Nuclear Development

OECD

Decommissioning Nuclear Power Plants

Policies, Strategies and Costs

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Decommissioning Nuclear Power Plants: Policies, Strategies and Costs

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 28 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

This publication is a contribution to NEA activities in the field of decommissioning. It focuses on issues relevant for policy makers in governments and the industry, complementing other documents prepared and published by the Agency, which cover the technical and regulatory aspects of decommissioning.

The report gives insights into decommissioning policies, strategies and costs in the 26 countries that participated in the study. It presents decommissioning cost estimates provided by experts from government agencies and the industry involved in decommissioning activities. Cost estimates for a large number of nuclear power plants, including a broad range of reactor types, sizes and sites, are analysed with an emphasis on understanding the main reasons for their variability.

The study was carried out by a group of experts from member countries and international organisations under the joint auspices of three NEA committees: the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC), the Committee on Radiation Protection and Public Health (CRPPH) and the Radioactive Waste Management Committee (RWMC). The RWMC Working Party on Decommissioning and Dismantling provided valuable comments on the report. The study also benefited from the participation of representatives from several non-member countries invited through, and supported by, the International Atomic Energy Agency (IAEA).

This study reflects the collective views of the participating experts though not necessarily those of their parent organisations or of member country governments. The report is published under the responsibility of the Secretary-General of the OECD.

TABLE OF CONTENTS

List of Tables

List of Figures

EXECUTIVE SUMMARY

As many nuclear power plants will reach the end of their lifetime during the next 20 years or so, decommissioning is an increasingly important topic for governments, regulators and industries. Commercial nuclear power plant decommissioning activities, impending in some countries and in full swing in others, have led to a generally growing trend in industrial, regulatory and policy-level activities in the field over the past 10 years. This trend is expected to continue, as an increasing number of facilities enter into their active decommissioning phase.

This trend has several interrelated implications for governments and for the nuclear industry. From a governmental viewpoint, particularly in a deregulated market, one essential aspect is 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. For this reason, there is governmental interest in understanding decommissioning costs, and in periodically reviewing decommissioning cost estimates from nuclear installation owners. Robust cost estimates are key elements in designing and implementing a coherent and comprehensive national decommissioning policy including the legal and regulatory bases for the collection, saving and use of decommissioning liability funds.

From the industry viewpoint, it is essential to assess and monitor decommissioning costs in order to develop a coherent decommissioning strategy that reflects national policy and assures worker and public safety, whilst also being cost effective. For these reasons, nuclear power plant owners are interested in understanding decommissioning costs as best as possible and in identifying major cost drivers, whether they be policy, strategy or "physical" in nature.

National policy considerations will guide the development of national regulations that are relevant for decommissioning activities. Following these policies and regulations, industrial managers responsible for decommissioning activities will develop strategies which best suit their needs, while appropriately meeting all government requirements. Decommissioning costs will be determined by technical and economic conditions, as well as by the strategy adopted.

Against this backdrop, the present report analyses the relationships among decommissioning policies as developed by governments, decommissioning strategies as proposed by industries, and resulting decommissioning costs. Major cost drivers, of policy, strategy and technical nature, are also discussed.

It should be noted that the costs reported by participating countries for the purposes of this study reflect specific models and strategic choices, and were developed in each national situation and in some cases in the context of establishing funds to support decommissioning. Furthermore, although the questionnaire requesting policy, strategy and cost data was clear with respect to elements to be considered in the scope of decommissioning, national programmes do not necessarily divide their estimate elements in the same fashion. This leads to a wide variety in what was globally included under the reported cost estimates.

The review of the data collected for the study showed a wide variation in many aspects of national decommissioning policies in the participating countries. Decommissioning strategies adopted by industries also vary from country to country and from operator to operator. The variability between countries, utilities and power plant characteristics in a number of areas related to decommissioning leads to cost differences that are identified and analysed in the report.

Important aspects that were found in the study to have significant effects of decommissioning costs include:

- The end state of the facility after decommissioning (e.g. green field, long-term stewardship of some facilities, site reuse for other industrial or nuclear purposes).
- The national policy, and site-specific application, of site release criteria.
- The inclusion of waste disposal costs, totally, partially, or not at all, in the decommissioning scope and cost estimates.
- The manner in which waste arising from decommissioning is classified, in terms of whether or not radiologically regulated disposal is required.
- The assumed costs for waste disposal, recognising that no country reported having operating disposal facilities for all types of waste that would be generated by decommissioning processes.
- The decommissioning strategy option assumed for costing purpose (e.g. longer or shorter safe-store periods and choice of decommissioning end point).
- The national labour costs that were assumed.
- Social and political factors, such as the decision to decommission very rapidly, or to release sites only to very stringent radiological criteria.
- Uncertainties in the estimates and their treatment in cost models.

In addition to these general aspects that affect costs, the study also identified several physical characteristics of the power plant considered that were also significant cost drivers:

- type and size of the reactor;
- number of units on the site;
- operating history of the plant; and
- the amount of waste assumed to be generated.

In spite of cost variability, the study showed that decommissioning cost estimates reported remain below 500 USD/kWe for nearly all water reactors but are significantly higher for gas-cooled reactors (around 2 500 USD/kWe) considered in the report.[1] Labour costs generally represent a significant share of total decommissioning costs ranging from 20 to 40%. Some analysis of cost structure was performed based upon the responses including data on various cost components. According to the information provided, the two cost elements representing a major share of total costs are dismantling and waste treatment and disposal, accounting for around 30% each. Three other cost

1. The gas-cooled reactors considered in the study are rather old units not to be compared with the advanced HTGRs currently under development. See tables 4.1 and 4.2, pp. 55-56 for details on the 4 GCR cost data sets provided for this report.

elements represent around 10% each of the total: security, survey and maintenance; site cleanup and landscaping; and project management, engineering and site support. Other cost items generally do not exceed 5% of the total decommissioning cost.

In its findings, the report stresses that in all countries, decommissioning costs are robustly estimated and thoroughly analysed by the operators, the regulators and the governments and that measures are in place to ensure that adequate funds are accumulated timely to fund decommissioning expenses.

The findings from the report are based on responses to a questionnaire sent to participating countries. It should be noted that not all responses were of the same level of detail, and it was felt that further detail in responses would have allowed more in depth comparisons in a more valid fashion. It is suggested that further work in the field could be undertaken in an international framework to support a more robust quantitative analysis of decommissioning cost drivers. Such studies could contribute to additional clarity, particularly with respect to comparison of decommissioning estimates taking into account scope variability.

1. INTRODUCTION

As many nuclear power plants will reach the end of their lifetime during the next 20 years or so, decommissioning is an increasingly important topic for governments, regulators and industry. Commercial nuclear power plant decommissioning activities, impending in some countries and in full swing in others, have led to a generally increasing trend in industrial, regulatory and policy-level activities in the field over the past 10 years. This trend is expected to continue, as an increasing number of facilities enter into their active decommissioning phase.

The term "decommissioning", when applied in its broadest sense to nuclear facilities, covers all of the management and technical actions associated with cessation of operation and withdrawal from service. It starts in the planning stage before a facility is shut down and extends through eventual removal of the facility from its site (*dismantling)* to de-licensing. These actions may involve some or all of the activities associated with dismantling of plant and equipment, decontamination of structures and components, demolition of building, remediation of contaminated ground and disposal of the resulting waste.

One significant purpose of decommissioning and dismantling (D&D) is to allow removal of some or all of the regulatory controls that apply to a nuclear site whilst securing the long-term safety of the public and the environment, and continuing to protect the health and safety of decommissioning workers in the process. Underlying this are other practical objectives including release of valuable assets such as site and buildings for unrestricted alternative use, recycling and reuse of materials and the restoration of environmental amenity.

On an industrial level, processes and techniques for the decommissioning of nuclear installations have advanced greatly over the past 20 years, to the point where most situations can now be addressed with feasible approaches. Decommissioning, however, requires regulatory approval and oversight, the directions of which are guided by national policy. In several instances, Governments have only more recently begun to address in national legislation approaches to decommissioning policy and regulation. International overviews of approaches to national policy and regulation in decommissioning which may lead to harmonisation are only now beginning to emerge. Therefore, industrial strategies to decommissioning, which are subservient to national policy and regulation, can differ considerably from country to country and from region to region.

While decommissioning activities are well understood and integrated in each national regulatory framework, the current status of national awareness of the full range of activities necessary to successfully complete decommissioning projects differs from country to country. The readiness of governments and industry to engage actively in decommissioning depends *inter alia* on the age of nuclear power plants in operation and the size of the nuclear power programme in place in various countries. Specific areas that need attention to enhance national readiness to fully address decommissioning issues include waste disposal, and legislative and regulatory frameworks.

Deregulation of electricity markets raises new issues in connection with covering the expenses associated with decommissioning activities. The cost of decommissioning, which has always been recognised and integrated in nuclear electricity generation cost, becomes a more important criterion in deregulated markets where competition calls for lowering of production costs. In this context, national policy and regulations are being adapted or developed that may affect decommissioning costs and the manner they are included in the price charged to electricity consumers.

