small impact on the costs.

The major changes in decommissioning costs took place, when the regulatory requirements changed and the free release limits were lowered from 10 kBq/kg to 0.1 kBq/kg in late 2000s. This increased the waste volume and the costs of decommissioning significantly in the 2008 decommissioning plan.

The latest cost estimate in 2012 included the updated costs of the repository expansion, based on the real costs of the excavation work done at the repository for the extension of the operational waste repository.

## 6.10. Uncertainties and contingencies

Decommissioning cost estimates for Loviisa NPP are based on the actual labour and subcontractor costs at the Loviisa plant and other departments participating the decommissioning, as well as budget offers received from various suppliers. In some areas, like the final disposal costs, the real construction and operational costs of the existing low- and intermediate-level waste repository were used as a basis for cost estimates.

Labour costs are dominating the decommissioning costs, covering more than 70% of the total decommissioning costs, if the subcontracted work is taken into account. Hence, the major uncertainties are related to the estimation of the man-hours of different tasks, as well as the total duration of the decommissioning works.

Final disposal costs, including the costs of the expansion of the repository at Loviisa site, are well known from the earlier expansions of the repository. Along with the risks there are also some possibilities that could decrease the costs. An example of these is the construction of a shallow land disposal facility for very low active waste, which could be a cheaper waste disposal route for some of the waste.

One uncertainty related to the costs is the actual amount of contamination in the reactor and auxiliary buildings as well as in the secondary side. This may lead to higher waste volumes and manpower need in dismantling works, and to larger own organisation costs in case of delays in the overall schedule. The impacts of larger waste volumes of low-level waste on the final disposal costs is, however, minimal in the Loviisa case, since the capacity of the repository can be easily expanded if needed.

The licensing process for decommissioning and decommissioning waste disposal in Finland includes various steps. The process starts with environmental impact assessment (EIA) and includes also a political decision-in-principle (DIP) from the parliament. Both EIA and DIP include public participation, and the local community has a veto right in case of DIP. The licensing process begins already before the actual decommissioning project in the early 2020s during the plant operation phase. The most uncertain part of the licensing process at the moment is the licence termination after all decommissioning work has been done and the waste has been disposed of, since the experience of such a process is lacking in Finland.

Cost estimations have always had 10% contingency for the total cost. This has been considered enough based on the experience from the other large projects realised in the Loviisa NPP.

### **6.11. Identified cost drivers**

Decommissioning is a very much labour intensive process. In the case of Loviisa NPP, the labour costs (own personnel and the subcontractors) cover more than 70% of the total decommissioning costs. Waste treatment and final disposal costs, on the other hand, represent less than 10% of the decommissioning costs.

### **6.12. Lessons learnt**

The availability of a clear waste management route is a great advantage for the decommissioning planning and cost estimation. The fact that the waste disposal facility is owned and operated by the plant operator makes it possible for optimisation of the whole waste management route from dismantling works to the final disposal.

The decommissioning planning for Loviisa NPP started already in 1980s. The decommissioning plans have been updated every five to six years. The planning has used data from the plant operation and modern computer tools (3D CAD-tools, MCNP-simulations) in the estimation of waste volumes. This, together with the use of actual cost information from the plant, has formed a good basis for reliable decommissioning cost estimate.

## Chapter 7. Case study of the Netherlands: Decommissioning of the Dodewaard nuclear power plant

### 7.1. Historical background

The 55 MWe Dodewaard BWR went critical for the first time in July 1968, and was synchronised with the electrical grid in October of that year. The plant was not turnkey, but consisted of components of various manufacturers. The nuclear island was of an early General Electric design.

In 1997, after 28 years of successful operation, the plant was taken off the grid, as it was seen that there was no place anymore for a nuclear plant of this size in the liberalised electricity market.

### 7.2. Strategy

The owner of the plant, the “Samenwerkende Electriciteitsproducenten” (Sep) decided for a strategy of delayed dismantling via a period of safe enclosure. The following design criteria were decided:

- bunkerised system of all contaminated areas, with one entrance only;
- active air conditioning system;
- new waste water collection system;
- new electrical system;
- remote surveillance.

All radioactive waste in the Netherlands is collected and stored by one central facility, Centrale Organisatie Voor Radioactief Afval (COVRA), in the Vlissingen industrial area in the south of the country.

### 7.3. Decommissioning schedule/issues and approaches

The decommissioning schedule is given in Table 7.1.

Directly after the ceasing of electricity production, the post-operational phase began (Figure 7.1). In this period, the reactor was unloaded and the nuclear fuel transported to British Nuclear Fuels Limited (BNFL), United Kingdom, for reprocessing. Also the wet radioactive waste has been removed, the refuelling pool emptied, and systems that had no function anymore were decommissioned. In 2003, after obtaining the required licences and submitting an environmental impact report, a two-year reconstruction period began, in which the safe enclosure was realised. This enclosure was completed in 2005, and is planned to stand for 40 years. The decision for delayed dismantling was based on a study on the decommissioning costs of both Dutch nuclear plants made in 1994. This report concluded that it would be preferable to delay the dismantling for radiological and financial reasons. By radioactive decay, the dismantling would be simpler after the waiting period of 40 years, and a dose rate reduction for the workers

could be realised. The dose rate reduction appeared to be limited at 2 Sv. The financial advantage however would be considerable. With an interest rate of 4%, the starting capital needed for the decommissioning after 40 years was relatively low.

In 2011, the dismantling plan was approved by the Minister of Economic Affairs. The plan needs to be revised every five years, and if necessary adapted to the latest insights of optimal strategies.

**Table 7.1: Decommissioning schedule**

Date	Milestone
26 March 1997	Ceasing of electricity production; start of post-operational phase
20 May 1999	Application for Nuclear Energy Act licence
2001	Specifications and conditions ready
2002	Contractor selection
2002-2003	Detailed engineering
23 April 2003	Plant declared "fuel free"
May 2003	Start of reconstruction period
1 July 2005	Start of period of safe enclosure
17 March 2009	Transport of HLW from reprocessing to storage facility COVRA
13 September 2011	Approval of dismantling plan by the Minister of Economic Affairs
2016	Revision of dismantling plan
2021	Revision of dismantling plan
2026	Revision of dismantling plan
2031	Revision of dismantling plan
2036	Revision of dismantling plan
2041	Revision of dismantling plan
2045	Start of dismantling

**Figure 7.1: The Dodewaard nuclear power plant in operation (left) and in safe enclosure (right)**



#### 7.4. Boundary conditions

The dismantling plan approved in 2011 was based on a cost analysis executed by the German engineering firm NIS Ingenieurgesellschaft mbH (NIS) in 2009. This cost analysis

was based on starting points defined in a technical requisition file (TRF). The TRF was drafted by representatives of the ministries of Economic and Environmental Affairs, COVRA, NIS and GKN (the Dodewaard plant operating company). GKN was assisted by Belgatom. The final version of the TRF was approved by all parties before the start of the dismantling cost calculations. By this approach any discussion about the results of the calculations afterwards was avoided. The TRF gives starting points on, among others, wages, waste packages, release limits, decontamination and release techniques and calculational software.

As basis for the radioactive inventory, the Dodewaard Information System has been used, updated for radioactive decay. This system consists of a database in which for all components of the installation mass, location, contamination and nuclide vector have been listed.

Requirements for a building for release measurements, the new site infrastructure, and transport routes within the buildings have been fixed. The method of “dry” contamination has been selected, avoiding the production large quantities of waste water and sludge.

### 7.5. Radioactive waste features (e.g. volumes and activity) and management strategy

Directly after the ceasing of electricity production, the post-operational phase began, in which both spent nuclear fuel and other radioactive waste was removed. The spent nuclear fuel is discussed in the next section. The wet radioactive waste was taken from the storage tanks of the plant and cemented with radioactively contaminated material. Besides used fuel, the spent fuel basin contained also other components with considerable activity, like BWR control blades, in-core lances and construction parts from the reactor. These were loaded into so-called Mozaïk containers.

The numbers of the various types of waste drums can be found in Table 7.2. Also this waste has been transported to the COVRA waste storage facility.

**Table 7.2: Types of waste from the Dodewaard post-operational phase**

Number	Drum with waste type
13	Mozaïk containers
258	90-litre drums with compactable waste
242	200-litre drums with scrap and cemented waste
82	1 000-litre drums with resin and filter agent

### 7.6. SNF management

The spent nuclear fuel (SNF) of the Dodewaard plant has been sent to BNFL in Sellafield for reprocessing. The reprocessing resulted in separated uranium and plutonium, and vitrified highly radioactive waste. The 55 tonnes of uranium and 383 kg plutonium have been reused as fuel in European operating reactors. The 28 years of operation of the Dodewaard plant resulted in 28 canisters of vitrified highly radioactive waste. In 2009, these canisters have been transported to the COVRA storage facility for radioactive waste.

### **7.7. Project management/organisation**

The safe enclosure has been realised by the Dutch firm Homij Technisch Beheer, with the assistance of GKN engineers.

### **7.8. Site remediation**

The site will be restored to “greenfield”.

### **7.9. Variation of cost estimates over time**

The current cost estimate for the final dismantling of the Dodewaard plant amounts to EUR 180 million, based on the assumptions of the TRF. Transport and storage at COVRA make up about 25% of this sum. The dismantling plan will be adapted to the new insights on optimal strategies in 2016. Before the start of new calculations and analyses, a new TRF will be drafted by the stakeholders.

Already now it can be recognised that various developments and improvements of techniques may bring down costs. For instance, up till now it has been foreseen to cut down large components into smaller pieces, but it can be seen in neighbouring countries that large components are being stored in one piece. Also, the melting of slightly contaminated material could be considered, resulting in the concentration of the radioactivity in the slag. Conditional release also has not been applied yet.

Additional cost reduction could be achieved by the application of automated measuring of material release. Also the filling of waste packages could be improved by better computer technology. Both techniques lead to a reduction of man-hours. Also the shape of packages has been developed: whereas the dismantling plan still assumes the use of cylindrical packages, cube-formed containers have been developed that are easier to handle and to stack, like the German KONRAD container.

Also cost increasing developments are taking place, like the storage costs for radioactive waste that rise almost annually. Also the insurance costs have increased since the Fukushima Daiichi event. Policy changes by the Dutch authorities led to increased security requirements and increased fees for owners of nuclear installations. Finally, a public awareness problem appeared too: material with an activity so small that it has been measured to be fit for unconditional release, but also still can be detected, is not accepted by the scrap processing industry, as they fear not to be able to get rid of the material anymore. Much more of such material will be released during final dismantling. Storage of this material at COVRA would increase costs considerably.

### **7.10. Lessons learnt**

In preparation for the safe enclosure, the decommissioning of systems that had no function anymore appeared to be complex, because parts of the installation were taken out of service, while other parts had to remain in service. By the many (electrical) cross-links this appeared to be very time-consuming.

### **Reference**

Kers D.A. (2014), “De ontmanteling van de kernenergiecentrale Dodewaard” (The dismantling of the Dodewaard nuclear power plant), *Nederlands Tijdschrift voor Stralingsbescherming* (Dutch Journal for Radiation Protection), Vol. 5, Number 1, Spring (in Dutch).



## Chapter 8. Case study of the Slovak Republic: Decommissioning of the Bohunice V1 nuclear power plant

**Figure 8.1: Jaslovské Bohunice site**



### 8.1. Historical background

The V1 nuclear power plant (NPP) located in Jaslovské Bohunice site (Figure 8.1) is a nuclear unit with two reactors, VVER-440 model V-230. In the V1 NPP there are installed two pressurised water reactors VVER 440 of type V-230 to slightly enriched uranium (low enriched uranium dioxide  $UO_2$  2.5% U-235) located in the fuel assemblies. Water is moderator and coolant at the same time, regulation is provided by control rod and by variability of the concentration of boric acid solution in the coolant. Thermal capacity of one reactor is 1 375 MWt, designed electrical output of one reactor unit is 440 MWe. The reactor is technologically connected with the primary circuit, consisting of primary pipeline and six steam generators, which produce steam by the secondary side. Circulation of coolant between the reactor and steam generators provides six main circulation pumps installed in circulation loops. Each circulation loop is equipped by two main closing valves, one for hot and one for cold branch. Part of primary circuit is pressuriser, of which task is to compensate thermal and pressure changes in the primary circuit. The pressuriser is by connecting pipeline interconnected to the integral part of the primary pipeline. The operation is supported by common technological systems of primary and secondary parts, chemistry, electrical and other systems.

Within the accession process to the European Union (EU) in 1999, the Slovak Republic committed itself to the premature shutdown of units 1 and 2 of the Bohunice V1 NPP. Unit 1 by 31 December 2006 and unit 2 by 31 December 2008. Both units were shut down on the agreed dates.

The EU recognised that the early decommissioning of the Bohunice V1 NPP represented a significant financial burden for the Slovak Republic and therefore the EU decided to provide financial compensation for the Slovak Republic in form of contribution to the Bohunice International Decommissioning Support Fund (BIDSF) administered by the European Bank for Reconstruction and Development. BIDSF is intended to finance or co-finance selected projects for disposal of the Bohunice V1 NPP and for activities related to decommissioning of the Bohunice V1 NPP. The European Union has contributed to the BIDSF a total amount of EUR 613 million, out of which EUR 90 million was allocated from the PHARE programme, and EUR 100 million was granted for a transitional period 2004-2006 and EUR 432 million was allocated for the Financial Perspective 2007-2013. By Council Regulation (Euroatom) N. 1368/2013, the additional financial assistance for the period 2014-2020 was provided in amount of EUR 225 million.

Conditions for international co-operation concerning the Bohunice V1 NPP decommissioning were established by the Framework Agreement between the Slovak Republic and the European Bank for Reconstruction and Development (EBRD) on the process of the Bohunice V1 NPP decommissioning signed on 16 November 2001. The European Commission (EC) and other contributors established the BIDSF to finance or co-finance the provision of goods, works and services in support of the decommissioning of both units, among other purposes. They invited the EBRD to administer the grant funds. In November 2001, a Framework Agreement was signed by the Slovak Republic and the EBRD to govern the operation of the BIDSF.

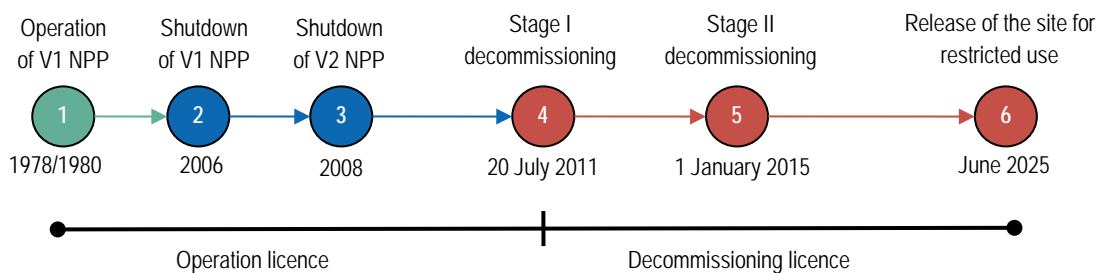
A Project Management Unit (PMU) was formed initially by Slovenské Elektrárne and transferred later to Jadrová a vyrad'ovacia spoločnosť, a.s. (JAVYS), the current owner and operator of Bohunice V1 NPP. External Consultant was selected to support the PMU activities. The PMU was set up to manage all the decommissioning projects.

Contributors to the BIDSF, where the EC plays an important role, are regularly involved in monitoring and commenting of the process through the Assembly of Contributors. All of the Bohunice V1 NPP decommissioning projects as well as projected measures in the energy sector are based on the strategic documents of the energy sector approved in the Slovak Republic. Mentioned strategic documents include the Energy Policy of the Slovak Republic, Energy Security Strategy of the Slovak Republic, the V1 NPP Conceptual Decommissioning Plan, the V1 NPP Decommissioning 1<sup>st</sup> Stage Plan and the Bohunice V1 NPP Decommissioning Strategy Report.

## 8.2. Strategy for NPP V1 decommissioning

The licensed option for decommissioning was “immediate dismantling”. The main features of this option are the immediate and fluid dismantling of the equipment, the demolition of buildings down to the bottom of the foundation pit and the preparation of the area to make it available for further industrial (non-residential or farm uses) use, therefore the final plant status will be named, in environmental context, as “brownfield” due to the residual radiological impact even if from the construction point of view it resembles more to the greenfield. Figure 8.2 provides for the timeline for NPP V1 decommissioning.

The pre-decommissioning activities (1 January 2008 to 20 July 2011) included the total defueling the reactors into the respective spent fuel pools and then into the on-site independent interim spent fuel storage facility, preparation of waste processing facilities, conditioning the historical wastes, plant physical and radiological characterisation, modifications to electrical and mechanical systems and their tag-outs to allow start-up of the dismantling operations, access control and physical security. During this stage, technical studies, technical specifications and tender dossiers for contracting the stage I projects were performed.

**Figure 8.2: Timeline for V1 nuclear power plant decommissioning**

Stage I of decommissioning phase (20 July 2011 to 31 December 2014) activities encompass the removal of non-active systems and demolishing of structures no longer needed. This includes the removal of systems from the turbine building, demolishing of structures such as the cooling towers and other buildings associated with the cooling function, partial dismantling of electrical outdoor equipment and switchgears, removal of systems and demolition of the diesel generator building, dismantling of some outdoor tanks and the preparation of buffer waste storage places on-site and primary circuit decontamination. During this stage, technical and procurement documentation will be prepared to contract the stage II projects and some conditioning of the buildings for future use will be also be performed.

Stage II decommissioning phase (1 January 2015 to 2025) activities cover the removal of the remaining plant systems and demolishing of remaining structures within the decommissioning scope. This includes the removal of systems and components from the reactor building, the auxiliary building, and the cross side and lengthwise electrical buildings. Outdoor tanks and buried piping trenches and cables will also be dismantled. Building decontamination and demolition will be performed once they are empty.

### **8.2.1. Strategic and conceptual documents developed in relation to Bohunice NPP V1 decommissioning**

The shutdown of V1 NPP units 1 and 2, V1 NPP pre-decommissioning process and V1 NPP decommissioning process are planned, prepared, managed and implemented based on the following strategic documents:

- V1 NPP Conceptual Decommissioning Plan (2006);
- Environmental Impact Assessment Report of V1 NPP decommissioning (2006);
- Bohunice V1 NPP Decommissioning Strategy Report (2010);
- V1 NPP Decommissioning Stage 1 Plan and Licensing Documentation (2010);
- Decommissioning Database (2011);
- Resolution No. 400/2011 issued by Nuclear Regulatory Authority of the Slovak Republic, granting the licence for Stage 1 of V1 NPP decommissioning (2011);
- Strategy of the Peaceful Use of the Back-End Cycle of Nuclear Energy (2012);
- Strategy of Bohunice V1 NPP Decommissioning (2012);
- Detailed Decommissioning Plan (2014);
- Environmental Impact Assessment Report of 2<sup>nd</sup> Stage of V1 NPP Decommissioning (2014);
- V1 NPP Decommissioning 2<sup>nd</sup> Stage Plan and Licensing Documentation (2014);

- Resolution No. 900/2014 issued by Nuclear Regulatory Authority of the Slovak Republic, granting the licence for stage 2 of V1 NPP decommissioning (2014).

The updated document **Detail Decommissioning Plan (DDP)** was developed to fulfil the requirements in compliance with Council Regulation 1368/2013 on Union support for the nuclear decommissioning assistance programmes in Bulgaria and the Slovak Republic.

The main areas within DDP concerns with the preparation of decommissioning **implementation milestones** based on **work breakdown structure (WBS)**, constant update with IPBTS (decommissioning **time schedule**), **estimation of decommissioning costs** based on internationally recognised standards – International Structure for Decommissioning Costing (ISDC) structure performed on the **level II and III** (for V1 NPP decommissioning projects up to year 2025) and development of **key performance indicators (KPIs)** – a tool which enables **constant monitoring** of decommissioning activities.

The DDP document is structured according to the following content:

- basic information about V1 NPP decommissioning;
- decommissioning licensing process;
- Bohunice V1 NPP decommissioning project;
- BIDSF decommissioning projects;
- decommissioning project schedule;
- decommissioning cost estimation;
- risk management;
- key performance indicators.

The Detailed Decommissioning Plan schedule gives a complete overview of the status and progress of the decommissioning projects, and includes the decommissioning project main phases taking into account the bases, criteria and scope defined in the different sections of this document. Seventy-five individual BIDSF projects were identified to accomplish the Bohunice V1 decommissioning programme. These are added with the ongoing maintenance and care of the facilities and equipment with supporting administrative and management activities.

The Detailed Decommissioning Plan Schedule Critical Path goes through three main topics projects:

- get the licensing documentation for the regulator permission for the decommissioning;
- get the availability for the different waste storages;
- decommissioning activities in the reactor building (including the modifications required to develop the D&D activities).

The critical path analysis shows as critical the following projects:

- V1 NPP decommissioning 2<sup>nd</sup> stage plan and licensing documentation;
- environmental impact assessment report of 2<sup>nd</sup> stage of V1 NPP decommissioning;
- interim storage of radioactive waste (RAW) at Bohunice site;
- modification of the plant and installation of new equipment;
- reactor coolant system large components dismantling;

- auxiliary buildings system removal – stage 1;
- dismantling of systems in V1 NPP controlled area – part 2;
- buildings decontamination;
- buildings demolition and backfilling;
- final survey and site release.

In addition, DDP shows the critical path with a float time of 120 working days.

### **8.2.2. Key performance indicators**

Key performance indicators are stated in order to permit to measure relevant attributes in a clear, timely and efficient manner. KPIs definition will cover also the identification of goals in order to know what outcome is expected and what sort of deviation from a target would be regarded as negative and what positive.

A clear statement of KPIs depends strongly on quality of planning for all the decommissioning projects and activities. The document will include a detailed planning covering all the activities at a project level according to the following scheme:

- Grant agreement (GA) phase: includes the timing from starting the preparation of the project identification sheet (PIS) to the signature of the GA.
- Tender phase: includes the timing from starting the preparation of the technical specification/terms of reference to the signature of the contract with the successful tendered.
- Implementation phase: includes the period from contract signature to project activities finalisation.

The key performance indicators that have been identified as a sufficient for progress monitoring of the V1 NPP decommissioning projects are the following.

### **8.2.3. Project delivery**

KPIs included in this category show if the milestones established in the Decommissioning Project are being completed on time.

#### *Implementation milestones (KPI1)*

This index is the result to divide the number milestones of the project implementation phases to be met in a reportable period of time by the expected number of milestones of the project implementation phases to be met according to the base line. In particular, this KPI shows if the projects implementation phases are developed according to the base line. This KPI will be presented for each BIDSF project under implementation stage (contracted).

#### *Key (critical path) milestones (KPI2)*

This index is the result to divide the number key milestones (milestones in the critical path) to be met in a reportable period of time by the expected number of key milestones to be met according to the base line. In particular, this KPI shows schedule deviations in the projects located in the critical path.

### **8.2.4. Financial performance**

KPI included in this category will monitor the financial performance by the estimated value of the work completed by a contracted project as of today.

### *Cost by activity for contracted projects (KPI3)*

This index is the result to divide the contracted cost of the main activities quoted in the signed contracts as part of the “schedule of lump sum prices”, and the final cost.

#### **8.2.5. Health, safety and security performance**

To monitor the ability to protect workers from ionising radiation two indicators will be controlled.

##### *Collective effective dose (KPI4)*

This indicator will monitor the total radiation dose incurred by the decommissioning workers as the sum of all the individual doses.

#### **8.2.6. Environmental performance**

Volume of radioactive wastes (low-level radioactive waste [LLW] and very low-level waste [VLLW]).

##### *During decommissioning (KPI5)*

This indicator will monitor the progress of decommissioning through checking the volume of radioactive wastes produced in relation to the foreseen volume.

### **8.3. Boundary conditions, legal framework**

The Slovak Republic and entities operating within (i.e. including JAVYS) draw from long-term responsible back-end nuclear strategy, being considered and executed already since 1980s. Conceptual and legislative conditions were established for all aspects of RAW treatment and disposal, including decommissioning of nuclear facilities. Based on the created conditions, interim spent fuel storage and RAW treatment centre were built. Nowadays, their presence significantly improves initial conditions of V1 NPP decommissioning.

The basic national document setting boundaries for decommissioning of all nuclear facilities in the Slovak Republic, including operational and decommissioning RAW treatment is the strategy of the peaceful use of the back-end cycle of nuclear energy, being periodically reviewed and approved by the government of the Slovak Republic.

Preparation and updated of the strategy of the peaceful use of the back-end cycle of nuclear energy is provided by the National Nuclear Fund of the Slovak Republic, established by the Act No. 238/2006 Coll. The National Nuclear Fund of the Slovak Republic is also responsible for management, review and improvement of national financial mechanism, necessary for gathering funds for decommissioning of nuclear facilities (including V1 NPP).

Overall management (including licensing procedures) of all stages of nuclear facilities' existence is governed by the Atomic Act – Act No. 541/2004 Coll. – as amended and subsequent executive decrees of the UJD SR. The Atomic Act incorporates all relevant international treaties and EU legislation into national legal environment and any and every step in V1 NPP decommissioning must follow these established procedures.

Apart from the Atomic Act, decommissioning activities will be governed mainly by UJD SR Decree No. 30/2012 Coll. on details of requirements for the handling of nuclear materials, nuclear waste and spent nuclear fuel, Decree No. 57/2006 Coll. on details concerning the requirements for shipment of radioactive material and Decree No. 58/2006 Coll., as amended, on details on the scope, contents and manner of preparation of documentation for nuclear facilities needed for individual decisions.

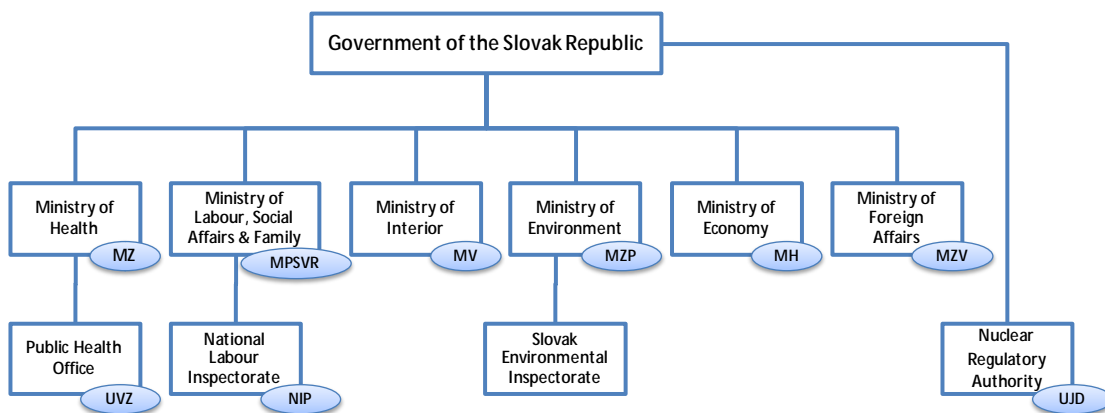
Requirements for dose optimisation are defined in the relevant Slovak legislation, the primary one being Act No. 355/2007 Coll., as amended, on protection, support and development of public health, and governmental resolution No. 345/2006 Coll., as amended, on basic safety requirements for ionising radiation health protection of employees and public). According to valid legislation, any decision on new technologies and technological procedures is obliged to demonstrate the optimal option, mainly in case of possible alternatives, which shall not exceed legal limits for radiation and eventually stated limit doses. The optimum option shall be sufficiently demonstrated already in the phase of technology selection or technological procedure. The proposed solution must be accepted by the state regulatory bodies.

The bases for comparison of individual alternatives are estimates of individual and collective doses, production of radioactive waste and release of the radioactive waste into the environment. In case of uncertainties, the optimisation shall be performed by quality or quantity methods using the financial equivalents (governmental resolution No. 345/2006).

The as low as reasonably achievable (ALARA) principle shall be applied in accordance with the internal procedure. This shall guarantee the optimisation of activities in the actual radiation situation in V1 NPP. In compliance with the principle of radiological protection each activity causing radiation exposure to employees shall be optimised. Optimisation of exposure on inhabitants is solved within the licensing process for radioactive waste release into the environment.

The Slovak legislation defines the competencies of the involved governmental bodies and organisations on the supervision of the peaceful use of nuclear energy within the framework of decommissioning and radwaste management by the corresponding acts according to the following structure (Figure 8.3).

**Figure 8.3: Structure of Slovak regulatory bodies**



## 8.4. Radioactive waste features

### 8.4.1. Legislative framework for waste management

Treatment and disposal of waste is governed in general by Act No. 223/2001 Coll., as amended, on waste, and Decree of Ministry of Environment No. 284/2001 Coll., stipulating the waste catalogue. The Act on waste establishes the Recycling Fund and defines obligation of waste producers. According to this act, the legal responsibilities of JAVYS and/or its subcontractors and/or contractual counterparts concerning **hazardous and conventional waste management (i.e. except RAW management, which is governed by**

**separate Atomic Act**), are mainly: general minimisation of conventional and hazardous waste production, separation of hazardous waste according to its categories, storing hazardous waste in appropriate types of containers, monitoring of movement, storage and disposal of hazardous waste and manipulation and treatment of the waste by authorised personnel and processes.

The Atomic Act specifically stipulates conditions for management and treatment of radioactive waste, so that only licensed subjects can process and manipulate with RAW. JAVYS a.s. has obtained all relevant licences for such responsible and environmentally safe **management of radioactive waste** produced in Bohunice V1 NPP. The Atomic Act and Regulation No. 30/2012 Coll. lay down details on requirements for management of nuclear materials, radioactive waste and spent nuclear fuel as well as their classification based on their radiological content. The clearance of materials from a controlled area is a licensed practice based on the Public Health Act No. 355/2007 Coll., as amended and the governmental resolution No. 345/2006 Coll. in the field of health protection of the workers and public against the ionising radiation.

#### 8.4.2. Summary of radiological and physical inventory of the plant

The physical inventory covers three major entities of V1 NPP site: civil structures (SO), equipment (technological part and electrical, I&C and dosimetry equipment), consumables and other materials property of JAVYS. This physical inventory has been used as a basis to prepare the radiological inventory. The resulted total number of inventoried items and their mass are summarised in Table 8.1.

**Table 8.1: Summary of physical inventory by type of item**

Type of items	Number of items	Mass (kg)
Rooms and civil structures	10 313	721 767 871
Technological part	51 735	73 122 753
Electrical and I&C and dosimetry equipment	13 056	4 205 075
Consumables and other materials	41	5 297
<b>Total</b>	<b>75 145</b>	<b>799 100 996</b>

After operation termination the radiological situation of the V1 has been characterised. Total radiological inventory of V1 NPP recorded in DDB is given in Table 8.2.

**Table 8.2: Total radiological inventory of V1 nuclear power plant, activity (Bq) and mass (kg)**

Building and structures (SO)		Activated components	Contaminated civil structures	Contaminated equipment	Total
Total	Activity (Bq)	2.03E+17	4.42E+10	1.17E+13	2.03E+17
	Mass (kg)	1.39E+06	2.30E+08	1.16E+07	2.43E+08

The prevailing part of the induced activity (about 99.7%) is concentrated in the reactor internals (protection tube unit, reactor shaft, reactor shaft cavity, core basket energy control channels and shielding/ absorber assemblies). These components represent about 87% of the activated stainless steel and about 19% of the overall activated materials.

The remaining 0.3% of the induced activity is mainly concentrated in the reactor pressure vessel (RPV) claddings (about 0.1% of the overall induced activity) and the RPVs (about 0.2% of the overall induced activity). These components represent respectively about 12% of the activated stainless steel and about 78% of the activated carbon steel.



### 8.4.3. Management strategy of RAW

All historical and decommissioning wastes must be characterised in origin and classified as either i) radioactive waste or ii) clearable material according to their radiological characteristics. Further classification into the waste streams attending to the physical and chemical properties, is also required. Conventional waste from non-radiological areas shall be excluded from any RAW stream and non-radioactive material from radiological areas shall be subject to the clearance process.

**Table 8.3: Radioactive waste management strategy by radioactive waste stream**

RAW	Pre-treatment treatment	Conditioning	End destination
Radioactive organic sorbents and sludge	Incineration	Cementation in FCC	
	Bituminisation	Cementation in FCC	LLW disposal
		Cementation in two steps (drums and FCC)	LLW disposal
	Encapsulation and solidification by SIAL matrix		LLW disposal
Liquid radioactive concentrates	Bituminisation	Cementation in FCC	LLW disposal
Mixture of solid RAW	Sorting in combustible and compactable		
Contaminated metallic components	Conventional decontamination	—	Clearance VLLW disposal
	High-pressure compaction	Cementation in FCC	LLW disposal
		Packaging	Storage
Segmentation	Packaging	Melting	
Activated materials (concrete and metals)	Fragmentation	Cementation in FCC	LLW disposal
		Packaging	Storage
	Another possibilities will be defined base on D7.1	To one piece	LLW disposal
Contaminated building surfaces	Scarifying		VLLW/LLW disposal
Contaminated concrete debris and contaminated soils	—	—	VLLW disposal
		Cementation in FCC	LLW disposal
		—	Backfilling
Compactable non-metallic solid RAW	Low/high-pressure compaction	—	VLLW disposal
		Cementation in FCC	LLW disposal
Combustible RAW	Incineration, ash supercompacted with paraffin	Ash pellets cementation in FCC	LLW disposal

FCC = Fiber-reinforced concrete container.

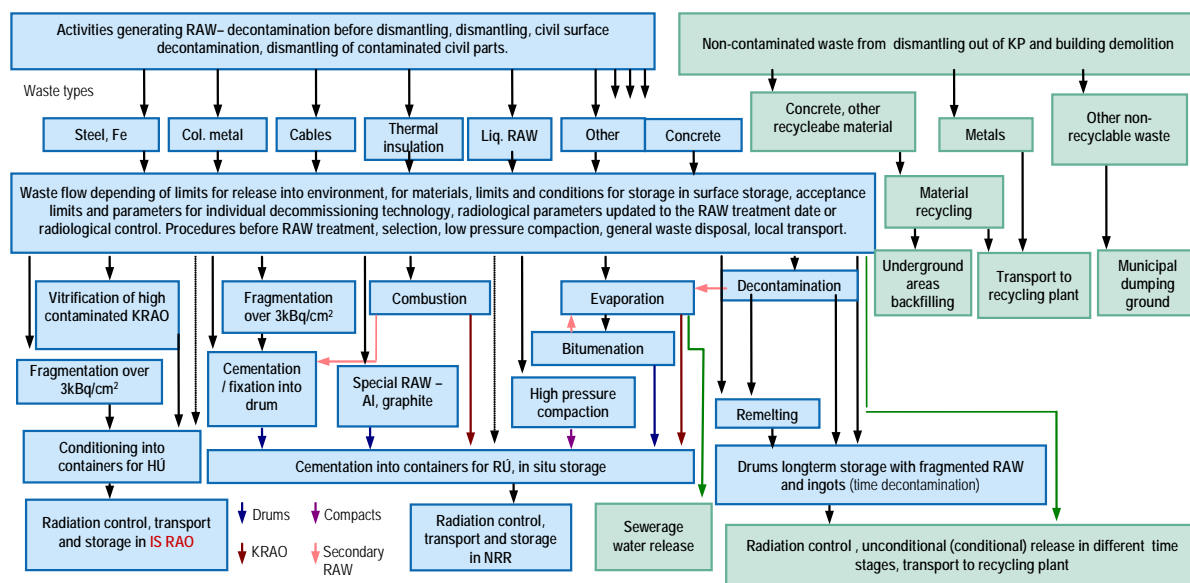
Monitoring at intermediate points in the process as well as at the end is required to verify that the treatment is effective and that the acceptance criteria for the selected repository are met.

The preferred management option and destination points for each waste class is summarised in Table 8.3.

Following the exclusion criteria of not treating material that is not radioactively contaminated as radioactive waste, building structures in radiological zones that are only surface contaminated, must be carefully treated to allow the clearance of the clean

material “on the wall”, before any demolition. This implies the decontamination of the surfaces using scrubbing tools as well as the regulatory approval of the infrastructure, including the facilities, the equipment and the associated methodology to be used to perform the final monitoring of the surfaces which are to be free released. After that, clean released structures can be demolished and managed as conventional waste or reused for other purposes (Figure 8.4).

**Figure 8.4: Waste handling process**



Contaminated debris from scarifying could be used, depending on its radiological characteristics, as follows:

- for backfilling the site or new structures;
- for completing waste packages not full with metallic waste;
- disposed of at the VLLW repository if they meet the acceptance criteria;
- immobilised with cement and disposed of at the NRR.

Contaminated soils are similar to concrete debris and will follow the same process.

Activated concrete cannot be decontaminated; rather, activated concrete structures will be dismantled or demolished in a controlled way and disposed of as VLLW or LLW or stored as intermediate-level waste (ILW) depending on their radiological characteristics.

Metallic systems and components shall be decontaminated before dismantling if required to maintain the dose to the operators as low as reasonably achievable (e.g. primary circuit). Piping systems shall be cut to the size of the decontamination equipment or the final package. Post-dismantling decontamination of metallic components should only be undertaken if the resulting material will meet the acceptance criteria for free releasing or disposal as VLLW and the associated secondary and final radioactive waste volume is much lower than the initial one and can be treated on-site.

Metallic material classified as ILW from the beginning or after decontamination will be immobilised in the final package with low density concrete, so as to maximise the volume of waste per container.

Other non-metallic secondary RAW that can be generated during decommissioning (e.g. HEPA filters, protective clothing, etc.) will be segregated according to their radiological class and physical properties.

JAVYS possesses a radioactive waste treatment centre which can process and treat combustible solid and liquid RAW, compressible solid RAW, non-combustible and non-compressible solid RAW and liquid RAW – concentrates, sludges and resins.

The Radioactive waste treatment centre includes solid RAW sorting plant, high-pressure press for reducing volume of non-combustible solid and liquid wastes, incineration facility reducing the volume of combustible solid and liquid waste, liquid RAW concentration plant and cementing line for consolidation and stabilisation. New melting facility is under preparation.

The final product of RAW handling is filled into fibre concrete containers, which are designed for the deposition in the National RAW Repository in Mochovce.

Interim integrated storage facility is under construction in Bohunice site to accommodate all RAW which do not meet the acceptance limits and criteria in National RAW Repository in Mochovce.

### 8.5. Spent fuel management

Interim spent fuel storage in Jaslovské Bohunice was commissioned in 1987. This is a wet-type facility where the spent fuel from Russian-designed water-cooled, water-moderated reactor (VVER) can be safely stored for a period of at least 50 years. In 1997-2001, a project of seismic retrofitting and capacity increase was executed.

All spent fuel from Bohunice V1 NPP was transported into interim spent fuel storage by 2011 as a condition before the issuance of Licence for the 1<sup>st</sup> Stage of Bohunice V1 NPP decommissioning.

### 8.6. Cost estimate

Costs have been determined considering the elementary decommissioning activities included in each decommissioning project planned to be carried out in both decommissioning stages. When estimating the decommissioning costs with the approach of “calculation by decommissioning project”, projects can be divided into different groups according to the input information for the cost estimate:

- **Projects already finished or ongoing:** There are projects in the pre-decommissioning and stage 1 of the decommissioning for which the actual cost of the project is known because they have been already awarded. The contract provides the prices for the work, services and procured equipment in the scope of the project, which is used in the cost estimate.
- **Projects granted under a grant agreement** with a technical study: In this case, an amount of money is allocated to each of the projects to be financed under the grant and there is a technical study for the project including a cost estimate. The grant agreement and the technical study is taken as the basis for the cost estimates.
- **Projects not included in a grant agreement** and without a technical study. This is the case for the projects in stage II of the decommissioning. The cost calculation for these projects is produced following the cost estimate methodology.

The resulting costs calculated according to the approach of “calculation by decommissioning project” have been then converted to the ISDC, provided a direct correspondence of activities at Level 3 in the ISDC matrix with the decommissioning project activities (Table 8.4).

In addition to the matrix for presenting the estimated cost data, the ISDC has been used as the checklist for selection of relevant ISDC activities in the decommissioning projects.

In the ISDC structure, the principal activities considered for the cost estimates are as follows:

- 01 Pre-decommissioning actions.
- 02 Facility shutdown activities.
- 03 Additional activities for safe enclosure or entombment.
- 04 Dismantling activities within the controlled area.
- 05 Waste processing, storage and disposal.
- 06 Site infrastructure and operation.
- 07 Conventional dismantling, demolition and site restoration.
- 08 Project management, engineering and support.
- 09 Research and development.
- 10 Fuel and nuclear material.
- 11 Miscellaneous expenditures.

Elements of costs are grouped into activity-dependent, period-dependent, and collateral costs to better determine how they affect the overall cost estimate, helping in the use of the costing methodology:

- **Activity-dependent costs** are those costs associated directly with performing decommissioning activities. Examples of such activities include decontamination; removal of equipment; demolition of buildings; and waste packaging, shipping and burial. They are calculated using unit cost and work difficulty factors applied to the physical and radiological inventory of the plant.
- **Period-dependent costs** include those activities associated primarily with the project duration: engineering, project management, administration, quality assurance, routine maintenance, health and safety, security activities, etc. These costs are calculated by estimating the manpower loading and associated overhead costs based on the scope of work to be accomplished for the specific activity and the salary rates for different staff categories.
- **Collateral costs** and costs for special items which do not fall in either activity-dependent or period-dependent categories. This category includes costs for activities such as procurement of construction or dismantling equipment used to support different activities, site preparation, health physics supplies, insurance, etc.

### 8.6.1. Activity-dependent costs

The unit factor method has been used to estimate activity-dependent costs by applying unit cost to the inventory of systems and structures for each elementary decommissioning activity.

The unit cost factor method provides a demonstrable basis for establishing reliable cost estimates. The detail provided in the unit factors, including activity duration, labour costs (by craft), and equipment and consumable costs, ensures that essential elements

have not been omitted. This method also considers work difficulty adjustment factors to account for the inefficiencies in working in a power plant environment.

Unit cost rates from the UNIKA 2008 suggested supply prices of co-ordination activities in construction process are used in the cost estimates.

When possible, the cost estimates have been developed using the site-specific, technical information available from the V1 NPP decommissioning project.

The physical and radiological inventory of the plant required for the activity-dependent costs has been provided by the existing "Decommissioning Database" produced in the frame of *BIDSF B6.4* project.

Information on waste flow from the ARSOZ Database has been used to classify the residual material from decommissioning in the different waste streams in order to estimate the costs related to waste management. List of prices for waste processing, transport and disposal provided by JAVYS are also used for the waste management cost estimation.

### **8.6.2. Period-dependent costs**

The period-dependent costs are produced considering the required duration of each activity that has been estimated in the decommissioning work schedule. The number and position of personnel required for the different elementary activities are defined according to the type of decommissioning operations. Once defined the personnel team suitable for the specific tasks to be performed, the personnel costs for each activity are then calculated as the number of hours required for each personnel category multiplied with the rate for that particular labour class.

### **8.6.3. Assumptions for the cost estimate**

The cost estimates presented in following sections have been developed based on the following assumptions and prerequisites:

- All assumptions made for the development of decommissioning work schedule are also valid for the cost estimation.
- The estimated cost data are considered as incurred cost during the implementation period of the projects. They are presented in 2011 EUR.
- The elementary costs for the elementary activities included in each decommissioning project are distributed according to the estimated duration of each activity in the decommissioning work schedule.
- Any equipment costs are presented on the basis of the purchase price in the country of origin converted into euro at the prevailing rate. No attempt has been made to obtain costs for the same equipment if purchased in the Slovak Republic.
- The programme of work and the resulting cash flows have been compiled on the basis that cash is available on demand. No attempt has been made to smooth cash flows throughout the project.
- Sufficient manpower, commercial equipment and materials are assumed to be available on demand.
- The costs for all the management activities of radioactive and non-radioactive waste from the decommissioning, including transport and final disposal or dumping are considered in the cost estimates.
- Costs have been calculated as cash costs at 2011 rates. No inflation is considered.

- The potential commercial or industrial profits obtained by future use of the site, recycled/reuse equipment and the financial benefits of the decommissioning funds are not considered.
- The costs associated to research and development activities are not estimated.
- Contingency in the cost estimates are included as follows:
  - No contingency is considered for the incurred costs for projects finished and ongoing.
  - The contingency applied for the projects under a grant agreement is that considered in the cost estimate in the associated technical study (generally 10%).

For preliminary cost estimates made for the projects not included in a grant agreement, a contingency of 8% is generally applied. However, higher contingencies are considered for special projects such as building decontamination or removal and dismantling of reactor coolant system components according to the practical experience of the estimator and international recommendations.

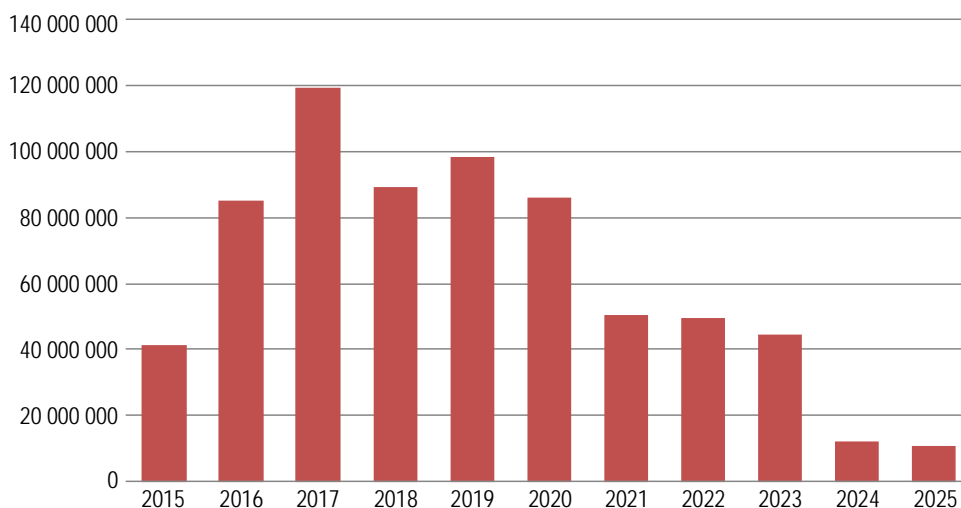
**Table 8.4: ISDC structure of the principal activities considered for cost estimates**

Cost item	Cost group					
	Labour		Capital	Expenses	Contingency	Total
	hours	NCU EUR	NCU EUR			NCU EUR
01 Pre-decommissioning	N.A.	41 227 803	0	5 798 786	89 412	47 116 001
02 Facility shutdown	N.A.	16 346 779	32 069 318	11 149 824	397 685	59 963 607
03 Additional activities for safe enclosure and entombment	N.A.	0	0	0	0	0
04 Dismantling activities within the controlled area	N.A.	73 902 174	21 311 707	26 341 346	23 884 298	145 439 526
05 Waste processing, storage and disposal	N.A.	171 182 411	49 360 370	59 082 462	47 027 477	326 652 720
06 Site infrastructure and operation	N.A.	47 442 393	12 262 440	85 176 458	1 548 742	146 430 033
07 Conventional dismantling demolition and site restoration	N.A.	78 482 682	2 390 044	94 877 535	11 494 035	187 244 295
08 Project management, engineering and site support	N.A.	124 751 999	1 577 450	44 956 239	11 965 668	183 251 357
09 Research and development	N.A.	0	0	0	0	0
10 Fuel and nuclear material	N.A.	322 861	5 566 580	21 568 521	0	27 457 962
11 Miscellaneous expenditures	N.A.	0	0	17 740 093	0	17 740 093
Total		553 659 104	124 537 910	366 691 264	96 407 316	1 141 295 594

Unit 1 and 2 of Bohunice NPP, respectively connected to the grid in December 1978 and March 1980, were prematurely shut down (unit 1 in December 2006, and unit 2 in December 2008) as a result of a commitment taken by the Slovak Republic during the negotiation for the accession process to the European Union in 1999. Many system modifications with the operating NPP V2 on-site (including the costs resulting also from the change of ownership) were necessary for the preparation of the anticipated decommissioning and the related licensing; costing approximately EUR 60 million.

The cost estimates assume the brownfield with restricted use with the complete remediation up to the bottom of the construction pit for the end state. The cost estimates reflects the technological complexities of VVER decommissioning and the prolonged projects preparation in accordance with applied EBRD procurement rules and formal approval processes at each phase (Figure 8.5).