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. For this reason, there is governmental interest in understanding decommissioning costs, and in periodically reviewing decommissioning cost estimates from nuclear installation owners. Robust cost estimates are key elements in designing and implementing a coherent and comprehensive national decommissioning policy including the legal and regulatory bases for the collection, saving and use of decommissioning liability funds.

From the industry viewpoint, it is essential to understand and monitor decommissioning costs in order to develop a coherent decommissioning strategy that reflects national policy and assures worker and public safety, whilst also being cost effective. For these reasons, nuclear power plant owners are interested in understanding decommissioning costs as best as possible and in identifying major cost drivers, whether they be policy, strategy or "physical" in nature.

In this context, this report reviews decommissioning policy, strategies and costs to investigate major cost drivers. The study analyses the relationships between policy, strategy and costs on the basis of information provided by participating countries and experts. National policy considerations will guide the development of national regulations that are relevant for decommissioning activities. Following these policies and regulations, industrial managers responsible for decommissioning activities will develop strategies which best suit their needs, while appropriately meeting all government requirements. Decommissioning costs will be determined by technical and economic conditions as well as by the strategy adopted.

Definitions

In order to facilitate the discussion of decommissioning, and to provide a framework for focusing this work, it is convenient to separate the concept of decommissioning policy from the concept of decommissioning strategy. These two are clearly linked, and even somewhat overlapping, however the following working definitions have been used to structure the presentation of results in the present study.

- **Decommissioning policy**: refers to government policy, and 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 strategy**: refers to industrial approaches, and includes all aspects of decommissioning projects that are proposed to national competent authorities in the context of application for permission to decommission.

Objectives of the study

The objective of this study is to present the range of current international understanding of policy, strategy and costs of decommissioning commercial nuclear power plants, highlighting various factors that may affect costs. This study is principally aimed at facilitating the understanding, by policy makers and regulators, of decommissioning policy, strategy and cost issues. However, the study is also intended to be practically useful to the decommissioning industry managers as strategies are developed.

To achieve this objective, this study analyses decommissioning cost, strategy and policy data supplied by participating countries, and reviews national decommissioning policies and regulations and industrial strategies for decommissioning activities. To understand how decommissioning costs are affected by policy and strategy, this study also qualitatively analyses relationships between policy, strategy and costs. In addition, the report present some insights on national approaches adopted to assure that appropriate funding is available for decommissioning activities.

This work has been structured based on earlier studies of decommissioning costs and funding that have been performed by the NEA, including: "*Decommissioning of Nuclear Facilities: An Analysis of the Variability of Decommissioning Cost Estimates*" (1991); and "*Future Financial Liabilities of Nuclear Activities*" (1996). The current work is intended to update these earlier studies, particularly as markets have significantly deregulated since the 1991 study of costs.

Scope of the study

Recognising that the cost of decommissioning can vary considerably depending upon the type of facility being considered, the scope of this study focused on commercial nuclear power plants of all types with relatively generic characteristics. Thus small, prototype commercial reactors have not been considered. Several widely used reactor designs (including PWR, BWR, CANDU, GCR and VVER) have been included, insofar as cost data has been obtained.

Other key scope aspects that have been assumed for the purposes of this study are as follows:

- It is generally assumed for the purposes of this study that decommissioning begins after all nuclear fuel has been removed from the plant areas that will be decommissioned. However, for some reactors – such as some gas-cooled reactors – where de-fuelling is a prolonged activity carried out in parallel with some decommissioning activities, de-fuelling is included in the costs reported.
- The cost of managing spent nuclear fuel following removal from the reactor and the interim storage facilities to be decommissioned is not included in the cost of decommissioning.
- The planned end point of decommissioning (unrestricted site and facility release, partially restricted site and facility release, site and facility reuse in a radiologically controlled fashion, etc.) has been taken into account qualitatively in order to produce valid cost comparisons.
- Reported costs are undiscounted, i.e. given in current price level of 2001.
- Reported costs represent estimates provided by respondents in 2001/2002, and may be based on models, studies or on actual decommissioning costs if decommissioning is underway or completed.

- Power plants that have experienced significant accidents have been excluded from this study because the costs of decommissioning will have been significantly affected as a result of the accident, thus making them no longer relevant for valid generic cost comparisons.

Working method

These objectives were broadly laid out by the NEA Nuclear Development Committee (NDC), which convened an Expert Group to refine the objectives, to identify a feasible approach, and to carry out the study. Because of the cross-disciplinary nature of decommissioning activities, it was necessary that the Expert Group include representatives from several of the NEA's standing technical committees, which are organised along disciplinary lines. As such, the Expert Group included members nominated through the NDC, the Radioactive Waste Management Committee (RWMC), and the Committee on Radiation Protection and Public Health (CRPPH). In order to appropriately co-ordinate this work with efforts being undertaken in other international organisations, notably the International Atomic Energy Agency (IAEA), and the European Commission (EC), representatives from these organisations were also invited to attend meetings and to contribute actively to the Expert Group's work. Through a series of three meetings, the Expert Group refined the task objectives to those presented here, agreed that the best mechanism to obtain the information necessary for a valid analysis was to develop and distribute a questionnaire, analysed the information received in response to the questionnaire and drafted this report.

The questionnaire was developed (see Annex 2) and distributed during 2001, and a limited follow-up, for the clarification of some responses, was undertaken in early 2002. The questionnaire was sent to national representatives from all NEA member countries and to all non-NEA member countries, with operating or permanently shut down nuclear power plants through the participation of the IAEA in this work. Responses were obtained from 26 countries out of a total of 31 concerned. The responding countries include: Armenia, Belgium, Brazil, Bulgaria, Canada, the Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Lithuania, the Netherlands, Pakistan, Romania, Russia, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Ukraine, the United Kingdom and the United States.

Given the defined scope and approach, from the outset it was recognised that a detailed explanation of policy, strategy and cost differences from country to country, or even from plant to plant within a given country, would be difficult if not impossible. Broadly speaking, however, in designing the questionnaire, the Expert Group preliminarily identified several policy and strategy aspects that could affect the cost of decommissioning. Based on this assessment, the questionnaire was tailored as best as possible to shed light on any substantial differences. This preliminary assessment of aspects that could affect costs included:

- national policy, if any, on decommissioning time-scale requirements;
- national policy, if any, on decommissioning start and end point;
- national policy, if any, on release of materials for unrestricted use;
- national policies and regulations on radioactive waste disposal;
- availability of, and conditioning requirements for, radioactive waste disposal;
- waste management and disposal cost;
- labour cost; and
- exchange rate.

Through a detailed analysis of the questionnaire responses, the Expert Group was able to considerably refine its understanding of policy, strategy and costs of decommissioning. This report presents information on decommissioning costs, and on policy or strategy aspects that may affect those costs. It provides some insights on the interdependencies between decommissioning costs, policies and strategies. It includes some information on the mechanisms that countries have put in place to assure that adequate and robust funding is available for decommissioning when it is needed and in appropriate amounts.

Other relevant international activities

In addition to the decommissioning cost study presented in this report, the NEA and other international organisations are performing other, related work. The following is a very brief summary of the most significant of these other projects.

OECD Nuclear Energy Agency (NEA)

Within the NEA, decommissioning is discussed within several Standing Technical Committees. Based broadly on the conclusions of a workshop held in Rome in 1999, The Regulatory Aspects of Decommissioning, the NEA programme of work in the area of decommissioning, other than the work of the NDC which is the subject of this report, includes the following:

- The Radioactive Waste Management Committee (RWMC) created its Working Party on Decommissioning and Dismantling (WPDD) in 2001 to address the policy and regulatory aspects of decommissioning. The recent (2002) publication *The Decommissioning and Dismantling of Nuclear Facilities: Status, Approaches, Challenges*, reviews the current situation in decommissioning, and identifies key issues. The WPDD has also created a web-based, publicly accessible database of national decommissioning policies, practices and projects.[2] This database will be updated yearly. Also available from the same web site are technical documents on the *decommissioning safety case*, the *release of materials from regulatory control*, and *the release of sites and buildings*.
- The Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) has, since its creation in 1985, worked to share industrial, project-level experience among decommissioning projects. The expertise of these decommissioning projects is used by the WPDD, and other NEA groups working in the area of decommissioning, notably the NDC Expert Group, as the technical basis for discussions.
- The Committee on Nuclear Regulatory Activities (CNRA) has focused its efforts on developing a policy-level understanding of regulatory issues in decommissioning. The CRNA plans to publish its views in a document titled *The Regulatory Challenges of Decommissioning Nuclear Reactors* during 2003.
- The Committee on Radiation Protection and Public Health (CRPPH) has, for some time, been contributing to the development of new radiation protection norms, as provided in the recommendations of the International Commission on Radiological Protection (ICRP). Part of this work involves the philosophy and practical approach to the release of sites, facilities and materials from radiological regulatory control. The CRPPH has recently issued two documents that address, among other things, these issues: *The Way Forward in*

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2. The address is: http://www.nea.fr/html/rwm/wpdd/welcome.html

Radiological Protection, An Expert Group Report, and Policy Issues in Radiological Protection Decision-making: Summary of the 2nd Villigen (Switzerland) Workshop.