**Figure 8.5: Cost estimates for 2015-2025, in euros**



In the case of the Bohunice V1 decommissioning project, the large components of primary circuits will be cut and fragmented into the specific containers and stored on-site in the integrated storage facility built for this purpose until the final disposal facility is available.

The specific nature of the project, in part financed by the European Commission and managed by the European Bank for Reconstruction and Development, require the use of specific procedures for planning, preparation and procurement of partial decommissioning projects with formal approval procedures at each step, which results in longer periods in pre-contractual phase and higher engineering cost (internal Project Management Unit, external technical and financial consultant to the EBRD) and is also the reason for the reported costs related to project management, engineering and site support.

Moreover, due to the grants allotment mechanism each individual BIDSF project is calculated on the higher range of cost estimate to avoid repeating the whole approval procedure. Actual tender procedures often results in significant decreases of actually contracted price for individual BIDSF projects. The total savings from individual BIDSF projects during the 1<sup>st</sup> stage of decommissioning exceeded EUR 40 million in comparison with the formal budget. Similar effects and savings are expected during the 2<sup>nd</sup> stage of decommissioning implemented through BIDSF projects as well.

Some BIDSF projects include the treatment of RAW from decommissioning. The estimates of such cost were based on the extrapolation of existing unit prices for RAW treatment which were valid for the year 2014. However, the actual unit prices will vary over the years and according to the EBRD rules only actually incurred cost will be repaid. This is additional potential area for the savings in total budget.

In the Slovak Republic waste is to be disposed of directly to a waste repository when available or stored on-site pending the availability of a waste repository. Initially, only VLLW and LLW will be transported off-site to already operational national repository (two double-rows (out of planned six) of the national repository are operational in Mochovce for LLW from operations and decommissioning, while VLLW repository is under construction). The radioactive waste not disposable in Mochovce National Repository will be conditioned in new integrated storage facility (currently under construction) in Bohunice.

Waste treatment costs were derived from existing unit RAW treatment cost which include the provisions for future decommissioning of RAW treatment facilities. The costs for decommissioning of Bohunice cover also the financing of construction of additional double-rows in national repository, construction of integrated storage facility in Bohunice and rehabilitation of existing waste treatment and disposal facilities.

## **8.7. Risk management**

A risk systematic analysis can help to determine the proper mix of preventive measures, transfer of risk to other parties, and retention of risk by the company. The benefits will accrue to the stakeholders, including government owners and Slovak society.

All activities in a Decommissioning Project involve risk. Risk management is applied to the entire company, at its many areas and levels, at any time, as well as to specific functions, projects and activities. The adoption of consistent processes within a comprehensive framework can help to ensure that risk is managed effectively, efficiently and coherently across the decommissioning organisation.






Project risk management is conducted on all BIDSF projects. The degree, level of detail, sophistication of tools, and amount of time and resources applied to project risk management is in proportion to the characteristics of the project under management and the value that they can add to the outcome. Thus, a large project that provides value to the Bohunice V1 NPP decommissioning would theoretically require more resources, time, and attention to project risk management than would a smaller, short-term, internal project that can be conducted in the background with a flexible completion deadline.

The main risk factors associated to the Bohunice V1 NPP decommissioning have been aggregated in six risk groups in order to facilitate their categorisation, analysis and subsequent control.

These include both internal risks and external risks. Internal risks are defined as those inbuilt in the ongoing project that may be managed through measures such as prevention or mitigation plans that may be adopted to reduce their probability of occurrence or ease their undesired impacts (Table 8.5).















**Table 8.5: Risk categorisation**

Score		Likelihood criteria	Impact criteria
	1. Very low	Unlikely to occur in the project lifetime or remote probability (< 2%)	< 2% cost overrun in the whole budget and no effect on schedule
	2. Low	Not likely to occur in the project lifetime or low probability (< 5%)	< 5% cost overrun in the whole budget or up to 1-year delay in schedule
	3. Medium	Likely to occur in the project lifetime or up to 10% chance of occurrence	< 10% cost overrun in the whole budget or up to 2-year delay in schedule
	4. High	Likely to occur more than once in the project lifetime or up to 25% chance of occurrence	< 25% cost overrun in the whole budget or up to 3-year delay in schedule
	5. Very high	Likely to occur every year or more than 25% chance of occurrence	> 25% cost overrun in the whole budget or more than 3-year delay in schedule

The six identified main risk are depicted, classified and assessed in the following chart (Table 8.6).













**Table 8.6: Risk assessment**

Risk		Type	Definition	Risk factors included	Likelihood	Impact
1	Asset risk	Internal	Cost overruns, delays or additional works as a result of encountering unforeseen conditions in the assets subject to decommission.	<ul style="list-style-type: none"> <li>- Levels of contamination</li> <li>- Structures</li> <li>- Materials</li> </ul>		
2	Operational risk (critical projects)	Internal	Cost overruns, delays or additional works caused by incidences or unpredicted modifications in the operations (projects).	<ul style="list-style-type: none"> <li>- Suppliers, contractors</li> <li>- HR, recruitment</li> <li>- Supply chain</li> <li>- Contracts, legal</li> <li>- Client requirement changes</li> <li>- Industry changes</li> <li>- Accounting and costing</li> <li>- Information systems</li> </ul>		
3	Operational risk (other projects)					
4	Regulatory risk	External	Cost overruns, delays or additional works product of Regulator decisions or changes in current nuclear or energetic legislation.	<ul style="list-style-type: none"> <li>- EU regulations</li> <li>- Slovak regulations</li> <li>- IAEA regulations</li> <li>- NEA regulations</li> </ul>		
5	Macroeconomic risk	External	Cost overruns due to changes to the macroeconomic assumptions used in the budgeting process or in the general socio-economic situation.	<ul style="list-style-type: none"> <li>- Funding shortfall</li> <li>- Interest rates</li> <li>- Exchange rates</li> <li>- Economic stability</li> <li>- Inflation</li> </ul>		
6	Hazard	External	Cost overruns, delays or additional works due to other unpredicted causes.	<ul style="list-style-type: none"> <li>- Natural events (floods, earthquakes...)</li> <li>- Environment</li> <li>- Social disturbance</li> <li>- Acts of sabotage, terrorism</li> </ul>		

### 8.7.1. Risk response measures

The main risk response measure are regular and timely risk reviews, at all levels of the decommissioning, from the total aggregate view hereby depicted to individual projects, especially critical projects, in order to facilitate an early identification and response to risk events that minimise their impact. In addition to that, some response measures to the aggregate risks identified in this document are depicted in the following chart (Table 8.7).

**Table 8.7: Risk response measures**

Risk		Likelihood	Impact	Proposed response measures
1	Asset risk			<ul style="list-style-type: none"> <li>- Continuous asset status assessment</li> <li>- Regular contamination testing</li> <li>- Contingency plans</li> </ul>
2	Operational risk (critical projects)			<ul style="list-style-type: none"> <li>- Contingency plans</li> <li>- Conditions with suppliers and contractors</li> <li>- Recruitment and retention of key personnel</li> <li>- Supply chain optimisation and monitoring</li> </ul>
3	Operational risk (other projects)			<ul style="list-style-type: none"> <li>- Review and standardised contracts</li> <li>- Define a client requirement change process</li> <li>- Define and monitor accounting and costing standards and processes</li> <li>- Define and monitor and IS security process</li> </ul>
4	Regulatory risk			<ul style="list-style-type: none"> <li>- Permanent contact with regulatory bodies</li> </ul>
5	Macroeconomic risk			<ul style="list-style-type: none"> <li>- BERD backing / guarantee to local funding</li> <li>- SWAPs or interest rate coverages</li> <li>- SWAPs or exchange rate coverages</li> </ul>
6	Hazard			<ul style="list-style-type: none"> <li>- Insurance</li> </ul>

Because of the format of Bohunice V1 NPP decommissioning project when the decommissioning takes place in the form of multiple BIDSF projects one of the main concern is to prepare the precise and exact project technical specification with clear rules, timetable and control mechanisms with multiple milestones and additional requirement that the external contractor performs at least 50% of workload by himself to limit the role of subcontractors. The quality and completeness of contracts is crucial to avoid the pressures for contract addendums and thus price increases or time delays. JAVYS demands the presence of contractor manager on-site as a mandatory requirement.

### 8.8. Lessons learnt

The political decision on the early closure of Bohunice V1 NPP accompanied with the privatisation project of Slovenské Elektrárne, within which all decommissioning activities were spin-off into a new company JAVYS, a.s. resulted in additional one-off costs for systems modification and change of ownership cost (e.g. new physical protection system).

The arrangement of financial assistance from European Union through EBRD introduced formal procedures for setting up the Bohunice V1 NPP total budget for decommissioning. The on-site PMU with Bank Consultant combined technical and financial expertise. The completeness of the budget and quality of cost estimates were enhanced. The budget was constructed as a comprehensive sum of individual 75 BIDSF projects with each own technical specification and cost estimate taking into account the cost for maintenance and care of facilities and equipment as well as the cost for administrative support activities.

Procurement of BIDSF projects is performed through standard public tender procedure following the EBRD public tender standards. Due to the required formal approval process for BIDSF projects the estimated value of the individual project is set in a conservative manner to avoid the repeating of all preparation and approval process. The actual price from tender procedure is often below the expected value with commercial risk for individual contractors of BIDSF projects.

The role of precise and complete contracts with the exact project technical specification with clear rules, timetable, control mechanisms and multiple milestones is crucial to avoid time delays and cost increases.

For Bohunice V1 NPP decommissioning programme it is important to include the sufficient time reserves in critical path taking into account the possible delays in public procurement procedures or risks in individual projects interdependency.

The total budget for Bohunice V1 NPP is periodically reviewed internally, as well as by EC and EBRD which is crucial to assure its completeness. It assumes the final site remediation as brownfield up to the bottom of the construction dip, cutting and fragmentation of main primary circuit components with full processing and treatment of RAW including their disposal cost and provisions for future decommissioning of RAW treatment facilities. The total budget includes the assumptions for the existence of full necessary infrastructure to conduct an independent decommissioning project in Bohunice V1 NPP.



## Chapter 9. Case study of Spain: Decommissioning of the José Cabrera nuclear power plant

### 9.1. Historical background

José Cabrera nuclear power plant (Figure 9.1) was the first commercial reactor in Spain. The construction began in 1964 and the plant went into operation in 1969. The nuclear steam supply system was made up of a light PWR reactor with electrical power of 160 MW and the auxiliary systems required for the efficient operation of the facility under safe conditions (Table 9.1).

**Figure 9.1: Site configuration during decommissioning projects**



**Table 9.1: Installation main data**

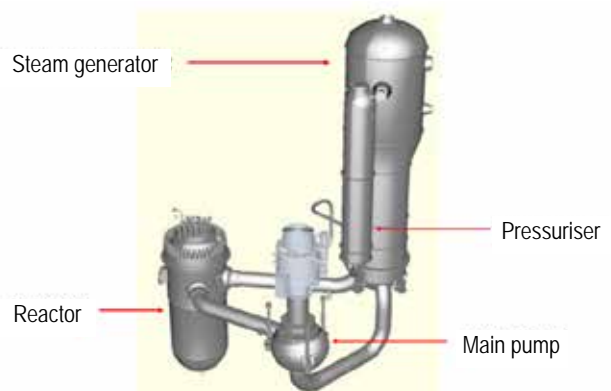
Type	Westinghouse – 1-loop PWR
Net electric power	160 MWe
Net thermal power	510 MWth
Fuel elements	69 – 14x14
Fuel type	UO <sub>2</sub> – enrichment 3.6% (U-235)
Mass UO <sub>2</sub> (core)	20.76 t
Control rod (banks)	17
Reactor vessel (diameter)	2.82 m
Reactor vessel (height without head)	5.87 m
NSSS (diameter)	70 cm
Containment	Reinforced concrete; stainless steel head
Spent fuel pool	In containment
Final cooling	Tajo River

## 9.2. Strategy

Spain possesses a national strategy for the decommissioning and dismantling of operating nuclear power plants (NPPs) that is presented by the General Radioactive Waste Plan (GRWP), the official document issued by the government that defines the national policy for both radioactive waste management and decommissioning.

The Sixth GRWP, currently in force, states as main assumption in relation to this subject that “total dismantling (Level 3) of the light water NPPs, to be initiated three years after their definitive shutdown” for planning and cost estimate purposes.

The decommissioning of José Cabrera NPP (Zorita) is the first total immediate dismantling project to be executed in Spain. It involves performing complex activities, such as the segmentation of all primary circuit components (Figure 9.2).

**Figure 9.2: José Cabrera nuclear power plant primary circuit**

What makes this dismantling project different from others conducted in Spain (Vandellós I) is undoubtedly segmenting the reactor vessel and its internal components, as well as directly conditioning the materials produced in disposal units (containers used up to now only in the El Cabril disposal centre). To implement this, it has been necessary to first undertake major refurbishment work of the existing installations, especially in the former turbine building and in the containment building.

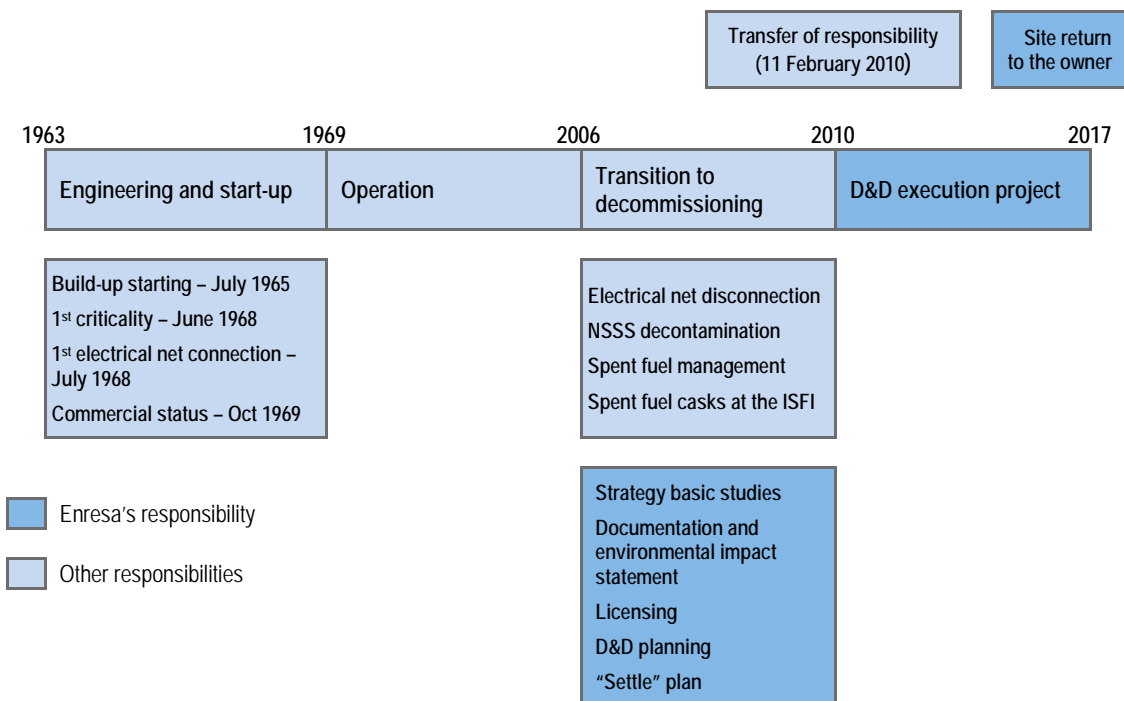
### 9.3. Decommissioning schedule/issues and approaches

José Cabrera NPP was definitively shut down on April 2006. During a transition period of three years, several post-operational activities were accomplished. The primary circuit was submitted to a chemical decontamination and the spent fuel was removed from the pool and transferred to an interim storage facility on-site. These activities were executed under the responsibility of the utility with technical and financial support from Enresa. Along this initial phase Enresa was developing the detailed design and planning of the project and preparing the reglementary documentation required to obtain the authorisation for the decommissioning project.

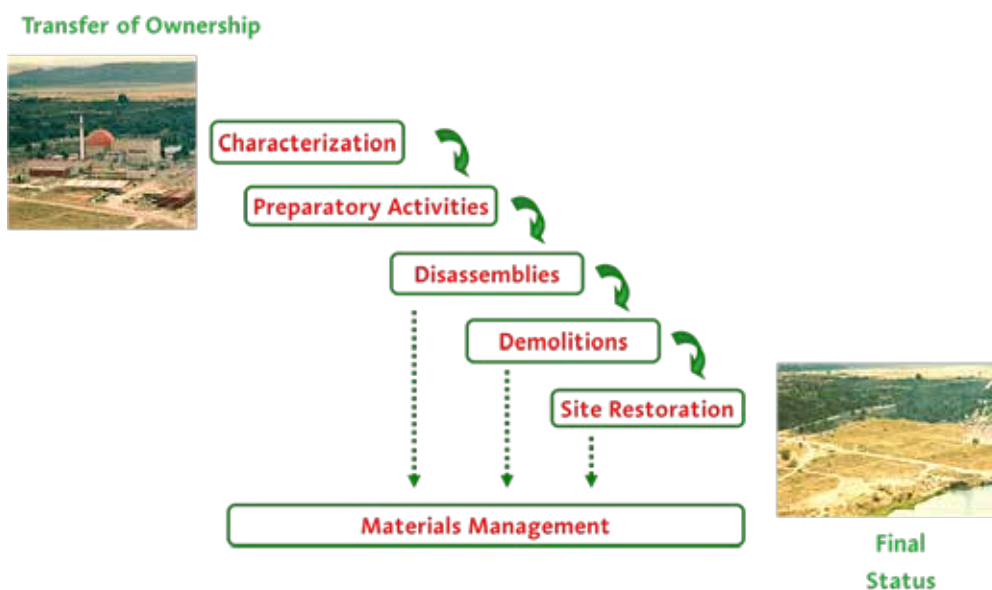
On February 2010, the Ministry of Industry granted the authorisation for the decommissioning project and the plant was transferred from the utility to Enresa.

The next diagram (Figure 9.3) shows the main phases of the life cycle of the José Cabrera NPP.

**Figure 9.3: Main phases of the life cycle of José Cabrera nuclear power plant**



The decommissioning project is a dynamic process that consists of a sequence of activities including, among others, preparatory activities, disassembly, decontamination tasks, demolition and the restoration of the site (Figure 9.4).

**Figure 9.4: Main steps of decommissioning**

One of the most important steps for decommissioning planning is the radiological characterisation of the facility. Generally the characterisation activities begin when the plant is still in operation, and they continue during the dismantling stage according to the needs. The scope of characterisation activities includes not only the installation but also the environment that could be influenced by the operation of the plant. Characterisation data must be collected to determine the type and extent of contaminants before any actual decontamination or dismantling (Figure 9.5).

**Figure 9.5: Steam generator radiological characterisation**

The initiation of dismantling works in José Cabrera NPP required that a series of support systems and auxiliary installations to be available. These preparatory works were carried out during the first two years of the project (2010-2011).

The electrical systems were modified including the installation of a new electrical supply adapted to the needs of the decommissioning process. Mechanical systems (fire-fighting, general services water supply, dilution effluents systems, etc.) and ventilation systems were adapted to new requirements.



The original control room has been replaced by a new surveillance post for the monitoring of systems still in operation.

During this initial period one of the most significant activities was the refurbishment and adaptation of the turbine building as an auxiliary installation for material management. In this respect this building has been reused as a treatment area and temporary store for radioactive waste.

In parallel other facilities related with material management (temporary waste stores, clearance area) were adapted and improved.

The dismantling of conventional elements applies to the components that do not have any radiological connotation. The most significant facilities which have been dismantled are the turbine building, the diesel building, the cooling towers and the electrical transformers, etc. (Figures 9.6, 9.7 and 9.8). The rest of conventional areas will be dismantled according to the progress of the project.

**Figure 9.6: Dismantling of the turbine**



**Figure 9.7: Works to reuse turbine building as radioactive waste storage**



**Figure 9.8: Demolition of cooling towers**



The dismantling of radiological areas represents the most significant activity from the point of view of dose, cost and time. The most complex task to be undertaken is the disassembly and segmentation of the major components of the primary system (reactor internals, vessel, steam generator, pressuriser and coolant pump), which are located inside the containment building.

Also, full or partial system decontamination is sometimes required to reduce occupational exposure during removal.

During 2011, several previous tasks were executed to prepare the reactor cavity and the spent fuel pool for the reactor internals segmentation (removal of concrete wall between cavities, characterisation and removal of remaining elements, inspection and waterproof improvement, filtration of cavities water, etc.). In 2012, started the reactor internals segmentation under water in the spent fuel pool using mechanical tools (Figures 9.9 and 9.10).

**Figure 9.9: Reactor cavities during segmentation activities**



**Figure 9.10: Segmentation of the lower internals**



In 2013, the most activated pieces from the lower internals, closest to the reactor core, with activity levels that do not enable disposal at El Cabril, were placed in four HI-SAFE casks, manufactured from carbon steel and high density concrete (Figures 9.11 and 9.12). These special wastes will be stored in the ISFSI with the 12 existing casks with the spent fuel from the plant.

**Figure 9.11: Special waste load containing the reactor internals**



**Figure 9.12: Transport of HI-SAFE cask to independent spent fuel storage installations**



The least active parts were removed from the cavity using baskets properly shielded, and transferred to the former turbine building, where they were inserted in concrete containers, conditioned and temporary stored until the transport to low- and intermediate-level activity waste disposal centre that Enresa operates at El Cabril (Figures 9.13, 9.14, 9.15).

**Figure 9.13: Removal of waste from reactor cavities for conditioning**



**Figure 9.14: Disposal unit**



**Figure 9.15: Shipment to El Cabril disposal site**

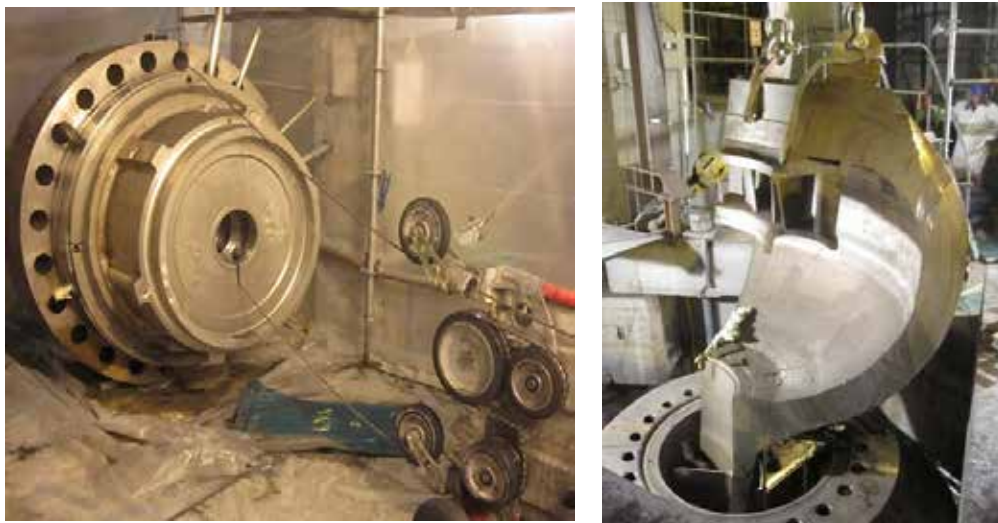


After the segmentation and conditioning of reactor internals, the reactor vessel itself will be cut underwater using similar technologies along 2014 and 2015.

Moreover, the rest of components from primary circuit and radiological systems or reactor and auxiliary buildings are being dismantled (Figure 9.16).

The decontamination of radiological buildings will be carried out following the removal of the components from the different buildings between 2015 and 2016. The surfaces of concrete walls located in radiological zones had to be declassified prior to their demolition, in order to ensure the absence of contamination. Once the buildings are completely empty, and after determining that both the walls and floors are free from contamination, conventional demolition will begin. From 2016 to 2017 the different buildings of the site will be demolished.

**Figure 9.16: Dismantling of elements from the primary pump**



Using the resulting debris, processed in situ, holes discovered in the foundation will be filled in, which will enable a restoration plan to be implemented leaving the site in the same condition as it was in the early 1960s of the last century, the period when the installation was built.

In 2014, an additional characterisation campaign of the site will be launched to complete existing data about condition of soils and underground structures.

During the site restoration it is forecast to remove contaminated soil and to apply a final site release plan to guarantee that the soils are clean of all residual contamination, in order to obtain the closure declaration (Table 9.2).

**Table 9.2: Schedule of the project**

	2010	2011	2012	2013	2014	2015	2016	2017
Preparatory activities	■							
Systems discharge	■							
Modification of systems	■							
Auxiliary facilities	■							
Conventional dismantling	■	■	■	■	■	■	■	■
Radiological dismantling		■	■	■	■	■	■	
Big components			■	■	■	■		
Other components			■	■	■	■	■	
Demolition and decontamination				■	■	■	■	■
Material management		■	■	■	■	■	■	■
Site restoration						■	■	■

#### 9.4. Boundary conditions

José Cabrera decommissioning project is being developed in accordance to the national strategy for decommissioning that gives a clear mandate to Enresa in respect to this point. Another influencing element with regards to the works being undertaken by Enresa is related to the end point of the site that will be returned to the owner free of any radiological constrain. These two points are main elements for the definition of the decommissioning plan proposed by Enresa, as licensee and “decommissioning agent”, to the competent authorities. Implementation and execution of such decommissioning plan becomes Enresa’s solely responsibility which covers related expenses via the dedicated fund for radioactive waste management that is being accumulated through the payment by the operators of regulated fees during operational lifespan based on Enresa’s cost estimates. Such financing system makes utilities free of any further financial liability in case of whatever difference between cost estimate and real cost.

#### 9.5. Radioactive waste features and management strategy

Spain possesses a significant infrastructure for the management of spent nuclear fuel and radioactive waste, from the administrative, technical and economic-financial point of view.

The GRWP currently in force makes a clear distinction between spent fuel and high-level radioactive waste and establishes that, as regards spent fuel, open cycle management is contemplated as the basic option.

The objective of temporary storage is to provide sufficient capacity to house the spent fuel generated by the Spanish nuclear power plants until such time as a definitive solution becomes available.

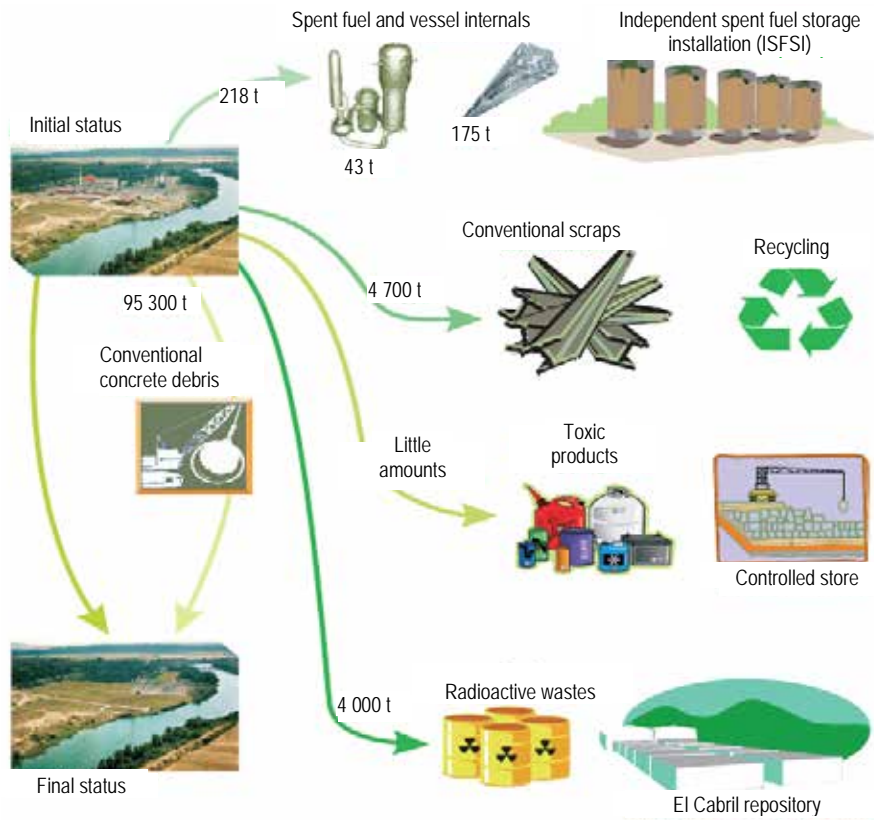
Regarding low- and intermediate-level radioactive waste (LILW), the “El Cabril” disposal facility in the province of Córdoba is the central axis around which the national LILW management system revolves. Its fundamental objective is the definitive disposal of this type of waste in solid form, although it also has various other technological capabilities.

According to the GRWP, Enresa has developed dedicated management routes for all the types of radwaste arisen from the decommissioning of José Cabrera NPP. Of the total of more than 104 000 tonnes, it is estimated 4 000 tonnes will be radioactive wastes, i.e. 3.88% of the total, of which 3.84% will be very low-level waste (VLLW), LILW and the remaining 0.04% special wastes and high-level waste (i.e. SF).

Materials management is an activity that is performed though all the phases of the decommissioning project. This activity is developed along four lines of management: conventional waste management, material clearance process, management of radioactive waste and management of hazardous waste.

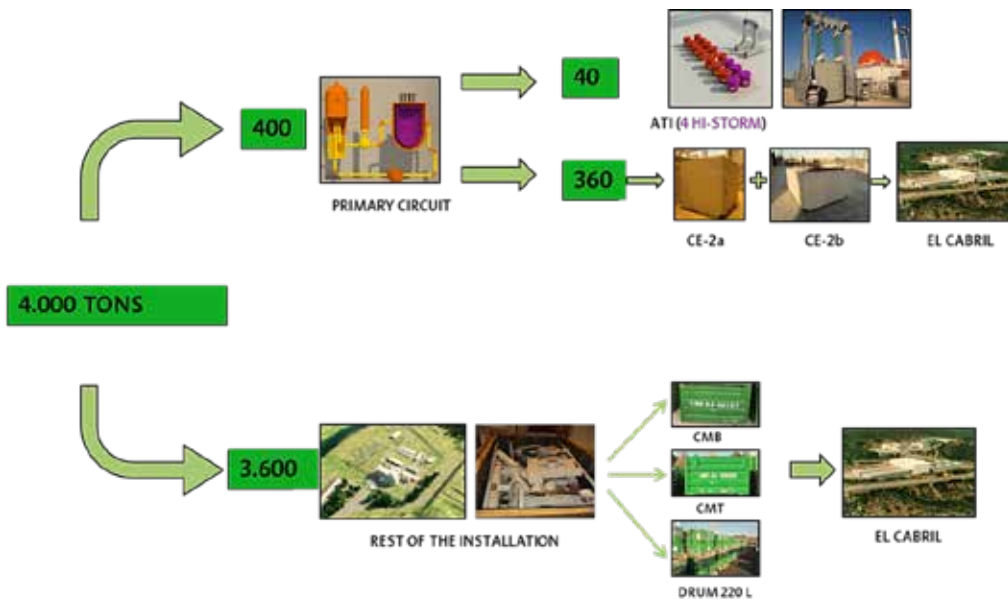
In order to minimise the volume of wastes and identify ways for reusing the rest of the materials, Enresa implements a management system guaranteeing their correct destination, especially for those arising from the active parts of the facility. In this respect, Enresa has developed, as in previous projects, a material clearance methodology to ensure that no material leaving the plant exceeded the levels of activity required by the regulator for consideration as non-radioactive. This methodology allows to manage clean materials generated during the decommissioning of radiological areas as conventional materials (Figure 9.17).

**Figure 9.17: José Cabrera nuclear power plant material management**



The next diagram details the typologies and amounts of radioactive wastes to be managed during José Cabrera NPP decommissioning project Figure 9.18.

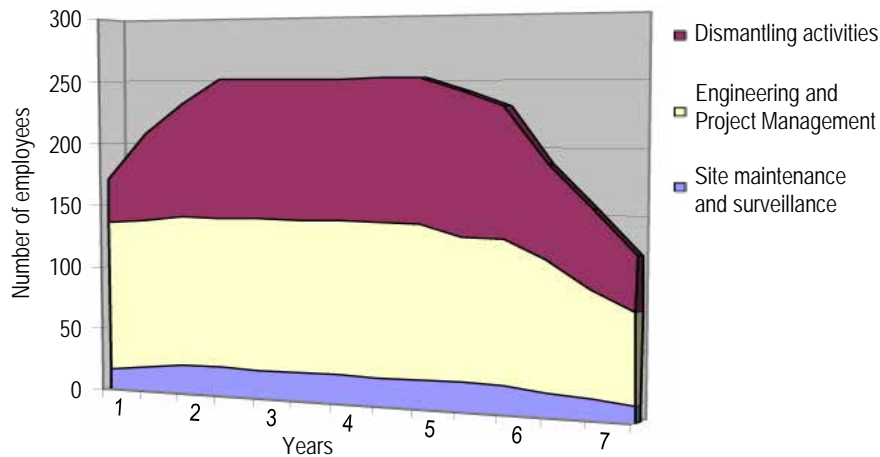
**Figure 9.18: Typologies and amounts of radioactive waste to be managed**



## 9.6. Project management and organisation

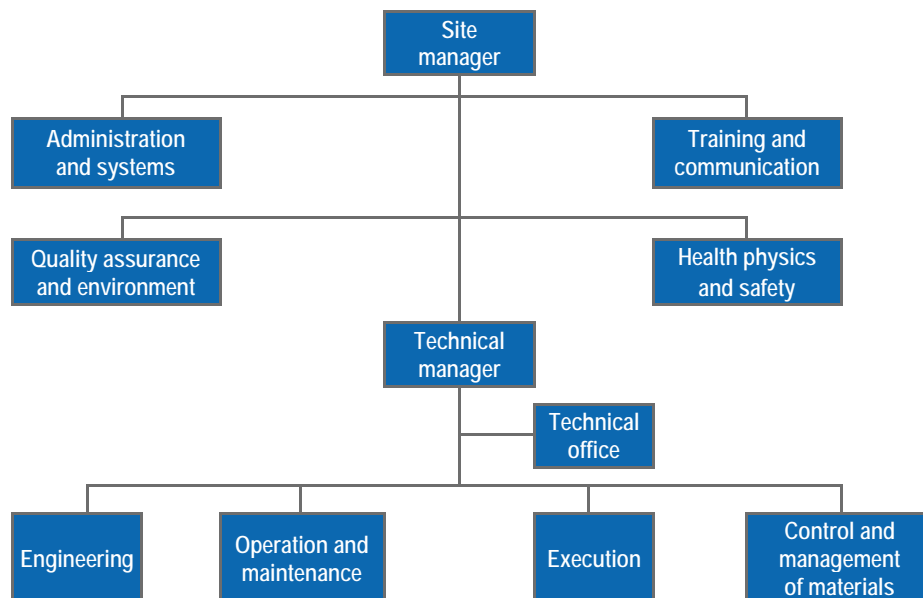
The organisational structure established during decommissioning and the responsibilities and functions of different departments involved are considered on the “Operation Handbook” which is a licensing document approved by the regulatory body and the Ministry of Industry. This document specifies the organisation and functions of the personnel under both normal and emergency conditions (Figure 9.19). It also describes the safety management in place and the basic training programmes established for licensed and unlicensed personnel.

**Figure 9.19: Personnel evolution during the project**



The organisation chart of José Cabrera NPP during decommissioning project is shown in Figure 9.20. Enresa is supported by specialised contractors during decommissioning projects. Presently there are approximately 250 people working on-site. Personnel working on the facility will be adapted according to the progress of works as we can see in the next graph.

**Figure 9.20: Organisation chart**



## 9.7. Site remediation

As has been stated above, future site remediation will be aimed to liberate the site of any radiological constrain and fulfilling any environmental condition for further industrial use. Reaching this status, will allow Enresa to return the site to its owner (i.e. utility) who will be then in position to decide on its potential reuse.

## 9.8. Variation of cost estimates over time

The decommissioning of José Cabrera NPP is ongoing. Presently the project achieves a progress of 60% approximately. The estimated cost has been calculated considering real costs corresponding to executed works (2006-2013) and the budget until the end of the project (2014-2017).

The main assumptions to establish the cost estimate for the dismantling of José Cabrera NPP are:

- cost estimate methodology:
  - real costs of executed works (2006-2012);
  - budget 2013-2017.
- storage of the spent fuel on-site until availability of CTS;
- decommissioning strategy:
  - fully remotely dismantling of reactor internal and vessel;
  - small piece removal, packaging and disposal of components from primary circuit;
  - site restoration.
- waste management:
  - to be disposed of directly to a waste repository;
  - decommissioning cost estimate does not consider radioactive waste (high-, intermediate- and low-level) disposal cost.

Initially costs were estimated following several methodologies.

### 9.8.1. Cost depending on the activity

These costs are calculated taking in account cost factors and the physical and radiological inventory of the plant. Cost factors consider duration of the activity, labour and procurement cost.

This methodology applies to the:

- dismantling of components (radiological and conventional);
- buildings decontamination and demolition;
- packaging and conditioning of radwaste (transport and disposal are not considered);
- site restoration.

### 9.8.2. Dismantling of large components

These costs consider following activities:

- segmentation of reactor internals;



- segmentation of reactor vessel;
- other components of the primary circuit;
- demolition of activated biological shielding.

### 9.8.3. Costs depending on schedule

Duration of specific tasks is estimated according to the decommissioning schedule. Costs are established taking into account teamwork composition and the hourly rates existing for each labour category (engineer, radiological protection technician, etc.).

This methodology applies to:

- engineering, licensing documentation development and works support;
- project management;
- radiological surveillance;
- supervision of works (execution, quality assurance, etc.);
- operation and maintenance of systems.

### 9.8.4. Other costs (taxes, security, insurance, etc.)

Table 9.3 shows the cost estimate for the José Cabrera NPP Decommissioning Project (EUR/2014) according to the guidance provided by the *International Structure for Decommissioning Costing (ISDC) of Nuclear Installations* that includes project cost, exploitation costs and SF management cost on-site.

**Table 9.3: Cost estimate for the José Cabrera NPP decommissioning project according to ISDC guidance**

Cost item	Cost (EUR <sub>2014</sub> )
Pre-decommissioning	13 000 000
Facility shutdown	4 000 000
Dismantling activities within controlled area	42 000 000
Waste processing, storage and disposal	10 000 000
Site infrastructure and operation	66 000 000
Conventional dismantling, demolition and site restoration	15 000 000
Project management, engineering and site support	52 500 000
Fuel and nuclear material	42 000 000
Miscellaneous expenditures	14 000 000
<b>Total</b>	<b>258 500 000</b>

## 9.9. Uncertainties and contingencies

Dismantling a nuclear power plant such as Zorita involves a number of risks and uncertainties that could compromise correct execution of the project and therefore could increase the cost initially forecasted. For this reason, it is necessary to employ a system of working that enables them to be identified at the earliest opportunity so that they can be managed in a timely fashion.

The main practices employed to identify actual and potential risks and opportunities that could affect the project at any time have been the following:

- constantly monitoring of the work schedule;
- carrying out detailed analysis of interfaces and uncertainties associated with each task involved.

Consequently, risk management has not been focused on as a specific activity, but has been an integral part of every meeting held by the multidisciplinary project team.

### **9.9.1. Cost drivers**

The next paragraph will describe some cost drivers, whose effective management could prevent from having economic deviations in the decommissioning project.

They are grouped around the following topics:

1. Project design.
2. Relationships with the regulatory authorities.
3. Contracting.
4. Waste management.
5. Project tracking.

#### *1. Project design*

The project design phase is basic to all dismantling. The more complete the documentation is prepared, the better the actual conditions at the plant and its operating history are researched, the fewer risks and uncertainties will arise during the implementation phase.

In the case of José Cabrera NPP, the preparatory work prior to the start of dismantling provided sufficient detail about the plant and its condition at the time of its transfer to Enresa. However, during the work there were setbacks resulting from a lack of knowledge about the actual state of the plant, in particular regarding the following:

- the radioactive waste inventory remaining at the plant, from the operations stage;
- the conservation status of some systems needed for dismantling;
- non-standard infrastructure and equipment;
- undocumented presence of toxic and/or hazardous products (asbestos).

In general, these occurrences required actions not initially planned as part of the work schedule, producing occasional overruns and delays in the early stages of the project.

For instance ventilation system of the plant was in a worse condition than initially preview. This situation provoked additional works (repair tasks of existing systems, design modifications, exhaustive test plan, etc.) in order to comply with regulatory requirements.

#### *2. Relationships with the regulatory authorities*

The decommissioning of José Cabrera NPP required a continuous dialogue with the regulatory authorities for various reasons, particularly the numerous partial authorisations required throughout the project. The authorisations required from the regulator included the following:

- implementing new systems required for dismantling;

- design modifications to original systems;
- material and surface clearance methodologies.

Achieving the work schedule, largely depends on these authorisations being granted at the right time and with conditions consistent with those already provided for the authorisation obtained at the start of the dismantling project as a whole.

The dismantling experience at the José Cabrera NPP shows that:

- Sometimes, especially at the beginning of the project, the time planned to obtain authorisations was unrealistic, and was shorter than actually required.
- As a corrective measure, in addition to adjusting schedules to accommodate the real time required, prior contacts with the regulatory authority were intensified, in order to make them aware in previous conceptual meetings and presentations, of the content of documents and proposals to be authorised. These meetings proved to be very effective, greatly facilitating the licensing processes.
- The regulations applicable to ventilation systems, at the time of the project authorisation, were less stringent than those applying when the modifications were made, several months later. This resulted in substantial changes to both the type of equipment to be installed, which had already been contracted, and the applicable test protocols, leading to overruns and delays in implementing these systems.

As a result, it was found that unstable regulations or regulations which change over time, are a risk relevant to dismantling projects, which are usually very long-term projects.

### 3. Contracting

The strategy adopted for contracting process and the management of the corresponding contracts, is a key aspect of project management.

The policy adopted in dismantling Zorita NPP has been to divide works into contracts, always incorporating the latest information available and with well-defined scopes and deadlines. The opposite option adopting only one or several large "turnkey" contracts is judged to be very risky because of the impossibility of defining the scopes in detail, and the difficulty of incorporating the contingencies that are inevitably required for this type of work.

After the contracts have been established, it is important to establish clauses enabling contractors to be penalised, incentivised or redirected, to reinforce control of works.

Some of the types of problems encountered during the work are as follows:

- Difficulty experienced by some contractors in performing the detailed engineering required. Some of the contractors were not used to work in nuclear sector. They had problems to prepare suitable documentation provoking a supplementary control and support by Enresa.
- The boundaries between the work carried out by different contractors may be blurred (example: in situ decontamination of components versus workshop decontamination, dismantling of systems and decontamination of surfaces, by different contractors).
- Difficulty in redirecting a contractor, due to the lack of penalty/termination clauses for interim deadline defaults.
- The lack, in some cases, of mechanisms to incorporate additional work (contingencies) within the scope of the contracts.

For example the adaption of the former turbine building as an area for treatment and storage of rad waste required additional works not initially previewed: increase of storage capacity (new foundations, thickness of the slab, etc.), waterproof tasks on the building roof, reinforcement of ventilation system and improvement related with industrial safety requirements.

#### 4. Waste management

Material management is a critical activity to comply with the objectives of cost and time associated to decommissioning projects. The availability of treatment processes and suitable facilities for material management on-site, such as disposal centres for the different typologies of radioactive wastes to be generated, is essential to assure the success of the project.

The waste generated by the dismantling has to be managed taking in account the acceptance criteria existing at the storage and/or treatment centres.

It is important to be familiar with all the flows of material to be managed and to ensure that they are all properly documented and authorised, so that waste can be dispatched from the site as soon as possible.

During the José Cabrera NPP dismantling, various material flows were not initially foreseen in the project waste management plan, which caused additional workloads and cost overruns.

On the positive side, the treatment conditions for specific waste were more advantageous than initially contemplated. So, the purification filters for the water from the cavities, where the segmentation was conducted, have been managed using the same types of concrete containers used for the reactor internals, instead of drums. This avoided numerous manual actions (slicing) and resulting in reducing costs, time and the radiological impact on workers.

#### 5. Project tracking

An ongoing and rigorous analysis of the work programme is essential for managing project risks. Providing timely and complete information on each of the activities, analysing potential problems in implementing them, and taking compensatory measures if such problems arise, are essential to mitigate the consequences of unforeseen events.

One example has been the contingency plan established for possible leaks in the liner of the spent fuel pool during segmentation of the reactor internals. Early implementation of a water recirculation system helped solve two incidents in which large pieces of metal collided with and pierced the liner, causing minor leakage of water from the cavities.

This thorough analysis of the programme led to the segmentation activities on the steam generators being advanced by at least 12 months. These tasks were initially scheduled after completion of the internals segmentation. In an “express” operation, initially not contemplated to take place at that time, before cutting up the internals, the primary circuit was drained and the hot and cold branches isolated, enabling the large component dismantling schedule to be significantly advanced.

Unlike construction work in which the sequence of actions must necessarily follow a predefined path, dismantling enables a certain degree of freedom and numerous parallel activities to be managed. A good work monitoring programme is key to take advantage of the opportunities presented.

### 9.10. Lessons learnt

Four years after the execution of the project started, a significant portion of the components of the José Cabrera NPP have been removed, and their waste properly

managed, those including the reactor internals, the cooling pump, the pressuriser and 50% of the steam generator. Presently the project is on time and on budget.

A detailed design, an effective project management and an exhaustive control of decommissioning schedule result essential to handle with the inevitable uncertainties and unexpected events during decommissioning.

Analysis and assessment of real costs associated to José Cabrera decommissioning project will contribute with valuable information to obtain accurate cost estimate for future projects.



## Chapter 10. Case study of Switzerland

### 10.1. Short historical background

A new Nuclear Energy Act came into force on 1 February 2005. It allowed the possibility of building new reactors, with the possibility of a referendum against their construction; no time limit is imposed on the life of existing nuclear power plant; the general licence is maintained. It introduces a ten-year moratorium on the export of nuclear fuel for reprocessing from 2006 to 2016. It also includes provisions for decommissioning, a concept of monitored long-term geological disposal of radioactive waste that combines elements of final disposal and reversibility, and a system for funding the costs of decommissioning and of radioactive waste management. It simplifies licensing procedures and introduces the general right of appeal. A new Nuclear Energy Ordinance came into force together with the act.

Following the reactor accident at Fukushima Daiichi, the head of the Federal Department of the Environment, Transport, Energy and Communications (DETEC) announced in mid-March 2011 that the pending procedures for handling applications for general licences for new nuclear power plants had been suspended. Then, in the course of 2011, with their decision to withdraw from the use of nuclear energy on a step-by-step basis, the Federal Council and Parliament laid the foundations for a new energy policy, the Energy Strategy 2050. In this context, the intention is to operate Switzerland's five nuclear power plants until they reach the end of their service life, not to replace them with new ones and decommission them.

### 10.2. Nuclear power plants: Overview

#### 10.2.1. Status and performance of nuclear power plants

Five nuclear power plants (NPPs) at four sites are currently in operation in Switzerland (see Table 10.1).

**Table 10.1: Status and performance of nuclear power plants**

Station	Type	Net Capacity (MWe)	Operator	Status	Reactor supplier	Construction date <sup>+</sup>	Grid date <sup>++</sup>	Commercial date	Shutdown date
Beznau I	PWR	365	Axpo AG	In operation	WH	01-09-1965	17-07-1969	01-09-1969	-
Beznau II	PWR	365	Axpo AG	In operation	WH	01-01-1968	23-10-1971	01-12-1971	-
Mühleberg	BWR	373	BKW FMB Energie AG	In operation	GETSCO	01-03-1967	01-07-1971	06-11-1972	Presumed 2019
Gösgen	PWR	1 010	Kernkraftwerk Gösgen-Däniken AG	In operation	KWU	01-12-1973	02-02-1979	01-11-1979	-
Leibstadt	BWR	1 220	Kernkraftwerk Leibstadt AG	In operation	GETSCO	01-01-1974	24-05-1984	15-12-1984	-

WH = Westinghouse Electric Corporation; GETSCO = General Electric Technical Services Corporation; KWU = Siemens Kraftwerk Union AG.

+ Date, when first major placing of concrete, usually for the base mat of the reactor building is done. ++ Date of the first connection to the grid.

There are four research reactors and two central disposal facilities for radioactive waste. Disposal facilities for radioactive waste are situated in the surroundings of the NPPs too. Switzerland's five NPPs have a total capacity of 3.3 GW, and an annual availability rate of approximately 90%.