European Commission

The European Commission (EC) is involved with the subject of decommissioning nuclear facilities both from the technological research and the regulatory points of view.

The research related activities are carried out within the Framework Programme for the European Union's research, technological development and demonstration. The Projects currently under execution represent the continuation of a long-standing effort in this area, started in the early eighties. Today, these Projects serve two main purposes: enhanced networking across Europe and structured access for the experts and the public to the important common documentary resources built through decades of practical works.

A good example of the former is the "Thematic Network on Decommissioning" – started in 2001– involving some fifty organisations and that covers all aspects specific to decommissioning, from technological to legal or strategic issues. Among the latter, the Project "EC decommissioning information Network" integrates the previously created databases on decommissioning costs and tools in a single platform accessible via Internet. Other Projects of this kind is the "Compendium on the state of the art in Decommissioning" or the "Standardised Decommissioning Cost Estimating of WWER[3]- 440 NPPs".

Furthermore the Commission is active in taking initiatives of legal scope in the nuclear field, very particularly addressing the back end of the nuclear fuel cycle. In January 2003, the Commission has submitted an ensemble of proposals in areas such as nuclear safety and the management of radioactive waste. These initiatives tend to give consistency to the regulatory framework at European level and to help solving uncertainties about the handling of the liabilities generated throughout the productive lives of nuclear facilities. Two proposals of Directive are currently under discussion at the Council of the European Union in view of adoption.

One of them regards the principles of safety of nuclear installations and paves the way to the setting of common safety standards in Europe. It addresses some basic elements of nuclear safety, such as:

- the independence and role of the safety authority, the need of inspections;
- the ensuring of the long-term management of all materials, including radioactive waste and spent fuel produced in the course of decommissioning;
- the attribution of responsibilities;
- the constitution of financial resources to ensure safety during operation and for the decommissioning of the installations;
- the creation of decommissioning funds; and
- the inspections at European level.

The second proposal deals with the management of radioactive waste and spent fuel. The key aspects of it are the following:

3. WWER is the IAEA version of VVER. Both are used in the publication.

- establishment by each Member State of a programme for the management of all radioactive waste and spent fuel including limit dates for the selection and operation of disposal sites;
- need of financing schemes in respect of the “polluter pays” principle; and
- continuing effort in the research and technological development in the field of radioactive waste, with an increased coordination at European level.

In order to achieve its objectives, the Commission is active in the consultation of the stakeholders in the subject of decommissioning an radioactive waste, participates in international groups and forums, and exchanges views with the other institutions, such as the European Parliament and the Council as part of the institutional law-making process.

International Atomic Energy Agency (IAEA)

The IAEA has a long-standing comprehensive programme of work on decommissioning and has published recently a number of reports on various aspects of nuclear facility decommissioning.

IAEA documents issued since 1999 include:

- *On-site Disposal as a Decommissioning Strategy,* giving an overview of the factors relevant to the selection of on-site disposal as a decommissioning strategy and the actual experience available (TECDOC-1124, 1999).
- *Review of Selected Cost Drivers for Decisions on Continued Operation of Older Reactors,* reviewing published information on the costs of safety upgrades, life extension and decommissioning, which are input data for a power system analysis of the options of earlier/later retirement (TECDOC-1084, 1999).
- *State of the Art Technology for Decontamination and Dismantling of Nuclear Facilities,* identifying and describing state of the art technology for the decommissioning of nuclear facilities (TRS-395, 1999).
- *Organization and Management for Decommissioning of Large Nuclear Facilities,* covering the organisational aspects of decommissioning and describing factors relevant to the planning and management of a decommissioning project (TRS-399, 2000).
- *Safe and Effective Nuclear Power Plant Life Management towards Decommissioning* aiming to promote and communicate the need for a longer-term perspective among senior managers and policy and strategy makers for decisions that have the potential to affect the life cycle management of a nuclear power plant, including decommissioning (TECDOC-1305, 2002).
- *Record keeping for Decommissioning of Nuclear Facilities: Guidelines and Experience,* provides information, experience and assistance on how to identify, update as needed and maintain the necessary records to assist in the decommissioning of nuclear facilities (TRS-411, 2002).
- *Decommissioning of Small Medical, Industrial and Research Facilities*, covering major issues such as: the need for and contents of early planning for decommissioning; access to decontamination and dismantling technology as needed; the need for a qualified and trained dedicated decommissioning team; project management and quality assurance (TRS-415, 2003).

- *Predisposal Management of Radioactive Waste, including Decommissioning* setting out the requirements for safe decommissioning (Safety Guide No. WS-R-2).
- *Decommissioning of Nuclear Power Plants and Research Reactors*, providing guidance to national authorities and operating organizations for the planning and safe management of decommissioning of nuclear power plants and research reactors (Safety Guide No. WS-G-2.1).
- *Decommissioning of Medical, Industrial and Research Facilities,* providing guidance to national authorities and operating organizations, particularly to those in developing countries (as such facilities are predominant in these countries), for the planning and safe management of decommissioning of such facilities (Safety Guide No. WS-G-2.2).
- *Decommissioning of Nuclear Fuel Cycle Facilities*, providing guidance to national authorities and operating organisations for the planning and safe management of decommissioning of nuclear power plants and research reactors (Safety Guide No. WS-G-2.4).

A study on the decommissioning costs of VVER-440 has been completed and published recently as a technical document (TECDOC-1322) entitled *Decommissioning Costs of WWER-440 Nuclear Power Plants*. It presents the decommissioning costs of VVER-440 in a uniform manner, using the cost item and cost groups of the 1999 joint publication of EC, IAEA and NEA *A Proposed Standardised List of Items for Costing Purposes,* thus providing a basis for understanding decommissioning costs differences.

The ongoing work includes:

- A technical document on Planning, Organisational and Management Aspects for Decommissioning of Nuclear Facilities: Operating Experience and Lessons Learned, that builds upon operating experience and intends to distil common issues and lessons learnt from actual case histories.
- A technical report on Operation to Decommissioning Transition that addresses management and organisation changes; radiological characterisation as support to decommissioning planning; de-fuelling; post operation clean-out; conditioning of operational waste; real scale and laboratory testing of decontamination and dismantling techniques; minimising expenditures; socio-economical and public acceptance aspects. Companion documents focusing on safety aspects during the transition from operation to decommissioning and on early termination of operation are under preparation also.

2. DECOMMISSIONING POLICIES AND STRATEGIES

Decommissioning policies and strategies are reviewed and analysed in the present study essentially from the viewpoint of their impact on the costs of decommissioning commercial nuclear power plants. In this connection, national decommissioning policies and the selection or development of a decommissioning strategy by the reactor site owners and operators are described in so far as necessary to identify the various factors that may affect costs. As noted in Chapter 1, for the purpose of the present study, the management of nuclear fuel is not considered to be a part of the decommissioning activities.

Decommissioning policy

Decommissioning policy, in the context of this study, refers to government policy, and includes all governmental (national or regional) choices, as described in laws, regulations, standards and mandatory requirements that will influence the framework in which decommissioning takes place. For example, requirements regarding the use of decommissioned sites, waste management policies, policies for re-use and recycling of materials, free release levels, public and worker health and safety policies, environmental safety policies, regional development aspects are seen as elements of the decommissioning policy.

It is widely accepted that the route to removal of regulatory controls depends on many factors and may involve various stages and interim uses. National policies differ and are influenced variously by such matters as the future use of nuclear power, the continued availability of trained staff, societal issues associated with the effects of facility shut-down, safety, costs and the broader financial issues such as how best to use available funds and when to deploy them.

The following review and analysis is mainly based on answers to a questionnaire received from twenty-six countries including sixteen OECD member countries. A number of questions related to decommissioning policy were included in the questionnaire (see Annexe 2, questions QP1 – QP22). The answers to the questions on policy related to funding mechanisms and schemes (QP16 – QP22) are analysed in Chapter 3.

It should be noted that the selection of potentially important policy issues was not unbiased or exhaustive. A pre-selection of policy issues was performed when the questionnaire was prepared with the view of including those which were thought to have the greatest impact on the cost issues or to be of particular interest to governmental bodies. Information from the respondents was requested regarding the following policy issues:

- scope and time-scale of decommissioning activities;
- requirements for selection of strategies;
- licensing requirements, de-licensing and future liabilities; and
- material management.

Although the respondents provided extensive information on most topics included in the questionnaire, the answers vary in degree of details and coverage and, moreover, did not always cover the scope intended by the drafters of the questionnaire. Therefore, the information presented in this report should be considered as indicative of approaches adopted in various countries and by various industrial operators. Similarly, the analyses and findings of the Expert Group are illustrative of generic trends and not intended to serve as a basis for comparisons between different countries and operators.