### **10.3. Legal framework and boundary conditions**

#### **10.3.1. Legal framework for funding of waste management and decommissioning**

In accordance with the polluter pays principle, producers of radioactive waste in Switzerland are responsible for ensuring its safe disposal at their own cost. The various ongoing costs (e.g. studies carried out by Nagra, construction of interim storage sites, site selection procedure for deep geological repositories) have to be paid as they arise. Decommissioning costs and expenditure associated with the management (including disposal) of radioactive waste after a nuclear power plant has been closed down, are secured through contributions paid into two independent funds by the operator:

- decommissioning fund;
- waste disposal fund.

The Nuclear Energy Act and the Ordinance on the Decommissioning Fund and the Waste Disposal Fund form the legal basis for these two funds. The Nuclear Energy Act requires the operator of a nuclear facility to regularly update the decommissioning plan during the operation period. At the end of the operational lifetime of the facility, he must submit a decommissioning project. After this project has been reviewed and approved by the authorities, a decommissioning order is issued by the licensing authority (DETEC). The legislation thus addresses all aspects of decommissioning at the appropriate stage of facility development.

Radioactive wastes arise from the commercial use of nuclear energy for electricity production and from the use of radioactive materials in medicine, industry and research (MIR). The "polluter pays" principle is anchored in Article 31 of the Nuclear Energy Act: "Anyone who operates or decommissions a nuclear installation is obliged to safely manage all radioactive waste arising from that installation at their own cost". Waste that does not arise from the nuclear power plants (MIR waste) has to be delivered to the Swiss Confederation in accordance with Article 27 of the Radiological Protection Act; the confederation charges a fee for this service.

The waste producers responsible for the construction and operation of facilities for the disposal of radioactive waste are thus the Swiss Confederation and the operators of the nuclear power plants. The duty of disposal is fulfilled according to Article 31 of the Nuclear Energy Act when "the radioactive waste has been transferred to a deep geological repository and the funds required for the monitoring period and the eventual closure have been secured" (see Figure 10.1, closure order).

Article 77 of the Nuclear Energy Act requires the operators of the nuclear power plants to set up decommissioning and waste disposal funds; following the shutdown of the plants, these have to contain sufficient capital to cover the decommissioning and waste disposal costs respectively.

The purpose of the decommissioning fund is to cover the costs of decommissioning and dismantling of nuclear installations and disposing of the waste arising from these activities; the fund has been in existence since 1984.

The purpose of the waste disposal fund is to cover the costs of disposing of operational waste and spent fuel assemblies following the definitive shutdown of a nuclear power plant. The fund was set up in 2000. Waste disposal costs arising during operation are paid on an ongoing basis from the operating accounts or from provisions



set aside in accordance with Article 82 of the Nuclear Energy Act and Article 669 of the Code of Obligations (see Figure 10.1 which provides an overview of the link between the sub-studies). The relationship between the licensing situation and securing of the financing of the post-operational phase, decommissioning and waste disposal is also shown in the figure.

The calculation of the contributions to the decommissioning and waste disposal funds and the financial provisions set aside by the operators for waste disposal is based on a comprehensive estimate of the decommissioning and waste disposal costs that is carried out every five years (Art. 4 of the Funds Ordinance).

The costs for the so-called post-operational phase are reassessed together with the updating of the decommissioning and waste disposal cost studies; these are paid directly by the power plants and provisions also have to be set aside for this purpose.

The expenditure associated with the post-operational phase corresponds neither to the definition of waste disposal costs in the sense of Article 3 of the Funds Ordinance nor to the definition of decommissioning costs according to Article 2 of the Ordinance. It falls under the operating licence and is thus to be considered as the final stage of the operational phase. The post-operational phase is financed directly by the plant operators, who have to set aside the necessary provisions.

The last estimate of the decommissioning and waste disposal costs was based on data from the year 2006. It was reviewed by the nuclear safety authority HSK (now the Swiss Federal Nuclear Safety Inspectorate – ENSI), approved by the Commission of the Decommissioning and Waste Disposal Funds (Funds Commission) and formed the basis for the provisions and funds contributions for the period 2007-2011. As part of the legally prescribed periodic updating, swissnuclear was requested by the Funds Commission at the beginning of 2010 to reassess the costs together with other organisations responsible for radioactive waste disposal in Switzerland and to submit the results by the end of 2011. The Federal Nuclear Safety Inspectorate reviewed the studies until October 2012. The conclusion of this review is provided in Section 5.

### **10.3.2. Boundary conditions and assumptions in the context of the Cost Study 2011**

In this case study the estimate of the decommissioning costs of the Cost Study 2011 is summarised. The next study is foreseen for 2016.

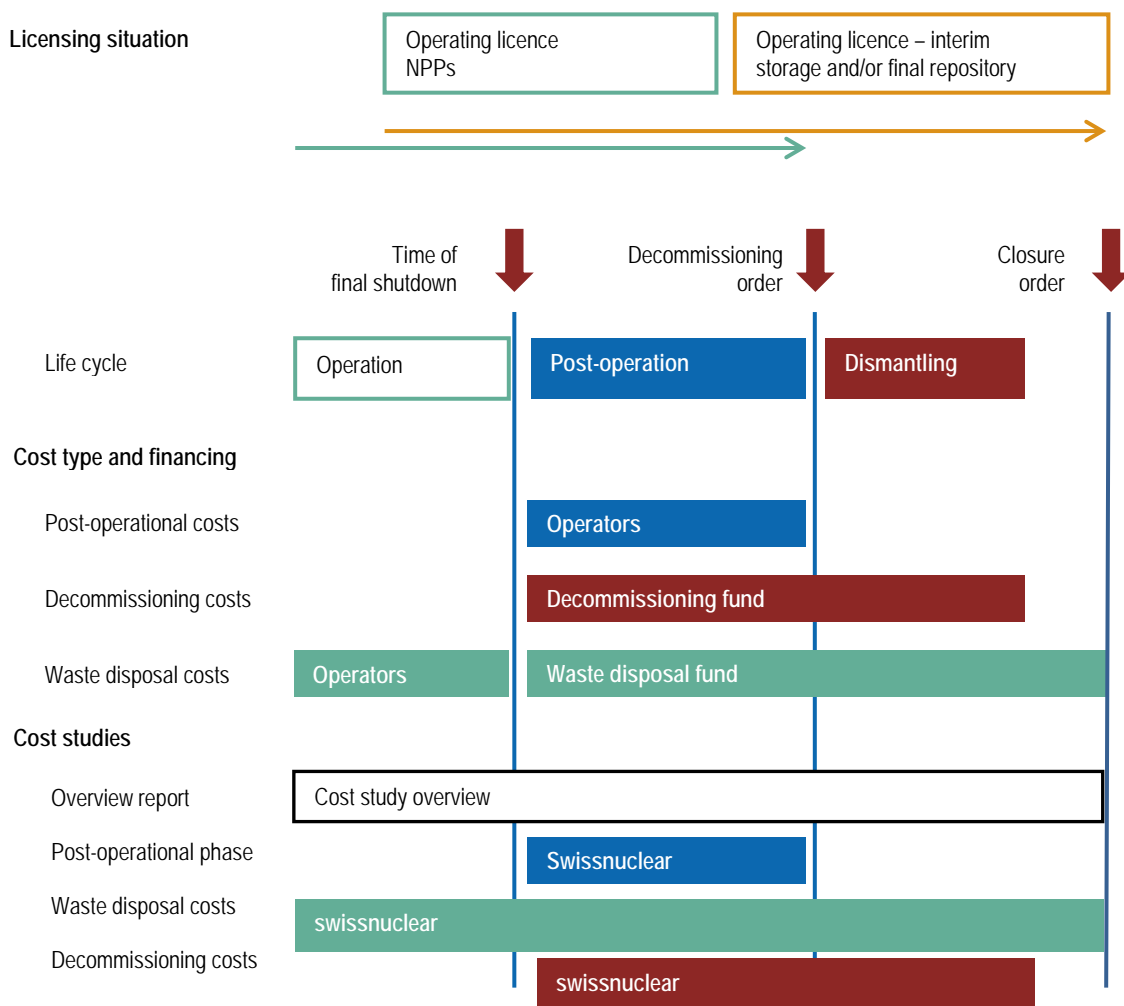
The implementation programme for the present cost study is based on the information in the Waste Management Programme of 2008. From 2016, the cost studies and the Waste Management Programme will be prepared synchronously.

Figure 10.1 shows the relationship between the licensing situation and the financing of the post-operational phase, decommissioning and waste disposal, including the main documents of the Cost Study 2011.

The basis for the calculations assumes an operating lifetime of 50 years for the nuclear power plants (Article 8 of the Funds Ordinance). If a plant can be operated for longer, the DETEC is responsible for modifying the calculation basis.

The decommissioning model used assumes that the condition of the plant at the start of the dismantling work differs from the operational state in that there are no longer any fuel assemblies in the plant and that all operating media that are no longer required, as well as the operational waste, have been removed from the plant. The post-operational phase begins directly after final shutdown of the plant. It comprises the (operational) measures that are necessary for the safe operation of the systems that are still required, as well as measures for preparing for decommissioning.

**Figure 10.1: Overview of the links between the sub-studies**



The activities in the post-operational phase are covered by the operating licence according to the Nuclear Energy Act (see Figure 10.1). During the post-operational phase, the fuel assemblies have to be further cooled, secured and packaged in transport and storage casks. The post-operational phase ends five years after the final shutdown of the plant. During this time, all the fuel assemblies have to be removed to a storage facility that is independent of the plant. The transfer of the operational waste to a centralised interim storage facility or a geological repository is also done during the post-operational phase.

The first decommissioning activities run in parallel with the post-operational phase; these include preparing the documentation for the decommissioning project and obtaining the decommissioning order, as well as making preparations for dismantling. The dismantling and demolition work begins after the post-operational phase, i.e. after the granting of the decommissioning order by the responsible department. An NPP will have been completely dismantled and returned to a greenfield site within 15 to 20 years after final shutdown. The plant is then released from the provisions of the Nuclear Energy Act.

As foreseen in the Funds Ordinance, Cost Study 2011 is based on the current Waste Management Programme. The disposal concepts defined in the programme are in line with legal and regulatory requirements and, in particular, they implement the legally

prescribed concept of deep geological disposal (pilot facility, test facility, main facility; monitoring phase following the operational phase). Once waste emplacement operations in the repository are complete and the disposal chambers have been closed, most of the surface facility will be dismantled and a monitoring phase begins. After ten years, the direct accesses to the disposal chambers and the access tunnel are backfilled and sealed. After a further 40 years, the entire facility is decommissioned and dismantled and the remaining underground installations are backfilled and sealed (see Figure 10.1, closure order).

### **10.3.3. Specific boundary conditions and assumptions for the Decommissioning Cost Study, Cost Study 2011**

Besides the data on the plant, a series of boundary conditions, assumptions and input data have to be specified for estimating the decommissioning costs; without these it would be impossible to estimate the costs of a project that lies far in the future. Unless explicitly mentioned, the assumptions were applied to both the Swiss nuclear power plants and the central interim waste treatment and storage facility.

The following boundary conditions apply for the Swiss decommissioning studies Cost Study 2011:

- Final shutdown of the plant is followed by a so-called post-operational phase that falls under the operating licence. The key activities of the NPP in the post-operational phase are the handling and removal of the fuel assemblies, control rods, neutron sources and other operational waste and media. The costs of these activities are contained in the operating reserves and the required funds are set aside; they are therefore not part of the decommissioning study. In the case of the central interim waste treatment and storage facility, there is no post-operational phase: decommissioning will take the form of immediate dismantling of the facility from 2065 once all the stored fuel assemblies and radioactive waste have been removed to a geological repository.
- Decommissioning takes the form of immediate dismantling of the plant, i.e. without a phase of safe enclosure. Decommissioning activities such as the preparation of the decommissioning project begin in parallel with the post-operational phase.
- Decommissioning follows orderly operation. Sufficient time is available for planning and preparation of the required documentation for decommissioning.
- It is assumed that an order for decommissioning will be granted by the responsible department after timely submission of a decommissioning project in line with applicable laws, ordinances and other regulations in Switzerland. At the same time, the responsible department specifies what work requires a clearance by the regulatory authority.
- The documentation to be submitted together with the decommissioning project presents the overall concept and also contains an environmental impact assessment. Once the decommissioning order has been granted, the implementation of the individual steps is done as part of clearances by the authorities.
- Effects due to delays caused by the procedure for obtaining the decommissioning order are not taken into consideration.
- Effects due to potential participation of the public in the procedure for obtaining the decommissioning order are not taken into consideration.
- It is assumed that the regulatory authority or its experts will monitor and support the progress of work over the entire dismantling period.

- It is assumed that the responsible department will decide soon after the orderly completion of the decommissioning work that the facility no longer represents a radiological hazard and can be released from the provisions of the nuclear energy legislation.
- The dismantling of installations and demolition of buildings are included in the cost estimates. In the case of the central interim waste treatment and storage facility, the following applies: The dismantling of the installations from the controlled zone and the demolition of building V (plasma furnace) are taken into consideration. After decommissioning, the rest of the facility can be made available for economic operation.
- The radioactivity inventory is made up of two components (for the central interim waste treatment and storage facility: only contaminated material): activated material (in the area of the neutron field) and contaminated material.
- The radioactivity inventory of the activated components was determined by Nagra for the present decommissioning study. The volume of contaminated material is calculated by analysing available plant-specific data and the values to be used for the study were determined. In the case of the central interim waste treatment and storage facility, the following applies: to determine the volume of contaminated material, available facility-specific data are analysed and the values for the study are determined. Natural radioactivity is not considered.
- Contamination is assumed to be present for all the installations in the controlled zone until control measurements show that the contamination is below the permissible clearance values. The basis for deciding this is provided by the clearance values contained in the Swiss Radiological Protection Ordinance (reference date 1 January 2011) (exemption limit (LE, limite d'exemption), guidance value (surface contamination/CS) and dose rate  $\leq 0.1 \mu\text{Sv/h}$  at a distance of 10 cm from the surface).
- All conventional buildings and the terrain of the site are checked for contamination. It is assumed that no contamination is present.
- The procedures and equipment used for decommissioning correspond to the technological state-of-the-art.
- It is assumed that suitable facilities are available for the further treatment and conditioning of dismantled materials, either on-site (e.g. specially constructed for this purpose) or externally (e.g. the plasma furnace at the central interim waste treatment and storage facility). Following system decontamination aimed mainly at reducing the dose rate, facility components are decontaminated for later clearance.
- Dismantling activities generate only low- and intermediate-level wastes. These are conditioned in accordance with the regulations applying in Switzerland (e.g. HSK Guideline B05) and agreements with the National Cooperative for the Disposal of Radioactive Waste (Nagra). It is assumed that the low- and intermediate-level radioactive waste (LILW) repository will be available from 2035. The costs of interim storage are shown.
- The disposal containers for radioactive wastes are assumed to be in line with the specifications provided by Nagra. The maximum activity per container is limited by the applicable transport regulations and not by the LILW repository. The voids in the containers are filled with suitable materials (e.g. cement-based fillers). It is also aimed to comply with the target value of  $5 \text{ W/m}^3$  for the specific heat output per container volume. Special thick-walled MOSAIK containers are used for

packaging activated reactor pressure vessel (RPV) internals. The MOSAIK containers will be sealed in an LC1 disposal container at the LILW repository site.

- The costs of transport from the plant/facility to the LILW repository are calculated using a specific cost basis per transport or storage container (CHF 10 000 per container), irrespective of the distance to the LILW repository.
- To demonstrate the absence of contamination, the building structures within the steel containment are dismantled under the conditions that apply for a controlled zone.
- The demolition of the buildings with a controlled zone is done after the relevant areas have been de-zoned by the authorities. All other buildings are demolished independently of this.
- Building structures are basically demolished to a depth of 2 m below the ground level of the power plant site. Facilities and installations are dismantled to greater depths and – if required – the building surfaces are decontaminated to below the applicable clearance values, released and de-zoned.
- The concrete rubble produced by conventional demolition of buildings is broken up and separated from the rebar. In the case of the central interim waste treatment and storage facility: The concrete rubble from conventional demolition of building V (plasma furnace) is broken up and separated from the rebar. 50% of it is then disposed of and 50% is used cost-neutrally for other purposes (e.g. road construction).
- To estimate the manpower requirements for carrying out the work, personnel qualifications are specified and standard rates derived from current practice are assumed. It is assumed that personnel with knowledge of the plant will be available.
- The dismantling of contaminated and activated components and the dismantling of the activated biological shield (bioshield) and the drywell wall will – as far as reasonable – be carried out in single or multiple shift operation.
- The surveillance of the plant will continue round the clock to an appropriate level.
- The effort required for the so-called operations during dismantling is defined and taken into account in the costs.
- The insurance premiums (nuclear insurances and property insurances) are assumed to be in line with current requirements (e.g. Nuclear Energy Liability Act). The planned increase in insurance premiums for nuclear liability is not taken into account as the relevant Convention has not yet entered into force (it still has to be ratified by some EU countries).
- If it is necessary for the cost calculations to convert currency from Euros to Swiss Francs, the following conversion rate is assumed: EUR 1 = CHF 1.40.
- The figures in this cost estimate are so-called “best estimates”. Such costs assume a detailed scientific-technical concept based on current knowledge and a clear time sequence of events. The costs are estimated realistically but without any additional safety reserves according to best expert understanding at current market prices (overnight costs).
- The decommissioning costs are recalculated at regular intervals to take into account the uncertainty associated with the calculation. The costs are calculated assuming the best possible use of current scientific-technical know-how and are based on prices applying at the time of the calculation.

## 10.4. Contents of studies and results

### 10.4.1. Summary of post-operational phase

A concept for implementing the post-operational phase of the Swiss NPPs was developed based on the boundary conditions and assumptions set out in Chapter 2. This takes into account practical experience from ongoing decommissioning projects (e.g. Stade and Obrigheim in Germany) and specific Swiss boundary conditions such as legal regulations, waste management strategies, etc.

Besides the activities associated with the removal of the fuel assemblies and the operational tasks required for maintaining the systems for cooling the fuel, the measures in the post-operational phase are focused on the following:

- disposal of the operational waste from plant operation;
- disposal of the operational waste arising during the post-operational phase;
- disposal of reactor waste (this can arise during the operational or post-operational phase);
- shutting down systems that are no longer required;
- orderly operation (including all repair and maintenance measures) of the systems that are still required as well as general facility operation (so-called post-operation).

The division of the costs arising in the post-operational period into operational, decommissioning and waste disposal costs is presented in the following tables.

Table 10.2 shows the total costs of the post-operational phase for the Swiss NPPs. The results of the 2006 cost estimate are shown for comparison purposes. The estimates are carried out in each case at the monetary value of the year of the estimate. To allow a direct comparison, the costs estimated in 2006 are projected from the 2006 price basis to the 2011 price basis using an inflation rate of 3% per year that is anchored in the Funds Ordinance and taken into account in the financial provisions model.

**Table 10.2: Cost estimates for the post-operational phase for cost study 2011 and cost study 2006, using a 2011 price basis (CHF million)**

Post-operational phase costs	PWR1	BWR1	PWR2	BWR2	Total
Cost Study 2011, price basis 2011	475	319	455	460	1 709
Cost Study 2006, price basis 2011	462	250	481	486	1 678
Difference absolute	13	69	-26	-26	31
Difference (%)	3%	28%	-5%	-5%	2%

Table 10.3 shows the breakdown of costs for PWR2. Please notice that the subtotal of CHF 448 million corresponds to position 02 (facility shutdown) in the International Structure for Decommissioning Costing (ISDC) Structure (Table 10.8) and that the operation of the wet storage facility (CHF 7.1 million) corresponds to position 10 (fuel and nuclear material) in the ISDC structure.

**Table 10.3: Costs of the post-operational phase for PWR2**

Cost type	Total costs post-operational phase 5 years CHF million
<b>Manpower costs</b>	<b>206.25</b>
Permanent staff	201.98
External staff	4.28
<b>Operating and maintenance costs (without operational waste)</b>	<b>146.04</b>
Auxiliary and operating materials	
Energy costs (electricity)	11.90
Ongoing maintenance	21.90
Swiss Federal Nuclear Safety Inspectorate costs	79.34
	32.91
<b>Water supply costs</b>	<b>2.20</b>
<b>Other expenditure</b>	<b>85.99</b>
Land and buildings	
Insurances	22.25
<i>Machine breakage insurance</i>	14.33
<i>Comprehensive property insurance</i>	2.02
<i>Nuclear liability insurance</i>	2.61
<i>Various</i>	9.67
Rents and leases	0.03
Business and administration costs	2.79
Social security costs	37.00
Other expenditure	3.63
	6.00
<b>Additional expenditure</b>	
Taxes	3.75
	3.75
<b>Subtotal</b>	<b>444.23</b>
<b>One-off costs after end of operation</b>	<b>3.80</b>
Disposal of reactor waste (without container costs)	3.80
<b>Subtotal</b>	<b>448.03</b>
<b>Operation of the wet storage facility during the post-operational phase</b>	<b>7.10</b>
<b>Total</b>	<b>455.13</b>

#### 10.4.2. Summary of Decommissioning Study Cost Study 2011, comparison with Cost Study 2001 (status 2006)

The Nuclear Energy Act and the Nuclear Energy Ordinance require updating of decommissioning plans for nuclear facilities on a regular basis (ten-year cycle) and, as necessary, taking account of changes made to the facilities, changes in the regulations and technological development. The Ordinance on the Decommissioning and Waste Management Funds requires a periodical update of the decommissioning cost estimate (five-year cycle). The operators of the NPPs have elaborated detailed decommissioning studies for their facilities that are based on the decommissioning plans.

The last full revision of the decommissioning cost study was in 2001. The study was updated in 2006 but not recalculated from scratch. To take into account knowledge and experience from ongoing decommissioning projects in Germany and the current conditions in Switzerland, swissnuclear requested the NIS Engineering Group (NIS Ingenieurgesellschaft mbH) to prepare new decommissioning studies for the Swiss nuclear power plants and the Zwiilag interim storage facility.

The results of the 2011 estimate of the decommissioning costs are compared in the table below with the estimate for 2001, updated in 2006. To allow a direct comparison, the costs estimated in 2006 are projected from the 2006 price basis to the 2011 price basis using an inflation rate of 3% per year that is anchored in the Funds Ordinance and taken into account in the provisions model. These studies were revised in 2011. The decommissioning plans have been reviewed and approved by the authorities from a technical and financial point of view in 2012. A new revision of the decommissioning studies will be submitted by the end of 2016.

Corrected for inflation, the decommissioning costs for 2011 are around 17% higher than the 2001 study (including the 2006 update). A significant contribution to the increase in costs is due to operational activities that continue to be required during dismantling (so-called operations during dismantling), the scope and duration of which has been expanded based on information from ongoing decommissioning studies. The above-average increase in the case of the PWR1 is largely due to the sequential dismantling of the two reactor units. For the first time, the new decommissioning study for the central interim waste treatment and storage facility was carried out on the same basis as the NPP studies. This means that the 2006 and 2011 studies for the central interim waste treatment and storage facility are difficult to compare, but this is also due to a significant cost element (operations during dismantling) for the central interim waste treatment and storage facility being allocated to the decommissioning costs rather than the waste disposal costs. For the sake of completeness, the resulting costs are, however, included in Table 10.4.

**Table 10.4: Estimate of decommissioning costs for cost study 2011 and cost study 2006 (update of 2001 study), using a 2011 price basis (CHF million)**

Decommissioning costs	PWR1	BWR1	PWR2	BWR2	H/I/LW interim storage	Total
Cost Study 2011, price basis 2011	809	487	663	920	95	2 974
Cost Study 2006, price basis 2011	631	440	605	835	31	2 541
Difference absolute	178	47	59	86	64	433
Difference %	28%	11%	10%	10%	204%	17%

Note: Differences in the sums are due to rounding.

N.B. The sum of the amount of PWR2 given in this table (CHF 663 million) and the amount of PWR2 in Table 10.2 (CHF 455 million) gives the sum in Table 10.8.

#### 10.4.3. Detailed comparison of 2001 study (status 2006) and 2011 study

In the 2001 and 2011 studies, the decommissioning measures were compiled hierarchically on different levels in a project structure plan and the contents and costs to be calculated were divided into work packages. These work packages are compared in Table 10.5.

The contents of the work packages “decontamination” and “radiological and worker protection” from the 2001 study were distributed among other work packages because of the similarity of content. The expenditure and costs for these two work packages from the 2001 study are divided into the new work packages for the 2011 study.



The work packages “project supervision by the authorities”, “construction site operation and protection of property” and “project and construction management” are brought together in the 2011 study in the work package “operations during dismantling”. This package contains all the activities that enable and maintain the operation of the construction site. This includes higher-level activities such as plant and project management, project co-ordination (e.g. supervising and guiding external companies), top-level construction management, contact with the authorities, required operating and maintenance activities and other expenditure. It also includes guarding of the plant until it can be released from the provisions of the Nuclear Energy Act. It is assumed that the authorities and their experts will permanently monitor the progress of the project. Compared to the 2001 study, the largest changes are in this work package (Table 10.5).

**Table 10.5: Work packages for planning and estimating decommissioning costs**

Work packages	
2001 study	2011 study
Planning and preparing documentation	Decommissioning project and decommissioning order
Review and licensing	
Preparing the plant for dismantling	Preparatory measures
Dismantling of contaminated components	Dismantling installations of the controlled zone – units 1 and 2
Dismantling of activated components (RPV and RPV internals)	Dismantling of RPV internals and RPV – units 1 and 2
Dismantling of biological shield	Dismantling of biological shield – units 1 and 2
Dismantling of remaining components	Remaining dismantling of installations of the controlled zone – units 1 and 2
Building decontamination and clearance of building surfaces	Decontamination and release of buildings
Decontamination*	
Radiological and worker protection*	
Conditioning and disposal	Material treatment and disposal
Emptying buildings and demolition	Dismantling installations in conventional areas and conventional demolition
Project supervision by the authorities	Operations during dismantling
Construction site operation and protection of property	
Project and construction management	
-	Dismantling of the interim waste storage facility

\* In the 2011 study, these items were spread in the other work packages.

The costs were determined using the NIS programmes developed specially for calculating the decommissioning and dismantling costs for nuclear installations. The programmes used to calculate the costs for the 2011 study are a further development of those used for the 2001 study.

The last full decommissioning studies were carried out for BWR1, PWR2 and BWR2 in 2001 and for PWR1 in 2002. The technical content of these cost studies was updated in 2006. All the information in this chapter that relates to the 2001 and 2002 studies is understood to include the updates made in 2006.

The costs in the 2001 study were determined on the 2001 price basis. For the cost calculation on the 2006 price basis, the results were adjusted using an annual inflation

rate of 3% per year (Art. 8, Funds Ordinance). In the 2011 study, the expected costs for decommissioning the Swiss nuclear power plants were completely recalculated on a 2011 price basis. In order to compare the results of the 2001 and 2011 studies, the costs for the 2011 study on a 2011 price basis are compared with the costs of the 2001 study on a 2011 price basis (escalated with the annual 3% inflation).

The basis for the cost calculation is a dismantling concept that corresponds to the current state of technology and takes into account procedures and techniques that are being used in ongoing dismantling projects.

The costs (2001 and 2011 studies) consist mainly of the following:

- manpower costs;
- material costs, e.g.:
  - investments (e.g. new equipment, remote handling equipment);
  - consumables (e.g. operating media, clothing, decontamination agents, tools).
- disposal costs, e.g.:
  - costs for external treatment of materials (plasma furnace at the central interim waste treatment and storage facility, melting facilities);
  - disposal costs;
  - container costs;
  - transport costs;
  - allocable repository costs.

The overall results of the cost estimates for the 2001 and 2011 studies are compared in the tables below, using the example of PWR2, a typical PWR.

These Tables 10.6 and 10.7 are structured as follows:

**Column A:** This column contains the results of the 2001 study, including the estimate of relevant changes from the year 2006, corrected for inflation to the price basis for 01/2011 (assumption: 3% inflation per year, Art. 8 of the Funds Ordinance). The costs for the work packages “decontamination” and “radiological and worker protection” are allocated to the work packages of the 2011 study.

**Column B:** This shows the percentage of the work package costs to the total costs.

**Column C:** This column shows the costs determined for the 2011 study (price basis 01/2011).

**Column D:** Similarly to column B, this shows the percentage of the work package costs to the total costs.

**Column E:** This shows the difference between the results for the 2011 study (column C, price basis 01/2011) and the results of the 2001 study escalated to the same price basis (column A).

**Column F:** This column gives the percentage difference in costs in columns C and A.

The work packages “decontamination” and “radiological and worker protection” in the 2001 study are no longer used in the 2011 study. The percentage distribution of the content of these work packages to other work packages is shown in Table 10.7.

**Table 10.6: Decommissioning costs for PWR2**

NPP decommissioning Cost Study 2001 (updated 2006)			NPP decommissioning Cost Study 2011			Delta	
Work package (WP) Cost study/price basis	A 06/2011* CHF million	B (A/total A)	Work package	C 11/2011 CHF million	D (C/total C)**	E (A-C) CHF million	F (E/C) Per WP
Planning and preparing documentation	25.6	4%	Decommissioning project and order	21.3	3%	-8.2	-28%
Review and licensing	3.9	1%					
Preparing the plant for dismantling	41.7	7%	Preparatory measures	44.0	7%	2.2	5%
Dismantling contaminated components	30.6	5%	Dismantling installations of controlled zone	24.2	4%	-6.4	-21%
Dismantling activated components (RPV and RPV internals)	34.3	6%	Dismantling RPV and RPV internals	39.5	6%	5.2	15%
Dismantling of bioshield	1.8	0%	Dismantling of bioshield and drywell components	3.9	1%	2.1	115%
Dismantling of remaining components	8.9	1%	Remaining dismantling of installations of controlled zone	12.9	2%	4.0	45%
Building decontamination and clearance of building surfaces	40.2	7%	Decontamination and release of buildings	36.9	6%	-3.4	-8%
Decontamination	***	***					
Radiological and worker protection	***	***					
Conditioning and disposal	111.1	18%	Material treatment and disposal	112.8	17%	1.7	2%
Emptying buildings and demolition	108.0	18%	Dismantling installations of conventional area and conventional demolition	52.8	8%	-55.2	-51%
Project monitoring by authorities	198.3	3%	Operations during dismantling	314.9	47%	116.6	59%
Construction site operation and property protection							
Project and construction management							
Totals	604.5	100%		663.1	100%	58.5	10%

\* Escalation according to Funds Ordinance (3%/year).

\*\* 0% means that the value is less than 0.5%.

\*\*\* Measures are contained in other work packages (see Table 10.7).

**Table 10.7: New distribution of measures in “decontamination” and “radiological and worker protection” work packages, PWR2**

Work package	[CHF <sub>01/2001</sub> million]	Percentage distribution
<b>Decontamination</b>	<b>39.87</b>	
Preparing the plant for dismantling	5.65	14%
Dismantling of contaminated components	1.77	4%
Dismantling of activated components (RPV internals and RPV)	0.62	2%
Dismantling bioshield and drywell components	0.09	0%
Dismantling of remaining components	0.68	2%
Building decontamination and clearance of building surfaces		0%
Conditioning and disposal	22.20	56%
Construction site operation and property protection; project and construction management	8.87	22%
<b>Radiological and worker protection</b>	<b>34.87</b>	
Preparing the plant for dismantling		0%
Dismantling of contaminated components	3.03	9%
Dismantling of activated components (RPV internals and RPV)	1.27	4%
Dismantling bioshield and drywell components	0.16	0%
Dismantling of remaining components	0.38	1%
Building decontamination and clearance of building surfaces	2.92	8%
Conditioning and disposal	8.70	25%
Construction site operation and property protection; project and construction management	18.41	53%

Column E shows that the following six work packages of the 2011 study have costs above those in the 2001 study (column A):

- preparatory measures;
- dismantling of RPV internals and RPV;
- dismantling bioshield;
- remaining dismantling of installations of the controlled zone;
- material treatment and disposal;
- operations during dismantling;

The higher costs for the work package “preparatory measures” are due to the reassessment (almost triple) of the required manpower.

The higher costs in the work packages “dismantling of RPV internals and RPV” and “dismantling bioshield” result from a reassessment (work package 4 → tripling/work package 5 → doubling) of the required manpower and the costs of the tools to be used.

The higher costs for the work package “remaining dismantling of installations of the controlled zone” result on the one hand from moving the dismantling effort from the work package “dismantling the installations of the controlled zone” into this work package and, on the other hand, from reassessment of the work effort involved. The costs

of these two work packages together give a slightly lower amount than the sum of the costs for the 2001 study (column A). Moving the measures between the work packages was due to the new time sequence for dismantling. In the present decommissioning study, dismantling of the activated components (RPV internals, RPV, bioshield, etc.) is assumed to take place earlier than in the 2001 study. The dismantling of the contaminated components therefore occurs later and is considered in the work package “remaining dismantling of installations of the controlled zone”. The higher allocable repository costs have an effect on the work package “material treatment and disposal”.

The fact that the total costs for the 2011 study are still around 10% higher than the inflation-adjusted costs for the 2001 study is mainly due to the work package “operations during dismantling”. This work package comprises all measures that ensure the operation of the construction site.

#### **10.4.4. Lessons learnt**

The 2011 decommissioning study and the associated cost calculation take into consideration the experience and know-how of NIS from ongoing decommissioning studies. The main changes compared to the 2001 study can be summarised as follows:

- Some of the decommissioning work is already carried out during the post-operational phase (e.g. shutdowns, system decontamination, providing replacement systems).
- The activated RPV internals are dismantled as early as possible in the project to allow water-bearing systems to be shut down, thus reducing maintenance and repair work.
- The boundary conditions set by the Swiss waste management concept (e.g. placing drums and MOSAIK containers in disposal containers only at the repository site) result in higher costs for the packaging of radioactive waste (e.g. MOSAIK containers) and transport to the repository. The allocable costs for the repository have also increased.
- The dismantling effort and the duration of dismantling work have increased/extended based on experience and know-how gained in real projects.
- Operations during dismantling have been completely reassessed based on new understanding. The new approaches are effectively responsible for the overall increase in costs.
- When planning becomes more detailed in the future, the possibility will exist for optimisation in some areas, e.g. material treatment and disposal (keyword: melting, packaging), use of replacement systems (keyword: maintenance and repair measures) or planning the timing of dismantling measures (keyword: time optimisation).
- It has become apparent from ongoing decommissioning projects in Germany in the last years that insufficient attention has been paid to this area of activity in the decommissioning cost estimates to date. In particular, the costs of maintenance and repair during decommissioning and dismantling have been underestimated.

### **10.5. Major results of the ENSI review, revision of funds ordinance and regulatory guideline on decommissioning**

In October 2012, ENSI published the result of its review of the Cost Study 2011.

ENSI concluded that the last updates or new cost studies for decommissioning which were prepared in 2011 by NIS Ingenieurgesellschaft mbH of Germany, on behalf of the

operators' organisation swissnuclear, took account of the latest knowledge available regarding the decommissioning of nuclear power plants. ENSI concluded that the 2011 cost study was delivered in complete form by swissnuclear, and that it was carried out correctly. The cost estimates presented in the 2011 cost study are what is known as "best estimates". "Best estimate" costs are expenses based on a detailed technical and scientific concept, in accordance with the latest knowledge available and a clear time progression of events. Furthermore, ENSI concluded that the total costs of decommissioning the nuclear plants in Switzerland can be kept, provided that planning is optimised and that lessons already learnt are incorporated. Moreover, the costs of dismantling should reduce in the future because there is a constantly growing experience in dismantling nuclear plants throughout the world. The total costs determined in each case are therefore within the bandwidths to be expected, as compared with international decommissioning projects. It is anticipated that the actual decommissioning costs will be within the usual industrial cost range of -15% to +30% as compared to the cost studies. This level of accuracy is adequate for the current status of planning.

According to a subsequent revision of the Ordinance on the Decommissioning and Waste Management Funds for Nuclear Facilities, a contingency of 30% of the overall overnight costs shall be taken into account for determining the provisions for the decommissioning and Waste management funds starting with the 2011 cost study.

In April 2014, ENSI put a new guideline into force that regulates all aspects of decommissioning and dismantling of nuclear installations in Switzerland (Guideline ENSI-G17). The new guideline respects WENRA's safety reference levels in the field of decommissioning and the corresponding IAEA Safety Standards. This guideline will for example apply when updating the decommissioning plans or preparing a decommissioning project.

For the next cost study CS16, a prudent consideration of risks and uncertainties may follow as a result of the 30% contingency. Also the application of the new Guideline ENSI-G17 needs to be addressed in the CS16.

## 10.6. Key players in Switzerland

The Federal Council is responsible for decision-making regarding the application for general licence. The decision of the Federal Council will be brought before parliament. It is then subject to an optional national referendum. The Swiss government consists of the seven members of the Federal Council who are elected by the United Federal Assembly for a four-year term.

DETEC is responsible for the decision-making regarding the application for construction and operating licence. Its decisions can be appealed to the Federal Administrative Court, and at a later stage to the Federal Supreme Court. About 1 900 people work within DETEC (including its agencies like the Swiss Federal Office of Energy – SFOE).

The SFOE has the lead on all three authorisation procedures. The SFOE employs almost 200 staff members. As of the beginning of March 2013, the SFOE comprises six divisions and two operational sections. The Swiss cost studies 2011 have been published by SFOE, see [www.stilllegungsfonds.ch](http://www.stilllegungsfonds.ch) (in German).

The Swiss Federal Nuclear Safety Inspectorate (ENSI) is the national regulatory body with responsibility for the nuclear safety and security of Swiss nuclear facilities. In the licensing procedures it is also responsible for safety-related examination and assessment of the facilities. Most of ENSI's expenses are covered by fees which licence holders have to pay to the federal government. ENSI currently employs around 150 staff members: physicists, mechanical, electrical and civil engineers, geologists, chemists, biologists and psychologists, in addition to technical and administrative personnel.

Other public entities involved in the above mentioned authorisation procedures are the Swiss Federal Nuclear Safety Commission (NSC), the Federal Office for the Environment (FOEN), the Federal Office for Spatial Development (ARE) and the cantons.

### **10.7. Radioactive waste features (e.g. volumes and activity) and management strategy in Switzerland**

In 1972, the producers of radioactive waste in Switzerland, i.e. the Swiss Confederation and the operators of the nuclear power plants, set up Nagra to take responsibility for waste disposal. Waste from MIR is collected (subject to a charge) and passes into the ownership of the Swiss Confederation, which is then responsible for its disposal.

#### **10.7.1. Waste management programme**

The waste producers are required by Article 32 of the Nuclear Energy Act to prepare a waste management programme (WMP). This is reviewed by the authorities and approved by the federal government (federal council). The WMP has to provide information on the volumes and types of radioactive waste, the required geological repositories and their design concepts, the allocation of the waste to the repositories, the programme for implementing geological disposal and the financing of waste disposal.

The WMP has to be updated periodically to take account of changing boundary conditions. The authorities are responsible for checking that the waste producers observe the terms of the Programme (including financing). The implementation programme for the present cost study 2011 is in line with the current Waste Management Programme (WMP08). From 2016, the cost study and the Waste Management Programme will be prepared synchronously.

#### **10.7.2. Waste disposal pathway**

The waste disposal pathway describes the steps carried out for disposing of radioactive waste as follows:

- preparing the scientific basis/inventorying of the waste;
- collection of operational radioactive waste by the waste producers;
- conditioning, i.e. transforming the waste into a state that is suitable for geological disposal, plus packaging;
- transport;
- reprocessing of spent fuel;
- interim storage;
- decommissioning of the nuclear installations and conditioning/packaging of the resulting decommissioning waste;
- emplacement of the waste in deep geological repositories.

After the spent fuel assemblies not foreseen for reprocessing have cooled sufficiently in the NPP cooling ponds or the wet storage facility, they are loaded, without pre-treatment, into transport and storage casks and stored in the interim storage facilities. Waste from reprocessing is also stored at the interim storage facilities. Low- and intermediate-level waste from the Swiss NPPs and MIR waste are conditioned in the waste treatment facility.

All radioactive waste is to undergo storage in repositories situated in suitable geological formations; near-surface disposal is not allowed. Since no repository is yet available, all radioactive waste is stored in interim storage facilities.

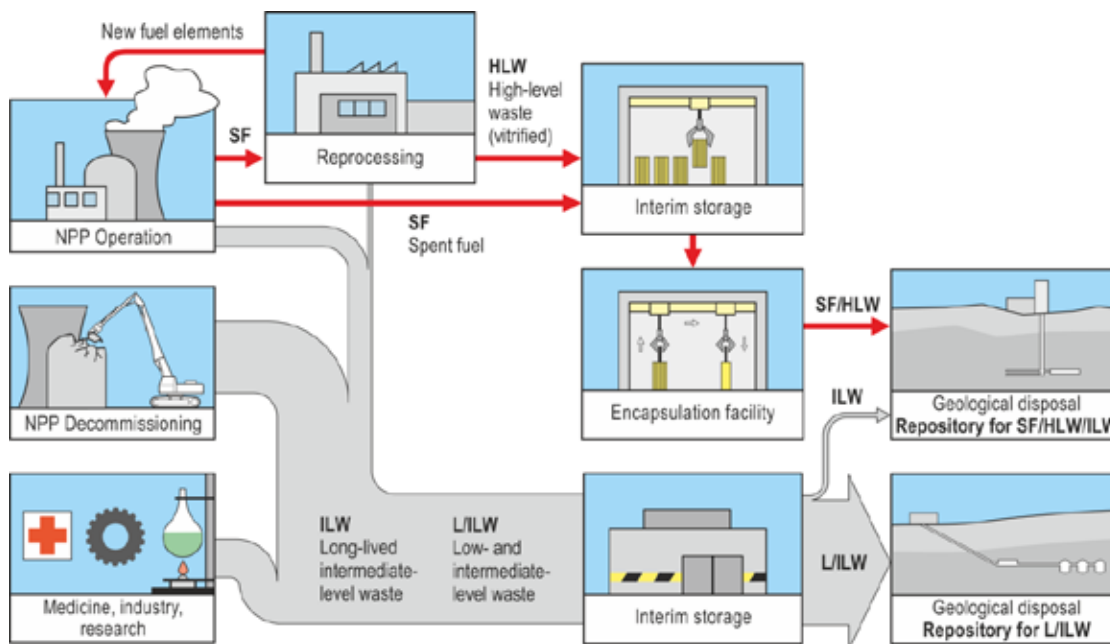
### 10.7.3. Storage facilities

At present, the following spent fuel and radioactive waste management facilities exist in Switzerland:

- NPPs: All Swiss NPPs have on-site installations for the conditioning and storage of their own operational waste.
- Central storage facility: This facility is comprised of an interim storage facility for spent fuel and all kinds of radioactive waste including decommissioning waste, conditioning installations and a plasma furnace for melting and incineration of low-level waste.
- Separate storage facility at Beznau nuclear power plant: It consists of a hall for low-level operational and decommissioning waste and a hall for the dry storage of spent fuel.
- Wet storage facility at Gösgen NPP: This facility storage is an additional spent fuel pond on the site of the Gösgen nuclear power plant. It is intended for independent operation over several years after the future shutdown of the Gösgen nuclear power plant.
- National collection centre and federal storage facility: These installations for radioactive waste from medicine, industry and research are operated by the Paul Scherrer Institute in Würenlingen.

A schematic representation of the waste disposal pathway is shown in Figure 10.2.

**Figure 10.2: Steps in the Swiss radioactive waste disposal pathway**



Source: Nagra.

### 10.7.4. Radioactive waste

The origin, types and volumes of radioactive waste for disposal in Switzerland are known. The waste undergoes continuous characterisation, inventorying and conditioning. In



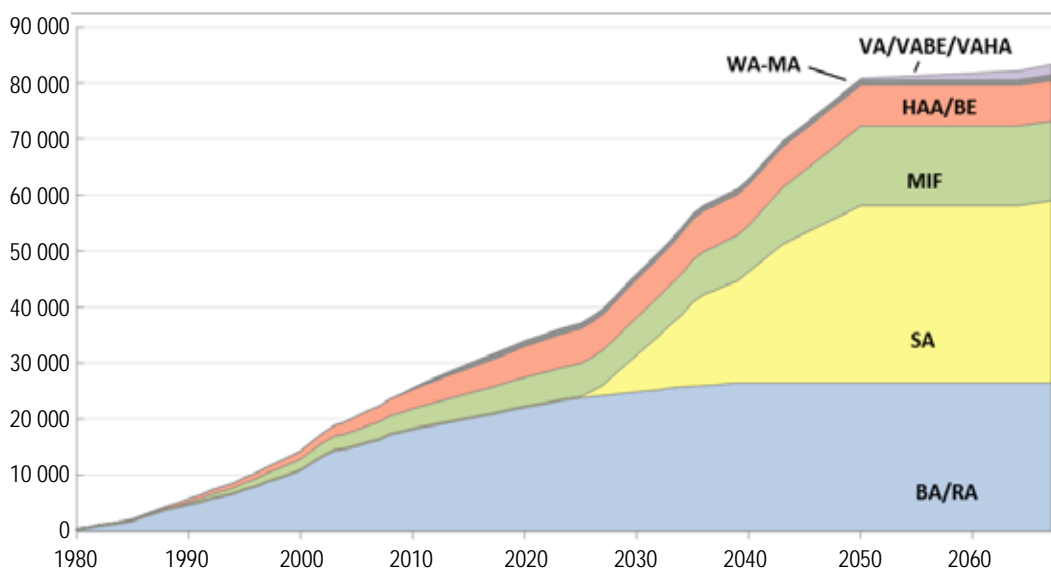
addition to a databank on waste that already exists, there is also a model inventory of waste that will arise in the future; together, these provide a reliable basis for planning and realising the required waste management infrastructure and securing its financing.

Radioactive waste is classified according to origin:

- operational and decommissioning waste from MIR;
- operational waste and reactor waste from the NPPs;
- decommissioning waste from the NPPs;
- spent fuel assemblies;
- reprocessing waste – vitrified high-level waste (HLW) and intermediate-level waste (ILW);
- waste from the encapsulation plant arising from the packaging of fuel assemblies and high-level waste.

Figure 10.3 shows the arising of radioactive waste (in m<sup>3</sup>) with time from the existing NPPs (assuming a 50-year operating lifetime) and MIR waste for a collection period up to 2050 Basis WMP08 and 2011 cost study (closure of the LILW repository).

**Figure 10.3: Evolution of radioactive waste (in m<sup>3</sup>) over time from the existing Swiss nuclear power plants for an operating lifetime of 50 years, and from medicine, industry and research for a collection period up to 2050\***



Source: Nagra.

\* Volumes of conditioned waste packaged in disposal containers.

BA/RA = Operational waste from NPPs (BA)/reactor waste (RA) from NPPs, i.e. activated metallic waste.

SA = Decommissioning waste from NPPs.

MIF = Operational and decommissioning waste from medicine, industry, research.

HAA/BE = High-level (reprocessing) waste (HLW) and spent fuel (SF).

WA-MA = Intermediate-level waste (ILW) from reprocessing.

VA/VABE/VAHA = Waste from encapsulation plants for ILW, LILW, HLW and SF.

In addition to origin, radioactive wastes have to be distinguished in terms of their hazard potential. In order of decreasing hazard, they are divided into:

- high-level waste (HLW);
- long-lived intermediate-level waste (ILW);
- low- and intermediate-level waste (LILW).

The Nuclear Energy Act anchors the duty of waste disposal in the form of the “polluter pays” principle and also states specifically in Article 31 that radioactive waste has to be disposed of in deep geological repositories.

However, the legislation leaves open the question of whether all waste types (HLW, ILW, LILW) should be disposed of in a single (combined) repository, with the highest requirements on geology, or in two separate repositories, with the requirements on geology and boundary conditions for the engineered barriers matched to the radiotoxicity and type of waste.

The current Waste Management Programme foresees two geological repositories – one for HLW and one for LILW. Based on current understanding, ILW will be emplaced in the HLW repository.

#### **10.7.5. Deep geological repositories and site selection process**

Two repositories are proposed, one for short-lived LILW and one for high-level waste and spent fuel as well as long-lived intermediate-level waste mainly from reprocessing (HLW). The site selection process has to follow a sectorial plan procedure within the framework of spatial planning legislation. The site selection process according to the sectorial plan procedure for deep geological repositories was started with the promulgation of the “Sectorial Plan for Deep Geological Repositories” on 2 April 2008 by the Federal Council. It will last around 15 years and lead to the decision of the Federal Council regarding the issuing of the general licences for the repositories.