Scope and time-scale of decommissioning activities

National definition of decommissioning

National policies define and delimit, in scope and sometimes in time, the decommissioning of a nuclear power plant. A possible delimiter of the scope could be the national definition of decommissioning, and in about half the responding countries, a definition exists. Some examples are:

- "The whole of administrative and technical duties and actions required for, or leading to, the stopping of the management of an installation and aimed at bringing the latter in a safe condition for workers, people and the environment". Belgium, Royal Decree of 20 July 2001, article 2, Definitions.
- "Those activities taken, in the interests of health, safety, security and protection of the environment, to retire a licensed activity/facility permanently from service and render it to a predetermined end state condition". Canada, CNSC Regulatory Guide G-219, Decommissioning Planning for Licensed Activities, June 2000.
- "The activities that dismantle the facilities after the final shut down of a nuclear power plant which has finished its role to make the state of facilities safe". Japan, Nuclear Safety Subcommittee
- "Decommissioning means such complex of measures after nuclear fuel removal that excludes the operation of the facility in purposes for which it was constructed and provides the personnel and public safety and the environment security" Ukraine, GPSA-98, article "Basic terms and definitions".

The common features of the different definitions are that decommissioning refers to the actions taken to reduce the residual hazards (radiological or otherwise) after cessation of generation with the aim of reaching a stable and safe end-state at the facility (unrestricted use, restricted use or new nuclear facility). Often the definitions also include specific reference to the ongoing safety of people and the protection of the environment during and after the decommissioning process.

Required starting and end points

The required start and end points of decommissioning activities, if specified in the national policy, have a direct impact on the scope of work included in "decommissioning" and thereby on decommissioning costs. The responses to the questionnaire illustrate a wide range of situations regarding this important issue. Sometimes, intermediate, post-closure stages exist and these stages are not always well defined or separated.

More than half of the respondents answered that there is no required starting point of decommissioning, while a third answered the contrary, i.e. that a required starting point exists. A few respondents did not answer the question.

In many cases, the starting point is the requirement to change from an operating licence to a decommissioning licence. It should however be noted that in some countries, like Japan, Sweden and the United Kingdom, no specific decommissioning licence is needed. The decommissioning activities are performed under the operating licence.

In Bulgaria, the Russian Federation and Ukraine, the de-fuelling is part of the pre-decommissioning activities. In countries with only one or two nuclear power plants like Armenia, Lithuania, and Pakistan, the start of the decommissioning work is specified in a national energy strategy plan or a specific law.

More than 60% of the responding countries answered that a required end point of decommissioning exists. Some respondents answered that the national policy does not require a specific end point but an end point is specified in the decommissioning strategy for cost analysis (Belgium), agreed upon between the plant operator and the decommissioning operator (Spain). In some countries (e.g. Switzerland) “green-field” conditions, i.e. essentially unrestricted release of the site, are assumed as end point for the purpose of cost estimates.

The respondents were asked to describe the required end point – if it exists. The answers confirm that different end points are indeed possible. Five responding countries (Finland, Hungary, Italy, the Netherlands and Czech Republic) answered that the required end point is unrestricted use of the site (removal of contamination and radioactive sources above clearance levels, or “green-field”). More precisely, in Finland, the responsibility of the nuclear power plant owner ends when all radioactive waste has been disposed of and the disposal has been approved by the regulator. In Armenia and the Russian Federation the site is foreseen for nuclear or other industrial use. In the United Kingdom, the United States and the Slovak Republic unrestricted use, restricted use or use for a new nuclear facility are viable options. In Japan it is recommended that the site of nuclear power reactors shall be re-used for nuclear power generation.

Mandatory time-scale

Seven countries answered that a mandatory time scale exists by which the end point of decommissioning must be achieved. In Italy, where nuclear energy production has been stopped since 1987 and even before for some units, the national policy objective is to finish decommissioning activities before year 2020. In Japan, the recommendation from the Nuclear Safety sub-committee is to finish the decommissioning activities 30 years after commencement. For the other five countries with mandatory time scales, the end point must be achieved within periods ranging from 40 to 100 years after shut down.

From the above, it is clear that the scope of the actual decommissioning work varies from country to country and even between different decommissioning projects. It is observed that different start and – perhaps more importantly – end points are allowed within national decommissioning legislation. In less than a third of the countries, including countries where no end point is fixed by legal requirement but is still assumed for the purpose of strategy definition and cost estimates, the option of unrestricted use for the decommissioned site is singled out.

Without additional details about clearance levels and de-licensing requirements it is difficult to evaluate the precise impact of the varying requirements on decommissioning strategy and costs. There are many variations of an acceptable end state for a decommissioned nuclear facility. Therefore, the starting and end points as well as the time-schedule of the decommissioning activities should be known and taken into account when comparing cost estimates for specific projects or trying to analyse the reasons for cost variability between different projects and countries.

Licensing requirements

The control of decommissioning activities to ensure that they are performed according to legal requirements varies from country to country according to national regulations. A regulatory authority can control decommissioning activities in many different ways – by a single overall decommissioning licence or by separate licences applying to discrete sets of activities. In some federal countries, national governments and the governments of the component States or Provinces of the federation share the regulatory powers. Different regulatory bodies may also be responsible for different aspects, such as planning, health and safety of people, waste disposal and environmental protection issues.

Experience has shown that considering decommissioning issues at the earliest stage in the life of a nuclear facility is essential to facilitate decommissioning activities and eventually reduce their cost. Today, plans and procedures for decommissioning are key features in the design of new nuclear facilities. A decommissioning plan, to be regularly reviewed and updated, is often required before an operating licence is issued for a new nuclear facility. Although this was not usually the case when many of the existing nuclear power plants were built, decommissioning plans and systems for their recurrent reviews now have been introduced also for these plants.

Responses to the questionnaire provide information on how decommissioning is licensed in the countries covered in the study. The main questions on this topic addressed: the need, or not, for a new license to shut down or/and to decommission a nuclear power plant; and the documentation requested by the authorities in order for the operator to gain consent to proceed with decommissioning.

Licence to shut down a nuclear facility, decommissioning licence

In eight of the twenty-six countries participating in this study, a specific licence, different from the operating licence, is required to shut down a facility. In nearly 80% of the countries, a specific decommissioning licence is required. Only in a few countries, for example Sweden, the United Kingdom and the United States, the decommissioning activities can proceed without a specific decommissioning licence. In that case the operating licence applies to decommissioning activities. For example, in Sweden, the operating licence covers also the future decommissioning and dismantling activities but specific requirements have to be fulfilled. In the United States, some reactor owners elect to obtain a separate licence for spent fuel storage; this allows termination of the original licence.

Documents required in order to gain consent to proceed with decommissioning

In order to proceed with the decommissioning and dismantling activities, certain documents are required by the national authorities. The requirements for reporting and the regulatory review process of decommissioning plans and safety management issues vary from country to country. However, some requirements are common to the countries that participated in the present study. For example, with a few exceptions, a safety case or a safety report must be presented to the authorities. In addition to this, an environmental impact assessment is often required.

The countries of the European Union and countries candidates to join the Union are bound by the terms of the European Commission legislation[4] to perform an environmental impact assessment (EIA) in connection with the decommissioning of nuclear power plants. In this European Union framework, specific measures are taken to inform and involve the public and the neighbouring countries.

4. 397L0011, Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment, Official Journal L 073, 14/03/1997 p.0005 – 0015.

If a new licence is needed for the decommissioning activities, the application must invariably be supplemented with a decommissioning plan, and supplementary documents (such as radiation protection programme, quality assurance plan, technical descriptions, time-plans etc.). Sometimes the requested documentation is extensive.

In the countries where no new licence is needed in order to proceed with the decommissioning activities, reports are usually required at a few fixed, pre-determined occasions. For example, in the United States, the following documents must be submitted:

- Certification of permanent cessation of operations.
- Certification that fuel has been permanently removed from the reactor vessel.
- Post-shutdown activities report.
- Updated cost estimate for decommissioning and the amount in the decommissioning fund.

Issuing new license in order to exclude the possibility for continued operation of the nuclear power plant, which is sometimes mandatory, may be economically advantageous for the operator as earlier mandatory safety measures and provisions applicable to plant operation will no longer need to be observed. It is, however, difficult to draw any firm conclusions about the economic impact of the need for a specific decommissioning license because mandatory regulatory requirements may exist even in the absence of the need for a specific license.

For example, in both Sweden and the United States regulatory requirements of several different authorities/agencies may need to be addressed before decommissioning can begin. In the United States, the NRC authorises the decommissioning of the radiological contamination while other authorities, such as the US Environmental Protection Agency or the individual States, regulate non-radioactive hazards at the site. It is important, however, to note that in that case a flexible, stepwise process of authorisation is possible, reflecting the changing physical situation in the plant and the related evolution of hazards during the different decommissioning stages.