### **10.8. Decommissioning variants for Switzerland**

According to standard international practice, there are several different strategies for decommissioning a nuclear power plant. For legal reasons (Art. 26 par. 2d together with Art. 31 par. 2a of the Nuclear Energy Act), Switzerland considers only immediate dismantling or deferred dismantling with safe enclosure.

The decommissioning variant is selected in line with Swiss legislation, namely the nuclear energy and radiological protection legislation, as well as environmental legislation.

The main objective when selecting the strategy is to ensure that, after proper completion of the decommissioning work, the facility no longer represents a source of radiological hazard and is thus no longer subject to the provisions of the nuclear energy legislation.

Legal decommissioning requirements are taken into consideration when making the decision. These include in particular:

- nuclear safety and security;
- the availability of another nuclear facility to which the nuclear materials present in the plant can be removed;
- possibilities for decontaminating the radioactive components;

- the possibility to dispose of the radioactive waste, particularly the timely availability of operating deep geological repositories;
- the possibility to monitor the facility until all nuclear hazard sources have been removed.

Besides the aspects to be considered under the Nuclear Energy Act, other issues also have an influence on the decision. According to internationally accepted standards on protection of man and the environment as formulated in the regulations of the International Atomic Energy Agency (IAEA), the preferred variant is immediate dismantling. The following considerations also support this variant:

- Knowledge of the plant that only operating personnel have should remain available, i.e. no loss of know-how.
- Systems still available from operation can be used (e.g. ventilation systems, processing plants for radioactive waste).
- With longer waiting times (safe enclosure can last for more than 50 years), the ability to measure certain radionuclides becomes more difficult.
- The waste management strategy in Switzerland, i.e. restricted (in time) availability of a deep geological repository.
- Dismantling as soon as possible is preferable because of the small land area of Switzerland.
- Considerable experience is available from decommissioning projects with immediate dismantling (e.g. NPP Stade, NPP Obrigheim).

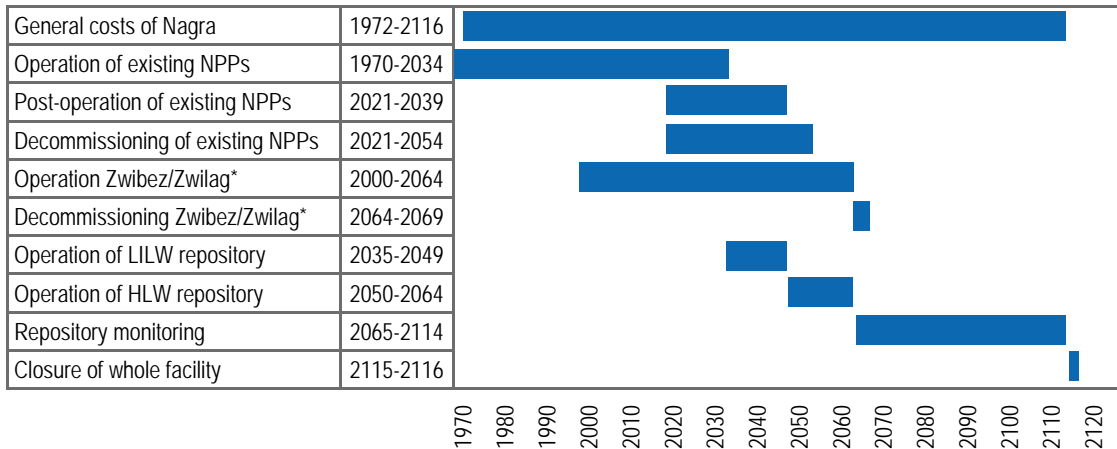
For these reasons, the immediate dismantling variant was assumed for the decommissioning study and for calculating the decommissioning costs in the 2011 cost study.

It is however possible that, given all the aspects to be considered, immediate dismantling will not actually be the best solution. The possibility is therefore kept open, in any revision of the decommissioning study based on new information, of selecting a different decommissioning strategy. The operator will justify the selected solution in the decommissioning plan.

### **10.9. Timeline of waste management facilities and NPPs in Switzerland in the 2011 cost study**

The financial resources for waste management activities began to flow with the founding of Nagra in 1972. The time period over which payments extend depends mainly on the operating lifetime of the nuclear power plants and the time over which the waste disposal pathway extends.

Figure 10.4 shows the assumed operational, post-operational and decommissioning times for the main nuclear facilities.

**Figure 10.4: Operational, post-operational and decommissioning times for the main facilities for 50-year operation of nuclear power plants (simplified presentation)**

\* Interim storage facilities.

**Table 10.8: ISDC structure of PWR2**

Cost item	Cost group					TOTAL (CHF million)
	Labour		Capital	Expenses material	Contingency	
	(hours)	(CHF million)	(CHF million)			
01. Pre-decommissioning	290 784	24.3	N/A	29.5	N/A	53.8
02. Facility shutdown						448.0 <sup>(1)</sup>
03. Additional activities for safe enclosure and entombment						N/A <sup>(2)</sup>
04. Dismantling activities within the controlled area	863 616	64.2	N/A	25.6	N/A	89.8
05. Waste processing, storage and disposal	449 904	32.4	N/A	76.5	N/A	108.9
06. Site infrastructure and operation, including site support	2 550 080	185.2	N/A	129.7	N/A	314.9
07. Conventional dismantling demolition and site restoration	516 880	31.6	N/A	12	N/A	43.6
08. Project management, engineering	326 976	52.0	N/A		N/A	52.0
09. Research and development						N/A
10. Fuel and nuclear material						7.1 <sup>(3)</sup>
11. Miscellaneous expenditures						N <sup>(4)</sup>
<b>Total</b>	<b>4 998 240</b>	<b>389.8</b>		<b>273.3</b>		<b>1 118.2</b>

(1) Accounted for in the post-operational cost study, duration of post-operation (facility shutdown) = five years.

(2) Direct dismantling.

(3) Costs of operation of the buffer storage during the post-operational phase included. Decommissioning of buffer in the decommissioning costs.

(4) Insurances covered in item 06.

## Chapter 11. Case study of the United Kingdom (Magnox fleet)

### 11.1. Historical background

The UK Nuclear Decommissioning Authority (NDA) was formally established in 2005 with a remit to provide the first ever strategic approach to decommissioning and cleaning up the UK's civil public sector nuclear sites. The NDA was tasked with introducing a new approach to nuclear decommissioning, providing a programme to improve the understanding of the full cost of the mission while reducing uncertainties. Through the programme the NDA, in the first three years of operation, developed a mature robust baseline against which we could drive down decommissioning and clean-up costs while maintaining and improving high standards of safety, security and environmental protection.

In 2005, the NDA put in place a Life Cycle Baseline Improvement Project. The intent was to develop a more reliable and effective mechanism to identify the liabilities on each site and their estimated costs. There was a focus on assessment of risk and allocation of contingency, with a standard work breakdown structure (WBS) implemented to enable comparison and alignment of the decommissioning cost estimates across the 19 civil nuclear sites.

The NDA's mission includes the Magnox (graphite reactor) nuclear power plants, ten of which are currently owned by Energy Solutions who are responsible for the management and operations. Calder Hall nuclear power plant (NPP) situated within the Sellafield nuclear licensed site is excluded from this analysis as it is currently part of the Sellafield baseline and has not been subject to the same changes and influences as the remainder of the Magnox fleet of NPPs.

Energy Solutions, under contract to the site owner the NDA, is responsible for electricity generation at Wylfa, defueling at Chapelcross, Oldbury and Sizewell A, and the decommissioning of Hunterston A, Berkeley, Bradwell, Dungeness A, Hinkley Point A and Trawsfynydd.

Bradwell is one of two Magnox sites, alongside Trawsfynydd, which is following an accelerated decommissioning programme. It is scheduled to become the first Magnox site to reach its care and maintenance phase in 2015 with the reactor decommissioning deferred. This approach is designed to develop experience to safely reduce the cost of decommissioning the remaining Magnox sites – a process known as “lead and learn”.

### 11.2. Strategy

The NDA approach to decommissioning (NDA Strategy 2011 ref) has six strategic themes which are applied across the NDA estate:

- site restoration;
- spent fuels;
- nuclear materials;

- integrate waste management;
- business optimisation;
- critical enablers.

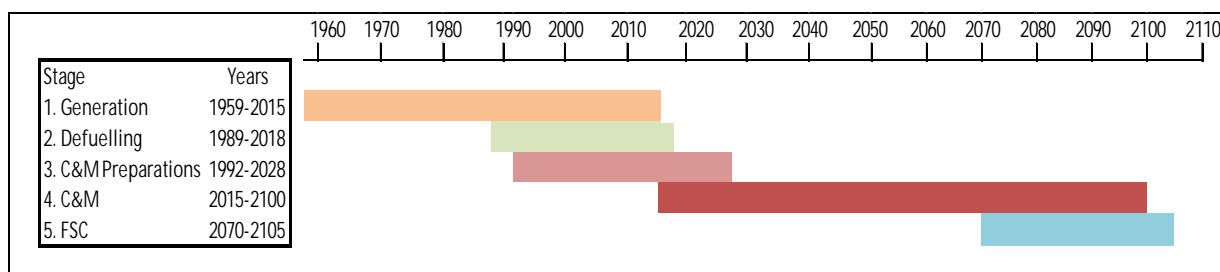
At the heart of the NDA Strategy is the priority to deliver an estate wide risk and hazard reduction delivering the mission cost effectively. Site restoration is the NDA's primary focus with strategic themes supporting this delivery. The NDA's end goal is to restore the designated sites to the point where they are released for other uses. To prioritise delivery, the NDA site restoration strategy focuses on reducing risks to people and the environment while restoring each site as soon as reasonably practicable to a condition suitable for its next planned use. The NDA's planned decommissioning strategies are embedded in lifetime plans being delivered by the site licence companies (SLCs), for this case study this assumes the deferred decommissioning of the Magnox reactors. To aid restoration of the sites the NDA will ensure the SLCs characterise their plants or facilities before the commencement of decommissioning.

Below the high-level NDA Strategy Magnox will manage activities at the graphite NPPs through five stages:

- generation;
- defueling;
- care and maintenance preparations;
- care and maintenance;
- final site closure.

Figure 11.1 demonstrates the timeline of the stages for Magnox Limited. The timeline spans from 1959, when the first Magnox site was operational, to 2105 – when the final Magnox site reaches the planned end state.

**Figure 11.1: Summary of decommissioning stages**



For the short term, Magnox will focus its sites efforts in these areas:

- generation – Wylfa;
- defueling – Chapelcross, Sizewell A, Oldbury;
- care and maintenance (C&M) preparations – Berkeley, Bradwell (scheduled to enter C&M in 2015), Dungeness A, Hinkley Point A, Hunterston A, Trawsfynydd (scheduled to enter C&M in 2016).

## 11.3. Magnox decommissioning

### 11.3.1. Schedule

The current schedule for the Magnox sites incorporates lessons learnt over the first five years of the NDA's operations detailed below in Section 11.6. In 2011, a revised schedule to C&M was drawn up for the ten Magnox sites, this was termed the Magnox optimised decommissioning plan (MODP). The MODP introduced cost reductions of more than GBP 1.3 billion into the Magnox lifetime plans and reduced the total time required to place all ten Magnox sites into C&M by 34 years.

The benefits of the MODP were achieved through a combination of new technical solutions and different working arrangements with the introduction of strategic programmes, in addition to extended generation at the remaining operating site, Wylfa. Further to the major schedule and tactical changes, there has been the introduction of the C&M Hub providing further Lifetime Plan cost reductions of approximately GBP 0.5 billion. Below the major headline changes, every single project had a scope, schedule and cost produced to underpin the MODP. The culmination of these changes is the schedule to deliver work more efficiently, bringing forward C&M entry dates at Bradwell and Trawsfynydd and progressing decommissioning work at other Magnox sites.

The key elements of the MODP are:

- Extended power generation – to maximise the value from the remaining operating life at Wylfa.
- Magnox Operating Plan (MOP) – to complete the programme for dealing with the remaining spent fuel.
- Bradwell and Trawsfynydd brought into C&M earlier.
- Chapelcross and Dungeness sites into an interim care and maintenance period.
- Implement programmisation.
- Berkeley active waste vault retrievals progressed.
- Workforce restructuring.

### 11.3.2. Approach

Due to the complexity of the process and technically challenging work involved, Magnox developed a programmisation approach to decommissioning. This approach broke down scopes of work into specific programmes, each with a clear focus and plan of work. Magnox grouped the common decommissioning projects across ten sites into strategic programmes to provide a consistent approach to work and drive value and innovation. The key principle was to embed a “lead and learn” concept and behaviours, where issues, efficiencies, tactics and procurement learning could be fed into the subsequent site plans. The following four programmes were established together with waste management and project management functions:

- Fuel element debris (FED) treatment:
 

The FED treatment programme is responsible for the retrieval and processing of FED to make it ready for final disposal, significantly reducing hazard at sites.
- Ponds:
 

The ponds programme is principally responsible for the decommissioning of the fuel storage ponds at sites, and the commissioning and decommissioning of active effluent treatment plants (AETPs).

- Intermediate-level waste (ILW) management:

The ILW management programme is responsible for the retrieval and packaging of operational solid and wet ILW for final disposal.

- Plant and structures:

The Plant and Structures Programme is responsible for deplanting, demolishing and remediating structures, buildings and land so that the sites are ready to enter care and maintenance.

The waste management function has the responsibility for maintaining waste inventories, developing disposal routes and maintaining the company decommissioning strategy, including strategic regulatory engagement.

By 2028, all ten Magnox sites are scheduled to be in the care and maintenance phase. This is when all required decommissioning preparations have been completed. The sites will then remain in a safe and secure state until they reach the commencement of final site clearance some 85 years after cessation of power generation.

### **11.3.3. Challenges/issues**

One of the main decommissioning challenges for Magnox is the retrieval of ILW from ageing underground vaults, sorting and packaging it into fit-for-purpose containers and placing it in suitable interim storage until it can be placed for permanent disposal in the geological disposal facility (GDF).

At most sites, on-site storage will be achieved through the retrieval of ILW into “MiniStores” or self-shielded containers and storage in an interim storage facility. To maximise cost and efficiencies, a generic intermediate storage facility (ISF) has been adopted across the ILW Programme. Design works were initially started at Bradwell with a lead and learn approach adopted for follow on sites. At Hunterston A and Trawsfynydd intermediate-level waste stores have been built and the encapsulation of the ILW remains the intent in line with earlier methodologies.

Other challenges include the management of interfaces and logistics at combined sites with either existing generation or new build NPPs and resource planning across the Magnox estate to enable effective utilisation, training and succession arrangements as the activities move from operations to decommissioning.

## **11.4. Boundary conditions**

### **11.4.1. Care and maintenance preparations**

The aim of C&M preparations is to minimise the amount of maintenance required during the C&M period.

The key activities to be delivered during this period are:

- The retrieval and processing of fuel element debris through dissolution or encapsulation and subsequent storage of waste.
- The decommissioning of the fuel storage ponds and active effluent treatment facilities.
- The retrieval and packaging of operational solid and wet ILW in readiness for final disposal, stored on-site in the interim storage facility until the availability of the GDF.
- The deplanting, demolition and remediation of structures, buildings and land prepared in readiness for entry to C&M.



- Reactor safetores deplanted, buildings reclad and monitoring equipment installed for the C&M period.

#### **11.4.2. Care and maintenance**

Care and maintenance is the period of quiescence to enable radiation levels to decay naturally. For the Magnox NPPs the current planning assumption is that there will be 85 years between the cessation of power generation and the start of final site clearance. The period of C&M varies depending on the timescales for care and maintenance preparations at each site noting the different volumes and types of waste on each site which need to be retrieved and packaged.

During this period there are plans for the following structures to remain on-site in a passive safe and secure state:

- reactors in safestore;
- ponds demolished or drained and capped;
- turbine hall voids filled or fenced for waste arisings at final site clearance.

An interim storage facility for ILW will be built at the sites, with the ILW waste will then be transferred to the geological disposal facility on a staged programme once it becomes available.

The current baseline includes for a remote monitoring facility and centralised management hub during this phase.

#### **11.4.3. Final site clearance**

Final site clearance (FSC) is the phase that takes the reactor site through its final stages of decommissioning with the removal of the reactor buildings and vessels. The first stage of FSC is the installation of facilities to house personnel and manage their welfare. Waste processing facilities are also installed to characterise, segregate, treat and dispatch the waste materials to its final destination. Reactor vessel dismantling facilities are constructed on top of the reactor pile cap to allow safe access to the vessel and removal of the materials contained within it. Magnox have assumed that ILW graphite constitutes the majority of waste.

### **11.5. Radioactive waste features**

More than 23 977 tonnes of non-radiological waste and 2 685 m<sup>3</sup> of radiological waste were dispatched from Magnox sites during the financial year 2012/2013. The typical types of waste generated at Magnox are:

- intermediate-level waste;
- low-level waste;
- hazardous waste;
- non-hazardous waste.

All sites have both solid and wet ILW waste streams that require retrieval, treatment and storage.

Table 11.1 summarises the key features of each Magnox sites.

**Table 11.1: Key features of Magnox sites**

Site	No. of reactors	No. of fuel channels per reactor	No. of elements per channel	No. of control rods	No. of turbo generators	Electrical output – design (net)	Electrical output – current (net)	Station lifetime output to date
Berkeley	2	3 275	13	132	4	300 MW	276 MW (out)	43 TWh
Bradwell	2	2 585	8	109	6	300 MW	242 MW sent out	Approx. 60 TWh
Chapelcross	4	1 969	5 or 6	48	8	196 MW exported	196 MW exported	Over 60 TWh
Dungeness	2	3 932	7	120	4	550 MW	420 MW	115.4 TWh
Hinkley	2	4 500	8	127	6	500 MW	470 MW (prior to shut down)	103 TWh
Hunterston	2	3 284	10	128	6	360 MW	300 MW	73 TWh
Oldbury	2	3 308	8	101	2	600 MW	434 MW (WANO RUP)	Over 137.5 TWh
Sizewell	2	3 784	7	107	2	580 MW	420 MW (WANO RUP)	More than 110 TWh
Trawsfynydd	2	3 740	9	110	4	500 MW	390 MW	69 TWh
Wylfa	2	6 156	8	185	4	1 180 MW sent out	473 MW sent out (2014)	Over 224 TWh

Wylfa is the last remaining nuclear power generation site for Magnox with reactor 1 currently licensed to generate until September 2014.

### 11.6. Maturity of cost estimates

Since 2005 when the NDA took on responsibility for the Magnox sites, a Lifetime Plan was submitted on an annual basis by the SLCs. The graph (see Figure 11.2) demonstrates the Maturity Curve of Lifetime Plan by year of submission for Magnox Limited, and is overlaid with key events which contributed to the changing profile of Lifetime Plan value. Further detail on the key events is outlined below.

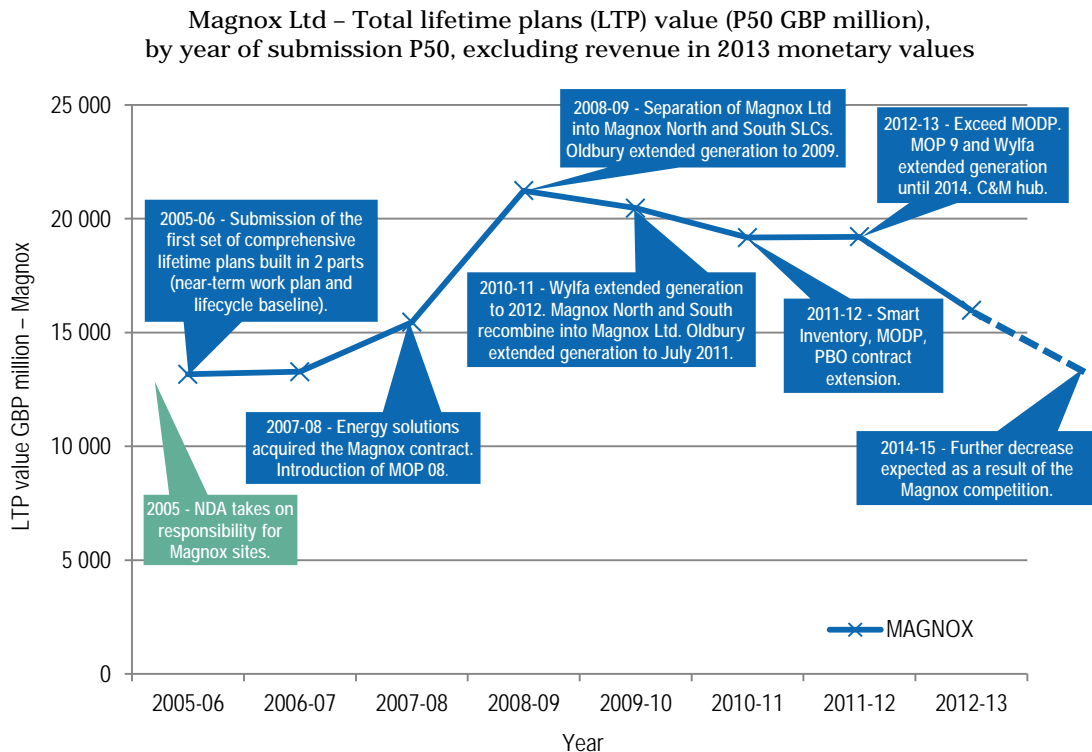
In 2005, the submission represented the first set of comprehensive plans built in 2 parts. The Near Term Work Plan (NTWP) included three years of more detailed information and the life cycle baseline included the remaining life cycle cost.

Energy Solutions acquired the Magnox contract in 2007. The main driver for increase in the 2007/08 submission was the impact of revising the Magnox operating programme (MOP 8), extending the time frame over which Magnox stations are defueled which increased the overall schedules to C&M entry. As a result the revised MOP 8 affected the decommissioning and clean-up liability at a large proportion of Magnox sites. In addition, the introduction of Magnox North and South as two independent SLCs, resulted in movements of support and overhead costs to the two centralised functions and although there were some efficiencies, additional resources were required to provide discrete technical support to the two separate bodies.

The Lifetime Plan value peaked in 2008/2009 to incorporate extended generation for Oldbury and the full extent of changes, as a result of MOP 8 were included. In addition to this, the focus on higher hazards in the near term reduced the annual expenditure levels at some sites and therefore re-phased decommissioning expenditures to later years. This increased the lifetime costs as site support expenditures (overheads) had to be maintained for longer. In 2008, the Magnox SLCs final site clearance costs including reactor dismantling and site landscaping were insufficiently developed and underpinned

for inclusion in the 2007/2008 accounts. As a result of a remodelling exercise and review during 2008/2009, the associated cost of realigning the final site clearance and care and maintenance costs were identified as approximately GBP 1 billion.

**Figure 11.2: Evolution implied of the overall cost estimates (lifetime plan maturity curve)**



In 2010, Magnox North and South recombined to form Magnox Limited, which drove a reduction in costs particularly in overheads and support areas. The “MODP” baseline changes were implemented as detailed in Section 11.3 over a number of months. Both Oldbury and Wylfa extended generation were included at this time resulting in an increase in the early year costs for operations and a consequential rescheduling of the subsequent phases.

In 2011, the “SMART” Inventory demonstrated a level of maturity and understanding of the full scope. This was the systematic review of the waste inventory of sites, getting more accurate waste volumes and increased characterisation resulting in a reduction in this area of the plan.

Further changes have occurred from 2012/13 with the balance between additional costs following further generation extension at Wylfa and the cost reductions introduced through the centralised “hub” for the management and maintenance of the sites during the C&M period.

Magnox Competition is currently ongoing with a preferred bidder announcement made in spring 2014. A further decrease to the Magnox baseline estimate is expected once the preferred bidder has taken over the Magnox contract.

In summary, a downward trend from 2009-2010 of decreasing Lifetime Plan value is demonstrated for Magnox once a level of maturity had been reached for the decommissioning plans and Magnox had developed an understanding of the full scope. The implementation of MODP was a contributor, drawing on actual experience through lead and learn and the benefits from approaching multiple sites in a systematic way.