Requirements for selecting a strategy, de-licensing and liabilities

Selection of a strategy, guidance provided, required options/alternatives to be considered

In more than half of the responding countries, the utilities/operators are explicitly requested to perform a broad based strategy evaluation before selecting a decommissioning plan. In some of these countries, guidance is given on how to perform this task. It should be observed that some of the responding countries remark that even if no formal request exists for strategy selection, such evaluation is assumed to be performed.

In the OECD/NEA member countries of the European Union, in the framework of an Environmental Impact Assessment, designated national bodies assess different decommissioning alternatives.

In the Russian Federation, the operator of a nuclear power plant must perform a feasibility study five years before a unit is scheduled to be shut down. In this study, to be approved by the supervisory and the regulatory bodies, the operator analyses the technical and economical feasibility of options for decommissioning or alternatively extending the operational lifetime of the unit.

In the United Kingdom, various Government Departments and regulators provide general guidance on options or multi-criteria analysis. The basic guidance is to examine a full range of options before selecting the preferred strategy.

Requirements for de-licensing a site, future liabilities

A few countries have yet to define requirements for the future de-licensing of their sites. Some countries answer that de-licensing can be performed when all radioactive materials and other hazardous materials, including all radioactive contamination above some pre-determined levels, are removed from the site. Other countries answered that the absence of radioactive materials has to be confirmed by a suitable authority and reference is made to release levels or legal documents containing such release levels. Sometimes the applicable release levels are given in the decommissioning licence and could be specific for the actual decommissioning project.

In Canada, a Federal level Environmental Assessment might be required but in all cases, the national authority, the CNSC, must issue a licence to release the site. In the United States, it should be shown that the dose to a member of the public does not exceed 25 mrem/year (0.25 mSv/year), which is the same level as the authorised dose to the public during operation. In the Russian Federation, the de-licensing of a site is not a viable option. All the sites are multi-unit sites and when the dismantling of a nuclear unit is ready, the site should be prepared for building a new unit.

Seven of the responding countries have addressed the question of liability for costs of managing radioactive materials discovered after de-licensing. For these respondents, the former operator/owner of the plant remains responsible. In some countries, however, such as Hungary and Pakistan, the State/Government is the owner/operator of the plant. In all cases, according to the International Convention on Nuclear Safety, the State has the ultimate responsibility for handling radioactive material and covering any associated costs if there is no other legally responsible plant operator/owner.

The information provided shows that many countries already have well-developed systems for de-licensing a site but that there is no consensus within OECD countries on a preferred set of site release criteria or even the form of such criteria. Consultation with the public in the selection of procedures for site surveys and site release criteria is important for transparency and public acceptance of the decommissioning process.

In the context of the present report, it has been stressed by experts that when comparing the actual costs or the cost estimates for decommissioning, it is important to know the specific site release criteria and the particular measures that have to be taken in order to meet these criteria.

Material and waste management

Large volumes of material arise during decommissioning activities and the costs for radioactive material and waste management and disposal can make up a substantial part of the overall decommissioning costs.

Identifying clearly and preparing the different treatment pathways for re-use or disposal of each type of material or waste produced by decommissioning activities is key to cost effectiveness, minimisation of waste volumes and toxicity as well as safety and radiation protection of workers. For countries that foresee decommissioning and dismantling without extended periods of safe storage it is of prime concern to find site(s) for waste disposal, and to design and construct repositories or to provide appropriate storage facilities.

Examples of categories of material and waste to be considered in this connection include: radioactive and non-radioactive waste; material for authorised release; material to be recycled within the nuclear industry; and material to be re-used outside of the nuclear industry.

In order to collect information on those issues, respondents to the questionnaire were asked if repositories for all radioactive waste types arising for decommissioning are available, to provide information about the repositories available for decommissioning waste and to give information about any planned repositories for decommissioning waste. The respondents were also asked about the national policy for hazardous, non-radioactive waste and “mixed waste”, i.e. radioactive waste with an inherent amount of hazardous non-radioactive material. Finally, the respondents were asked if specific clearance levels and/or procedures for categorising decommissioning waste as non-radioactive or for making such materials exempt from regulations exist in their countries.

Repositories for radioactive decommissioning waste

It is significant that none of the twenty-six countries that participated in this study has repositories for all types of decommissioning waste.

The categories of existing radioactive waste that cannot be disposed of are stored for an interim period of time in appropriate facilities at the nuclear power plant sites or in specially designed national interim storage facilities. Pending construction and commissioning of suitable repositories for radioactive and other hazardous waste, dismantling activities are sometimes deferred. Since estimating decommissioning costs requires assumptions regarding waste disposal costs, the lack of repositories for some waste categories increases the uncertainty on total decommissioning costs and also their variability from country to country.

In some countries, e.g. Switzerland, national decommissioning work is planned in such a way that a repository is expected to be available at the time of decommissioning. In some countries, like Germany, interim storage facilities for radioactive waste have been constructed in order to proceed with decommissioning activities before repositories are available.

In seven of the responding countries, repositories which accept some low or intermediate level decommissioning waste already exist and these will often remain in operation for many years to come. The information given about these repositories is summarised in Table 2.1. 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 those repositories. Some restrictions usually also exist with regard to different chemicals, asbestos, graphite, free liquid, brass, or pure forms of carbon, magnesium, bismuth or fluorine.

The allowable surface dose rate on waste packages is often restricted to 2 mSv/h, a requirement stemming from international transport regulations. In some countries however, the use of shipping packages has enabled disposal of waste items with considerably higher surface dose rates.

In the United States, repositories, which accept some decommissioning waste, exist in South Carolina, Washington State and Utah, and one of the interesting features for these is that no specific limits exist on the size or the weight of acceptable packages. For example, in the Barnwell repository in South Carolina full-size steam generators have been buried.

In more than half the responding countries, repositories for radioactive decommissioning waste are planned. In France, Hungary, Italy, Romania, Slovenia, and Spain new repositories for very low and/or low- and intermediate-level radioactive waste are planned to be in operation within the next ten years. In Finland and Sweden, existing repositories for operational radioactive waste are planned to be extended in order to accommodate decommissioning waste.

In Germany, the Konrad mine received a license for the disposal of “non-heat-generating waste” in June 2002, which means that it could accommodate all types of radioactive waste, including decommissioning waste, except heat generating waste, e.g. spent fuel and solidified high level reprocessing waste. However, the license is now subject to litigation and as a result radioactive waste may be disposed of only after the court cases have been resolved.

Hazardous, non-radioactive waste

Decommissioning of nuclear facilities involves the management of large quantities of non-radioactive waste. This is waste that either has never been contaminated or activated or that has been released from nuclear control (see *Clearance levels*) because of its trivial radionuclide content. Such waste may include hazardous substances, for example toxic chemical compounds, asbestos, or other materials that require a specific management scheme.

In most countries, the same rules apply to the non-radioactive, hazardous waste from decommissioning of nuclear facilities as from other industrial enterprises. Either this is stated directly in the questionnaires or reference has been given to applicable national or regional legislation for such waste. In countries like Belgium, Canada, and the Russian Federation, communal, regional or provincial norms, policies, and rules apply to the non-radioactive hazardous waste. In Spain and Ukraine, special authorised enterprises manage this waste off-site. In a few countries, the question has yet to be addressed.

Non-radioactive hazards associated with radioactive waste

All types of radioactive waste may contain non-radioactive hazardous substances at varying concentrations. In some countries such waste is termed “mixed waste” if the amount of hazardous substances exceeds predetermined levels. Such waste needs special attention, in particular when it is to be disposed of in near surface repositories.

In a third of the countries, no specific national policy for mixed waste exists. In about 25% of the countries mixed waste management will be part of radioactive waste processing. In the Slovak Republic, mixed waste will be placed into long-term interim storage. In Sweden and the United States, the disposal of mixed waste is limited by the specific waste acceptance criteria of each waste repository.

As another example, Germany does not define a mixed waste category. The German policy is to dispose of radioactive waste in geological formations only and not to operate near surface repositories. The non-radioactive hazards associated with radioactive waste have been assessed within the safety assessment of the Konrad mine. It was found that hazardous materials associated with radioactive waste do not pose an additional hazard to the safety of present and future generations and can be disposed of safely in this deep geological repository.

Table 2.1. Summary of existing repositories that accept radioactive decommissioning waste

Country	Location (Type)	Opening year	Anticipated closing year	Characteristics of the waste limiting acceptability	Special materials not accepted at the repository
Czech Republic	Dukovany (Low- and intermediate-level waste from nuclear power plants)	1995	2100	Max. β, γ :1 x 10^{12} Bq/m^3, α: 3 x 10^7 Bq/m^3, Max. 0,9 Sv/hon surface. No limits on size of package, handling technique adapted to 200 (400) dm^3 drums Max weight: 550 kg	Free liquids; Pyrophoric and/or explosive materials; Hazardous chemical substances and preparations (e.g. PCB, asbestos, lead)
	Richard Litoměřice (Low- and intermediate-level waste from institutions)	1964	2070	Max. β, γ :1 x 10^{11} Bq/m^3, α: 2 x 10^8 Bq/m^3, Max. 1 mSv/h on surface. Max. size of package: 200 dm^3 drums Max. weight: 600 kg	
France	Centre de l'Aube, Soulaines	1994		Max: 1 x 10^6 Curie (for the total repository) Max. size of package: 4 m^3 Max. weight: 10 tonnes	Graphite; "Long-lived" waste
Slovak Republic	2 km Northwest of the Mochovce nuclear power plant	2001	2031	Max. 2 mSv/h on surface (Fibre reinforced concrete container) Package size: 1,7 x 1,7 x 1,7 m^3 Max. weight: 15 tonnes	Free liquids; Biodegradable substances (gas developing); Phyrophoric substances and substances producing exothermic reaction with water; Toxic or hazardous non radioactive waste
South Africa	District of Namakwaland Kliprand, Northern Cape	1986	2386	The limits for A1 and A2 materials are applicable as specified in IAEA Safety Standard Series No TS-R-1 Max. 2 mSv/h on surface of waste container Max. size of package: 2 m^3 Max. weight: 6 tonnes	Biological waste; Waste containing long lived alpha radio activity
Spain	El Cabril, Córdoba	1992		Max. α -emitters: 3700 Bq/g, Max. 50 mSv/h at contact (before conditioning) Max. size of package: 1,3 m^3 Max. weight: 1,5–2,0 tonnes	Acceptance criteria are related to activity levels, half-life and size

United Kingdom	Drigg, Cumbria, England (Low-level waste)	1959	2050	Max. α-emitters: 4 GBq/te Max. non – α: 12 GBq/te No additional shielding allowed, 2 mSv/h on surface at transport. Max. width: 2 438 m Max. length: 6 058 m Max. height: 1 320 m Max. weight: 35te delivered/ pre-grouting 42te post grouting/emplacement	Will accept some solid decommissioning low-level waste. Decommissioning waste may not be accepted if they have a significant impact on the available capacity (could apply to graphite due to high C_{14} content)
USA	Barnwell, SC	1971		Max. 50 000 Ci (one shipment) 2 mSv/h on surface at transport No size or weight limit	Hazardous waste SNM waste,[5] GTCC waste[6]
	Richland, WA	1965		Max. 60 000 Ci (one shipment) 2 mSv/h on surface at transport No size or weight limit	Hazardous waste SNM waste,[4] GTCC waste[5] Brass
	Clive, UT (Low-level waste)	1992		Class A waste[5] only 2 mSv/h on surface at transport No size or weight limit	SNM waste[4] Chemicals in pure form: carbon, magnesium, bismuth or fluorine

Clearance levels

In about 60% of the countries specific national clearance levels, or other ways to categorise decommissioning waste as "non-radioactive", making it exempt from regulation, exist. Italy and Spain are examples of countries in which clearance levels are specified for a site/decommissioning project or for a number of specific activities at a site (e.g. Caorso, Italy). In Canada, the regulator for a decommissioning site can specify clearance levels on case by case basis for waste. Belgium, Germany, the Russian Federation, and the United Kingdom are examples of countries with general clearance levels stipulated in national legislation.

The costs for the management and disposal of radioactive waste can be a substantial part of the overall decommissioning costs. Therefore, the availability and acceptance criteria of existing or planned repositories, the need for on-site interim storage facilities and the allowable clearance or free release levels impact on the selection of decommissioning strategy. This should be recognised when comparing estimated or actual costs between different decommissioning projects.

It is not within the scope of this study to perform detailed comparisons between the clearance levels in the participating countries. However, when comparing the costs or the cost estimates for

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5. Special Nuclear Material: Material containing Plutonium isotopes, ^{233}U, or Uranium enriched in the isotopes ^{233}U or ^{235}U.

6. In 10 CFR Part 61.55 "Waste Classification," the NRC defines disposal requirements for three classes of low-level waste, which are considered generally suitable for near-surface disposal. These are Class A, B, and C. Class C waste is required to meet the most rigorous disposal requirements. GTCC: Greater than Class C Waste, Waste that contains so high concentrations of long-lived radionuclides that they are not allowed to be buried in a near-surface disposal.

various decommissioning projects, it is important to know the approved levels or the underlying assumptions for free release of material.

Decommissioning strategies

As defined in Chapter 1, decommissioning strategy for the purpose of this report relates to how reactor site owners and operators apply national decommissioning policy. It covers specific plans and assumptions made in the context of decommissioning projects, particularly where this might have an impact on the associated costs.

In order to gather relevant information, a number of questions related to strategy and reactor site details were included in the questionnaire (Annex 2, questions QS1 to QS19). Information was requested for individual reactor sites, including:

- outline descriptions and data on the sites;
- what is included in the assumed scope for decommissioning;
- which decommissioning strategies have been considered;
- the methodology for determining the preferred strategy and the main factors
- considered; and
- dismantling and waste disposal plans.

All the information that was provided in response to the questionnaire has been collated and compared in order to assemble the summary presented below. In considering this summary, it should be noted that full answers were not always provided to every question for every reactor site or reactor and that there was some variability in how some of the answers were presented. Also, some countries provided data for reference or generic reactor types rather than for specific, named, reactor sites. Consequently, the trends reported below should be considered as indicative while individual data points illustrate the variability of the information provided.

Reactor site information

Responses to the strategy questions were received from 25 countries, covering over 200 reactors on over 80 sites, with the numbers of reactors per site varying between 1 (e.g. Latina, Italy) and 8 (Bruce and Pickering, Canada). Most responses refer to a specific nuclear power plant in a given country. However, some respondents provided more generic data representative of nuclear power plants in their respective countries. Germany and Spain gave data for a reference PWR and a reference BWR; Ukraine reported data for a reference VVER 1 000; and France provided a single data set covering 58 PWRs. In the following presentation and analysis, the German, Spanish and French data has been treated as being for a single reactor unit although it is recognised that each is representative of a number of units. This section of the report, including its figures, is based upon responses to the "Strategy" part of the questionnaire[7].

7. In Chapter 4, the text and figures are based on responses to the "Cost" part of the questionnaire. Since some respondents provided information on strategy but not on costs, the graphs of Chapter 4 are not fully consistent with those of this section.

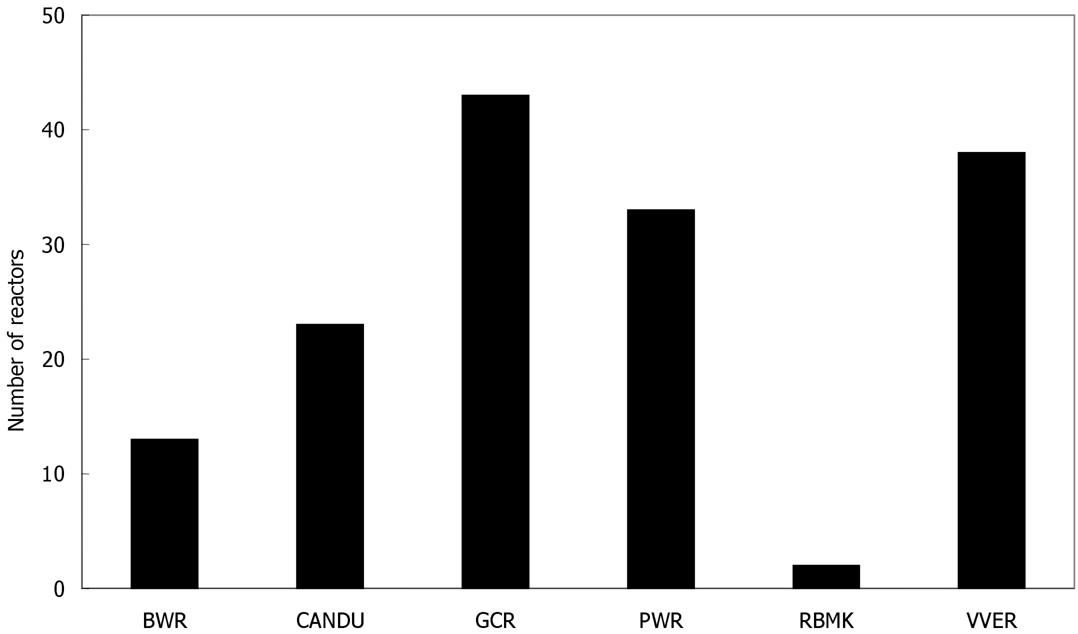
Reactor information

In order to assist in the analysis of the information provided on strategy issues, a number of questions were included in the questionnaire related to technical data on the reactor units. The responses to these questions are summarised below.

The data provided covers 6 different types of reactors of varying sizes from 49 MWe (Calder Hall/Chapelcross in the United Kingdom) to 1 455 MWe (Chooz B in France). The reactor types and numbers are shown in Figure 2.1 and the range of MWe capacities, along with the median values, are given in Figure 2.2 for each reactor type. This indicates that in general, for the reactor types considered, the gas-cooled reactors (GCR) have the smallest capacity and pressurised water reactor (PWR) the largest.