## 11.7. Uncertainties and contingencies

The NDA through the Programme Controls Procedures – Manual (PCP-M) specifies the requirements for the site lifetime plans (LTPs) in order to gain consistency of estimating scheduling and reporting across the NDA estate.

The Magnox NPP LTPs are maintained on a continuous basis through change control and multi-year performance reporting with an annual submission requirement. The electronic baselines are submitted on a P80 confidence level basis with the execution year set at P50 for funding purposes.

The SLC decides on a suitable estimating methodology for the stage of scope development and work/project definition. It is recognised that estimates are prepared at a moment in time and reflect the stage of scope development/maturity. It is however expected that as the scope evolves through staged development, the estimates are reviewed and updated to reflect the level of scope definition and appropriate methodologies are used to generate the estimates.

The NDA require the LTP estimates and schedules to take account of the assessment of uncertainty around the base estimates and the discrete risks pertinent to the scope of work. The base estimate is the reference point for the calculation of contingency and is assessed using quantitative risk (both threat and opportunity) modelling techniques.

Estimating uncertainty is expected to be produced using three-point estimates by augmenting the single-point base estimates with optimistic and pessimistic estimates and shall form the input to the quantitative risk analysis process. The SLC develops risk handling strategies for identified discrete risks and shall decide whether or not to include the cost exposure in the contingency assessment.

The SLC is responsible for the management of contingency between the base estimate and P50 during the execution year managed through annual funding, with the requirement that the draw-down of contingency is monitored and reported.

## 11.8. Project management/organisation

Over the time period from 2005 to 2013 there have been a number of different organisational models in place across the Magnox estate resulting in cost movements as these changes, all subject to Regulatory Management of Change, have been implemented.

The original organisational model established in 2005 had a central technical and governance head office function with all of the ten sites having their own site support and support services (project controls, HR, training, communications, etc.). The intent was for the sites to be largely standalone, although it was recognised that there was a requirement for a centralised resource pool of safety case, intelligent customer and design authority personnel to meet the regulatory capability requirements. It was identified that the use of this organisational model resulted in higher than necessary site fixed costs, and that centralisation of a large proportion of these resources would provide more efficient and effective utilisation.

The organisational structure of the site licence companies has changed over time and the current model has a central support office function in order to rationalise the support and overhead costs and effective funding and resource deployment to deliver the decommissioning activities.

## 11.9. Site remediation

Final site clearance is the phase that takes the reactor site through its final stages of decommissioning with the removal of the reactor buildings and vessels. Radioactive

contamination will be reduced to a level which meets the criteria for de-licensing, based on “no danger” as established by the Nuclear Inspection Inspectorate (NII) under the Nuclear Installations Act 1965. Where any radioactive substances remain on-site, the requirements of the Radioactive Substances Act will be applied. On this basis, the site will be delicensed.

Any non-radioactive contamination identified will be dealt with under the relevant regulatory regime to meet the requirement for the end use of the site and the current use of adjacent land.

The physical state of the licensed site is assumed to be as follows:

- Reactor buildings and associated structures and non-active drains will be removed to below ground level.
- Services, roads and car parks will be removed to below ground level unless they are required by the intended end use.
- Holes will be filled in using inert material, from both on and off-site sources including crushed concrete.
- Basements will be punctured to allow drainage.
- Active drains will be removed cleaned or grouted in situ to the extent necessary to meet de-licensing criteria.
- Surface water drains will be installed, where required, to suit the environment and intended end use.
- The site will be landscaped to blend with the local environment.

The physical state of NDA land outside of the licensed site will be addressed through the NDA’s Corporate Asset Management Plan. Required off-site waste routes are assumed to be available in line with current Lifetime Plan assumptions.

## **11.10. Lessons learnt**

Key lessons learnt are:

- Centralisation of functions and resources for support activities reduces the overhead/fixed cost burden.
- Funding constraints can significantly extend decommissioning periods due to high site overhead costs required to meet site licence and conditions.
- Selecting the most suitable resourcing strategy (make/buy decisions) utilising specialist contractors vs incumbent workforce e.g. for demolition and deplant.

### **11.10.1. Lead and learn concept**

- Embedding a lead and learn culture was the key principle for the strategic programmes. The benefits have been seen through MODP where learning has been taken from one project and applied to different locations, saving more than GBP 1.8 billion in costs and reducing time frames for the ten Magnox sites to reach C&M by more than 30 years collectively. The benefits of increased certainty are realised as lessons are applied across sites.
- Rather than each site working in isolation, as initially planned, the utilisation of a managed and sequenced approach to work programmes and mobile teams using a lead and learn philosophy provided cost and schedule benefits across the Magnox.

### **11.10.2. Programmed approach**

- Programmed approach recognising the differences between sites but have the same core decommissioning challenges, limiting the need for bespoke solutions and providing delivery benefits.
- Mobile teams vertically integrated with sites enabling hands on cross-site and cross-disciplinary learning have provided improved flexibility and efficiency for delivery, reducing the overall schedules during the C&M preps phase.
- Magnox have realised benefits to the baseline cost estimates through increased of understanding of waste inventories and characterisation rather than assuming maximum volumes and higher activity.
- Opening up of alternative waste routes has provided significant cost benefits and has resulted in reductions in the overall volume of packaged and stored waste.
- External impacts and influences e.g. MOP and defueling delays and extensions can significantly impact the timeline and hence costs as there is limited decommissioning work that can be completed during the intervening period.

## Annex A. Glossary

*NOTE: The sole purpose of this glossary, established by the Ad Hoc Expert Group on Costs of Decommissioning (COSTSDEC) in the process of their work, is to give readers clarity on terms used in this report. Care has been taken to be as consistent as possible with other sources. In case of discrepancy, this glossary does not take any precedence over other sources and should not be used as an official reference document.*

**Abandonment** – The surrender of property by a former owner, operator, or licensee of a facility in the condition it was in when operations were terminated. Little or no clean-up is performed before or after termination of operations. While abandonment could be financially advantageous to the abandoner, it is not an internationally accepted practice and often will result in greater damage to the environment, pose a greater risk to the public, and eventually result in a greater cost for facility decommissioning.

**Actual cost** – The exact sum expended or loss sustained, which may not necessarily be equal to the market value. It is in contrast to an estimated cost or list price. In contracting, actual cost includes direct labour costs, direct material costs, and other direct charges.

**Ageing** – General process in which characteristics of a structure, system or component gradually change with time or use.

**Ageing management** – Engineering, operations and maintenance actions to control, within acceptable limits, the ageing degradation of structures, systems or components.

**Brownfield** – Real property for redevelopment or reuse that could be constrained by the presence or potential presence of a hazardous substance or pollutant.

**Capital costs** – Expenditures related to depreciable assets such as buildings, structures, fixtures, equipment, or machinery (does not include day-to-day expenses such as payroll, inventory, fuel, or maintenance); these can also include the cost of financing the purchase of depreciable assets.

**Clean-up** – See **remediation**.

**Clearance** – Involves the removal of radioactive materials from regulatory control by the regulatory body.

**Clearance level** – A level established by a regulatory body and expressed in terms of activity concentration and/or total activity (or other relevant measure) at or below which a source of radiation may be released from regulatory control. Compare to **exemption**.

**Contamination** – Unintended or undesirable presence of radioactive substances on surfaces, or mixed within solids, liquids or gases (including on or in living organisms); or the process giving rise to such presence.

**Contingency** – As described in the ISDC report (NEA, 2012), specific provisions for unforeseeable elements of cost within the defined project scope. Contingency does not account for price escalation and inflation in the cost of decommissioning over the remaining operating life of the nuclear installation. Contingency includes an allowance for indeterminate elements and should be related to the level of design, degree of technological advancement, and the quality/reliability of pricing levels. Contingency does not include allowance for potential changes from external factors.

**Cost driver** – A cost driver triggers a change in the cost of an activity.

**Cost estimate** – The cost of decommissioning estimated by applying commonly accepted cost estimating practices to the scope of the decommissioning project, over its duration, taking into account the currency to be expended in each year of the project.

**Decommissioning** – Administrative and technical actions taken to allow the removal of (some or all) regulatory controls from a facility.

**Decommissioning cost** – Total expenses needed to complete the decommissioning and dismantling plan. Costs related to away-from-reactor spent fuel management, i.e. reprocessing, storage, and (final) disposal are excluded.

**Decommissioning end point** – Final target of the decommissioning plan. “On the completion of decommissioning actions, the licensee shall demonstrate that the end state criteria as specified in the final decommissioning plan and any additional regulatory requirements have been met. The regulatory body shall verify the compliance with the end state criteria and shall decide on termination of the authorisation for decommissioning” (IAEA, 2014: Section 9, Requirement 15).

**Decommissioning phase** – Well-defined and discrete set of activities within the decommissioning process.

**Decommissioning, phased** – Decommissioning strategy sometime adopted by countries, but not endorsed by IAEA. Phased decommissioning may take place if there is a need for a break in the decommissioning process to allow the resolution of technical issues, or to make provisions for specific waste management or for other resources to perform the work. It might also help in reducing the radioactivity level before pursuing the decommissioning process.

**Decommissioning plan** – Documentation containing information on the proposed decommissioning activities for a facility. This would allow the regulatory body to make a proper evaluation to ensure that decommissioning of the facility can be performed in a safe manner.

**Initial decommissioning plan** – Based on the decommissioning strategy, it includes the feasibility of decommissioning, main steps of the decommissioning/dismantling and the end state of the facility and is the basis for the estimation of decommissioning costs. This document is of a general nature during the design and operation phases and is to be updated during regularly during operation.

**Final decommissioning plan** – As the basis for commencing major decommissioning activities, it is prepared before the beginning of the decommissioning phase together with the safety case. This detailed document is updated as required during the decommissioning stages.

**Decommissioning policy** is a set of established goals or requirements for the safe, effective and efficient decommissioning of nuclear facilities. The national policy usually includes a specification of national roles and responsibilities, and is mainly established by the national government. It includes all governmental (national and regional) choices, as described in laws, regulations, standards and mandatory requirements that will influence the framework in which decommissioning takes place.

**Decommissioning programme** is a schedule of those activities and corresponding milestones foreseen in the decommissioning plan. Developed for planning and monitoring purposes, this document supports the implementation of the decommissioning activities.

**Decommissioning, starting point** refers to plant and site status at the time of the initiation of the decommissioning activities. It is a common practice that corresponding authorities may require the fulfilment of a set of conditions and/or activities to be



undertaken before allowing the licensee to initiate the dismantling activities (dismantling permit or authorisation).

**Decommissioning strategy** is the means for achieving the goals and requirements set out in the national policy for the decommissioning of nuclear facilities. It is normally established by the relevant facility owner or operator. It refers to industrial approaches, and includes all aspects of decommissioning projects that are proposed to national authorities in the context of application for permission to decommission. The line separating policy from strategy is not always clearly defined, and sometimes it is not clear whether an issue should be taken up as policy or strategy. For example, some policy makers might put into policy only the requirement for the decommissioning of nuclear facilities, and then rely on strategy makers to decide on the method for achieving this. Other policy makers might include a requirement for a particular decommissioning approach directly in national policy. Some countries may not distinguish between the two concepts and instead have a national plan that is a combined policy and strategy. The IAEA endorses two decommissioning strategies: immediate and deferred dismantling. The following strategies, while not endorsed by IAEA, have been implemented in different countries: phased decommissioning, entombment, abandonment. The decommissioning strategy also includes the definition of decommissioning start and end points (e.g. greenfield or brownfield).

**DECON** – see **dismantling, immediate**.

**Decontamination** – Covers the broad range of activities directed to the removal or reduction of radioactive contamination in or on materials, structures and equipment at a nuclear facility. Decommissioning of a reactor may be aided at certain stages by partial or total decontamination. Decontamination can be applied to internal or external surfaces of components and systems, structural surfaces, and the tools employed in decommissioning. The process of decontamination associated with decommissioning can be conducted before, during, or after dismantling (IAEA, 1999).

**Deferral period** – The period of time between shutdown and the date for the initiation of the main decontamination and/or dismantlement work.

**De-licensing** – See **release**.

**Demobilisation** – Disbandment of project infrastructure or personnel for decommissioning (see cost items 08.0501 and 08.0502 of ISDC respectively – NEA, 2012).

**Discount rate** – The rate at which funds from one year are evaluated in another year. The discount rate can be equal to funds owner's cost of capital (e.g. appropriate interest rate,  $i$ , on borrowed funds), an average cost of capital on borrowed funds and equity, or a rate specified by a relevant authority, such as a governmental body. Let the discount rate be equal to  $(1+r)$ , then a value in time  $t + 1$ ,  $V(t + 1)$  can be evaluated in time  $t$  as  $V(t) = V(t+1)/(1+r)$ . If the discount rate includes inflation, it is known as the nominal discount rate. If the discount rate does not include inflation, it is known as the real discount rate. The nominal discount rate is equal to  $(1+r)(1+p) = 1 + r + p + r*p$ , where  $r$  is the real discount rate,  $p$  (price index) is the inflation rate. If both  $r$  and  $p$  are small, then  $r*p$  can be ignored. However, if both  $r$  and  $p$  are greater than 10%, then the final term cannot be ignored. If the discount rate accounts for risk, care must be taken in discounting more than one period if the risk is changing from period to period.

**Discounted cost estimate** – The cost estimate discounted to a specific year using the appropriate discount rate. If the cost estimate is in the currency of a single year, then the real discount rate is appropriate and the discounted cost estimate is known as the "real discounted cost estimate." If the cost estimate is in the currency of the year of expenditure, then the nominal discount rate is appropriate and the discounted cost estimate is known as the "nominal discounted cost estimate", or simply the "discounted cost estimate." See **discount rate, cost estimate**.

**Dismantling, deferred** – Deferred dismantling (also known as safe storage or safe enclosure) is the strategy by which parts of a nuclear facility containing radioactive contaminants are either processed or placed into such a condition that they can be safely stored and maintained until they can subsequently be decontaminated and/or dismantled to levels that permit the facility to be released for other use (IAEA, 2002).

**Dismantling, dismantlement** – The disassembly and removal of structures, systems, or components. Dismantling (dismantlement) can be performed immediately after permanent shutdown of a nuclear facility or it can be deferred.

**Dismantling, immediate** – Immediate dismantling (also known as DECON) is the strategy by which, shortly after permanent termination of operations, the equipment, structures and parts of a nuclear facility containing radioactive contaminants are removed or decontaminated to a level that permits the facility to be released for unrestricted use or with restrictions imposed by the regulatory body. It implies prompt and complete decommissioning and involves the removal and processing of all radioactive material from the facility.

**Dormancy period, latency period** – Is the period of time in which parts of a facility containing radioactive contaminants are either processed or placed in such a condition that they can be safely stored and maintained until they can be subsequently decontaminated and/or dismantled.

**End state** – A predetermined criterion defining the point at which the specific task or process is to be considered completed. The licensee can apply for termination of the licence when the proposed end state of decommissioning activities has been reached.

**Entombment** – Strategy by which all or part of the facility is encased in a structurally long-lived material. It is not considered a decommissioning strategy per se and is not an option in the case of planned permanent shutdown (IAEA, 2014). It may be considered a solution only under exceptional circumstances (e.g. following a severe accident), and is still an option left open in some countries.

**Escalation (rate)** – Refers to the nominal change in decommissioning costs over time. The nominal escalation rate,  $e$ , is equal to the inflation rate,  $p$ , times the real escalation rate,  $e(\text{real})$ . The nominal escalation rate includes the inflation rate and can be approximated by construction cost indexes, such as the “Handy-Whitman” index. Because reported escalation rates are nominal, the real escalation rate must be inferred from the nominal escalation rate and the (real) inflation rate, i.e.  $[1 + e(\text{real})] = (1+e) / (1+p)$ , e.g. if the inflation rate,  $p$ , is 3% and the nominal escalation rate,  $e$ , is 5%, the real escalation rate is 1.94%, or approximately 2%.

**Exclusion** – A designation by the relevant regulatory body of sources of radiation that are not subject to regulatory control because they are not amenable to control (e.g. cosmic rays and potassium  $^{40}\text{K}$  found in the human body); these sources are said to be excluded from the regulatory process. Compare with **exemption**.

**Exemption or exempt** – A designation by the regulatory body for sources of radiation that are not subject to regulatory control because they present a low radiological hazard. Under this designation, a distinction can be made between sources that never enter the regulatory control regime (excluded) and sources that are removed from regulatory control because the associated radiological hazards are negligible (subject to clearance). The latter is especially pertinent to radioactive waste management, where sources of radiation are released from regulatory control in accordance with established clearance levels. Principles for exemption are presented in IAEA Safety Series No. 89 (IAEA, 2000). Compare to **exclusion** and **clearance**.

**Expenses** – Expenses are defined as costs for non-depreciable items, e.g. consumables, spare parts, protective clothing, travel expenses, legal expenses, taxes, insurance, consultants costs, quality assurance costs, rents, office materials, heating costs, water

costs, electricity costs, computer costs, telecommunication costs, cleaning, interest, public relation, licences/patents, decommissioning authorisation and income from asset recovery (“negative expenses”).

**Greenfield** – A site that has been granted unrestricted release from regulatory control, where all structures and equipment have been decontaminated and dismantled. Compare to **Brownfield**.

**High-level waste (HLW)** – Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long-lived radionuclides that need to be considered in the design of a disposal facility for such waste. Disposal in deep, stable geological formations usually several hundred metres below the surface is the generally recognised option for the disposal of HLW.

**Inflation rate** – The inflation rate,  $p$ , is the percentage change over time in a general price index (e.g. the gross domestic product deflator, the producer price index, or the consumer price index) calculated on a monthly, quarterly, or annual basis.

**Institutional control** – Control of a site by a relevant authority. This control may be active, including monitoring, surveillance, and/or remedial work, or passive (land use control) and may be a factor in the design of a nuclear facility (e.g. a near-surface repository).

**Intermediate-level waste (ILW)** – Waste that, because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near-surface disposal. ILW may contain long-lived radionuclides, in particular, alpha emitting radionuclides that will not decay to a level of activity concentration acceptable for near-surface disposal during the time for which institutional controls can be relied upon. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal. Therefore, waste in this class requires disposal tens of metres to a few hundred metres below the surface.

**Labour costs** – Payments to employees, including overheads, appropriate benefits, and payments to social security and health insurance according to national legislation.

**Learning factor** – This derives from savings obtained in the production of a series of identical units (or actions) as opposed to that of an individual unit with the same characteristics but produced in isolation. A learning factor (e.g. equal to 0.8 – or 80%, means that by doubling the units produced, the unit cost will be reduced to a value of 80% of the initial one).

**Liability** – Refers to a present or potential debt or obligation. A liability is recorded on the balance sheet of a company and can include accounts payable, taxes, wages, accrued expenses, and deferred revenues. Long-term liabilities are debts payable over a longer period, as opposed to current liabilities, which are debts payable within one year.

**Licence** – A legal document issued by the regulatory body granting authorisation to perform specified activities related to a specific facility. The holder of a current licence is the “licensee”.

**Low-level waste (LLW)** – Waste that has a greater radioactivity level than those defined for clearance, but with limited amounts of long-lived radionuclides and little heat generation. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near-surface facilities. This class of waste covers a broad range. LLW may include short-lived radionuclides at higher levels of activity concentration, and also long-lived radionuclides, but only at relatively low levels of activity concentration.

**Management system** – A set of interrelated or interacting elements (system) for establishing policies and objectives and enabling the objectives to be achieved in an efficient and effective manner. The management system integrates all elements of an

organisation into one coherent system to enable all of the organisation's objectives to be achieved. These elements include the organisational structure, resources and processes. Personnel, equipment and organisational culture, as well as the documented policies and processes are parts of the management system. The organisation processes must address the totality of the requirements on the organisation as established in, for example, IAEA Safety Standards and other international codes and standards.

**Monitoring** – Continuous or periodic measurement of radiological or other parameters or determination of the status of a system, structure or component. Sampling may be involved as a preliminary step to measurement.

**Nuclear facility** – A facility and its associated land, buildings and equipment in which nuclear materials are produced, processed, used, handled, stored or disposed of to such a scale that consideration of safety is required.

**Nuclear material** – Any radioactive material subject to safeguards to prevent its undue use.

**Nuclear safety** – The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards.

**Radiological protection** – The protection of people from the effects of exposure to ionising radiation, and the means for achieving this.

**Radioactive waste** – Refers to radioactive material in gaseous, liquid or solid form for which no further use is foreseen and which is controlled as radioactive waste by a regulatory body.

**Rate of return** – The rate at which an asset increases in value during one period. For example, the rate at which a regulated electric utility is allowed to earn in its tariffs on its assets (rate base). The real rate of return is equal to the nominal rate of return divided by the inflation factor. See **inflation**.

**Real rate** – Rate from which price inflation has been removed. See **discount rate**, **escalation rate**, and **inflation rate**.

**Release** – Once the relevant authorities have certified that all radioactive material and other hazards have been reduced to defined levels, the facility or site can be released from regulatory control such that the licence can be terminated.

**Remediation** – Measures carried out to reduce exposure to radiation from existing contamination of land areas to levels specified by the relevant authorities (through actions applied to the contamination itself, the source, or to the exposure pathways). Complete removal of the contamination is not necessarily implied.

**Repository** – An excavated, underground facility that is designed, constructed, and operated for safe and secure permanent disposal of radioactive waste. Depending on the nature of radioactive waste to dispose of different depths and types of repositories can be used, e.g. cavern-type, intermediate-depth geological repositories or a deep geological repositories. Geological repositories use an engineered barrier system and a portion of the site's natural geology, hydrology, and geochemical systems to isolate the radioactivity of the waste.

**Safe enclosure** (during decommissioning) – A condition of a nuclear facility during the decommissioning process in which only surveillance and maintenance of the facility takes place.

**SAFESTOR** – See **safe enclosure**

**Safety assessment** – Assessment of all aspects of the site, design, operation and decommissioning of an authorised facility that are relevant to protection and safety.

Note: assessment should be distinguished from analysis. Assessment is aimed at providing information that forms the basis of a decision on whether something is satisfactory. Various kinds of analysis may be used as tools in doing this. Hence an assessment may include a number of analyses.

**Safety case** – A collection of arguments and evidence in support of the safety of a facility or activity. This will normally include the findings of a safety assessment and a statement of confidence in these findings.

**Segregation (of funds)** – A legal guarantee that funds allocated for a particular purpose will not be spent on anything else (also known as “ring-fencing”).

**Shutdown** – the permanent end of plant or facility operation.

**Transition period** – Period of time between the unit’s shutdown and the initiation of decommissioning activities. Normally, it is a preparatory period for decommissioning. As indicated in “decommissioning – starting point”, it is a common practice that, to allow the commencement of decommissioning activities, the relevant authorities may require the fulfilment of a set of conditions.

**Uncertainties** – Foreseeable unknowns in the cost estimate within the defined project scope. See **contingency**.

**Undiscounted cost estimate** – See **cost estimate**.

**Use, authorised** – Use of radioactive materials or radioactive objects from an authorised practice in accordance with an authorisation.

**Use, restricted** – The use of equipment, materials, buildings, facility, or site that is subject to restrictions imposed for reasons of radiological protection and safety or for the existence of other hazardous materials.

**Use, unrestricted** – The use of equipment, materials, buildings or the site without any radiological-based or hazard-based restrictions.

**Very low-level waste (VLLW)** – Waste that does not necessarily meet the criteria of exempt waste (see exemption or exempt), but that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near-surface landfill-type facilities with limited regulatory control. Such landfill-type facilities may also contain other hazardous waste. Typical waste in this class includes soil and rubble with low levels of activity concentration. Concentrations of longer-lived radionuclides in VLLW are generally very limited.

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# Costs of Decommissioning Nuclear Power Plants

While refurbishments for the long-term operation of nuclear power plants and for the lifetime extension of such plants have been widely pursued in recent years, the number of plants to be decommissioned is nonetheless expected to increase in future, particularly in the United States and Europe. It is thus important to understand the costs of decommissioning so as to develop coherent and cost-effective strategies, realistic cost estimates based on decommissioning plans from the outset of operations and mechanisms to ensure that future decommissioning expenses can be adequately covered.

This study presents the results of an NEA review of the costs of decommissioning nuclear power plants and of overall funding practices adopted across NEA member countries. The study is based on the results of this NEA questionnaire, on actual decommissioning costs or estimates, and on plans for the establishment and management of decommissioning funds. Case studies are included to provide insight into decommissioning practices in a number of countries.