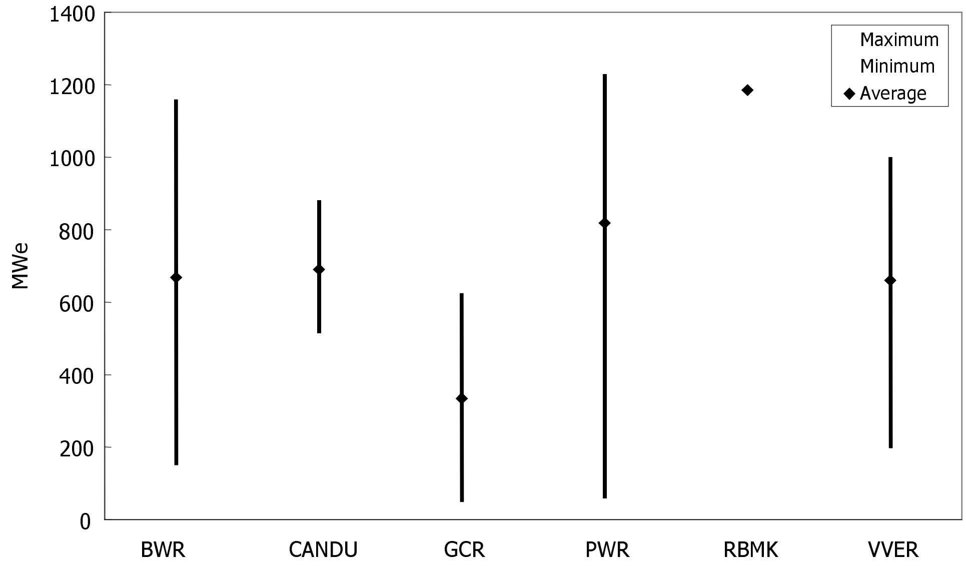
The majority of the reactors considered have steel reactor pressure vessels but 12% are reactors utilising pressure tubes and 9% have concrete reactor pressure vessels.

Figure 2.1. Reactor types for which decommissioning strategy information was provided



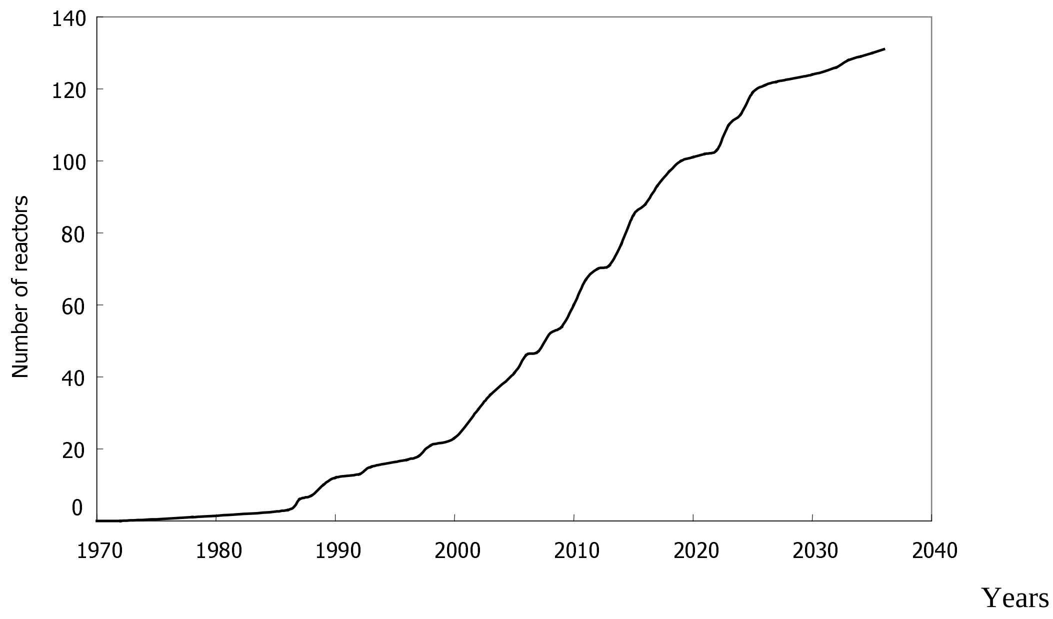
Some information was provided by respondents to the questionnaire on the operational history of the reactors in order to check whether anything might be influencing the decommissioning strategies selected, or the decommissioning costs. No significant operational incidents were reported for these reactors, other than a turbine hall fire (Vandellos in Spain). However, it was noted that some plants had been subject to refurbishment or replacement (Dukovany in the Czech republic, Borssele in the Netherlands, Novovoronezh in Russia, Bohunice in the Slovak Republic and Krsko in Slovenia), some had suffered minor leaks (e.g. Haddam Neck in the United States) and not all had operated continuously (in Armenia, Canada, Italy).

Figure 2.2. Capacity of the reactors for which decommissioning strategy information was provided



The majority of the reactors for which information was provided are still operational but about 20% have already been shutdown. Information on actual or predicted shutdown dates was provided for about 60% of the reactors considered. The cumulative shutdown profile for these reactors is presented on Figure 2.3. This shows that there is predicted to be a steady increase in the number of reactors being shutdown between now and about 2030 when most will be shutdown. However, it should be noted that the shutdown dates for the reactors that are still operational are those assumed for costing purposes and are not necessarily committed.

Figure 2.3. Cumulated number of shutdown reactors



Waste quantities

A wide variety of reactor types, sizes and structures is covered by this report. This has an impact on the quantities and types of radioactive and non-radioactive materials that will result from their decommissioning. Therefore information was requested in the questionnaire on both radioactive and non-radioactive materials with the intention of addressing in the report the whole of the reactor site, including the conventional – non-radioactive – plant and buildings.

Because different countries and utilities have different conventions as to how they present decommissioning waste data, there was variability in the questionnaire responses. For example some of the responses related to the reactor island only, whereas others addressed the whole of the reactor site, including the conventional – non-radioactive – plant and buildings, e.g. turbine halls. In order to make comparisons between reactors and reactor types, the detailed analysis of the data has therefore focused on radioactive materials. There tends to be greater confidence in this information as it was the most consistently provided.

An analysis of the radioactive waste quantities reported is presented in Figures 2.4 to 2.7 that indicate the variability within and between reactor types. It should be stressed that the findings from data analysis are indicative of trends but not definitive since some responses were incomplete. The data in Figures 2.4 and 2.5 are presented in terms of weight per reactor, or unit, and show the maximum and minimum range as well as the median value per reactor type.

Figure 2.4. Weight of radioactive materials from the reactor

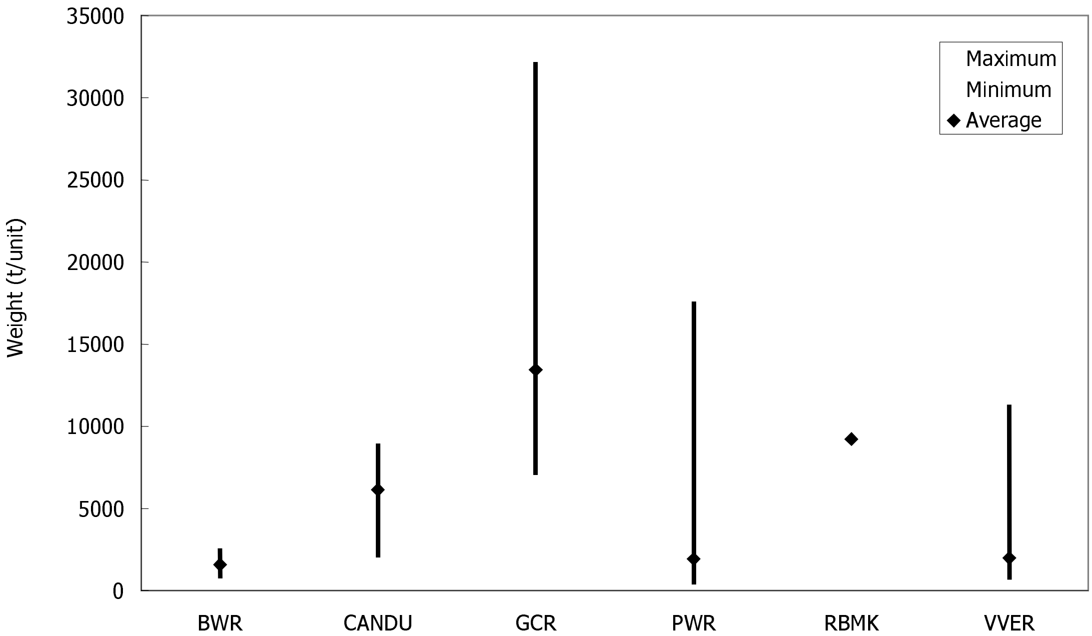


Figure 2.4 relates to the radioactive reactor materials only and shows that gas-cooled reactors (GCRs) produce significantly more radioactive waste than all other reactor types. For all other reactor types, the weight of radioactive reactor materials are generally lower and show less variability within each reactor type.

Figure 2.5 shows data for all radioactive materials, not just that related to the reactors. Again, GCRs have the largest quantity of radioactive materials but the variability of quantities within each reactor type is broader than for radioactive reactor materials. This probably reflects differences in the extent of reactor support facilities and equipment on different reactor sites.

Figure 2.5. Total weight of radioactive materials

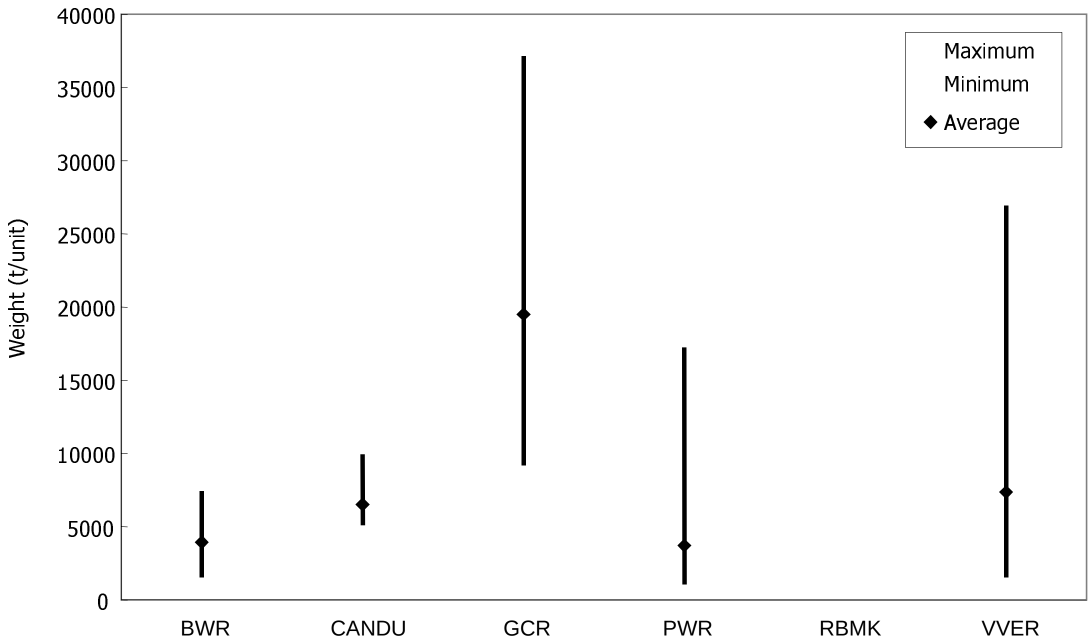
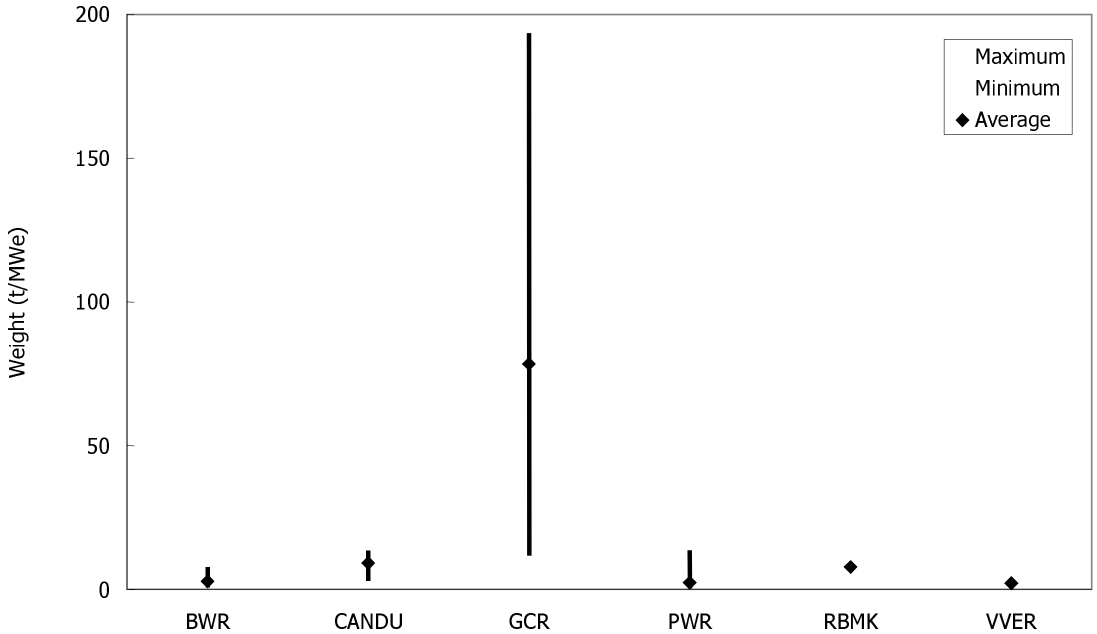


Figure 2.6. Weight of radioactive reactor materials per MWe



In order to check whether reactor capacity has an effect on waste quantities, the data presented in Figures 2.4 and 2.5 have been normalised, in terms of tonne/MWe, and re-presented in Figures 2.6 and 2.7. These show that reactor capacity is not a determining factor on waste quantities. In addition, it can be seen from Figure 2.6 that the difference between gas-cooled reactors and other reactor types is more marked when considering normalised data.

Figure 2.7. Weight of total radioactive materials per MWe

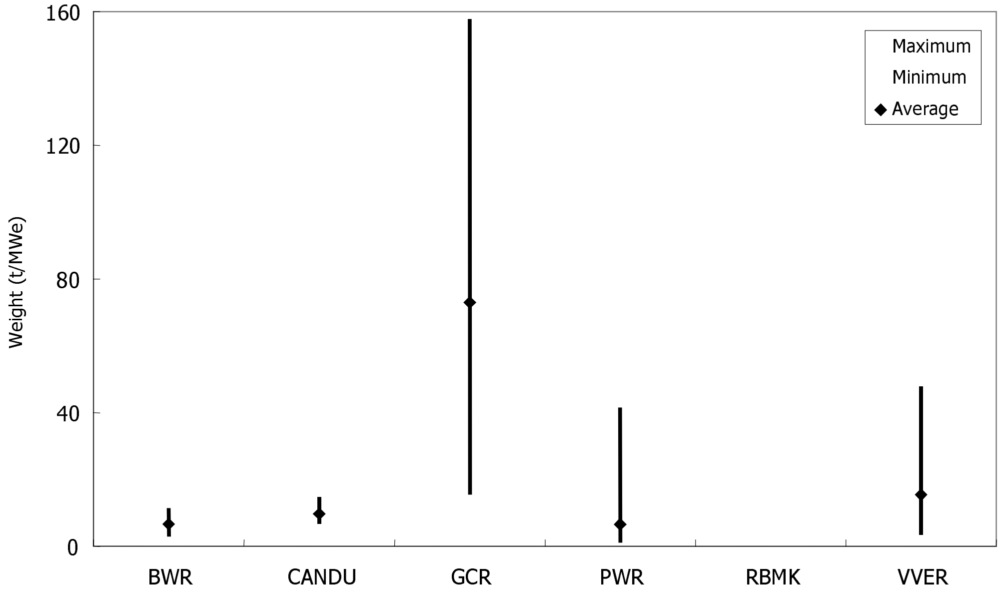


Figure 2.7, which – similarly to Figure 2.5 – presents all radioactive materials shows a greater variability between reactor types, although the gas-cooled reactors are still showing the highest normalised weights. This greater variability between maximum and minimum values probably reflects the differing extent of reactor support facilities and equipment among individual reactors and reactor types.

It can be seen from this data that there is a significant variability in radioactive waste quantities, not just between reactor types but also between reactors of the same type. Although it has not been presented in the graphs, this also appears to be the case when the data provided on non-radioactive materials is considered.

Because the quantity of materials on a reactor site will have a direct bearing on the costs of decommissioning, e.g. in terms of the extent of dismantling required and the quantity of radioactive waste requiring disposal, the large variability in weights identified in these figures will inevitably have an impact on the costs of decommissioning. Irrespective of their power capacities, reactors producing larger masses of radioactive materials will have higher decommissioning costs.

Responsibility for decommissioning

A question was asked in the questionnaire as to whether the responsibility for the reactor sites changes in moving from the operational to the decommissioning state. The majority of countries responding indicated that the responsibility for decommissioning remained with the utility or operator. However, in two countries (Hungary and Spain) the responsibility for decommissioning is transferred to a different national body. The transfer of responsibility should not affect costs *per se* but may have an impact on contingency margins included in cost estimates.

With respect to who is responsible for selecting the decommissioning strategy, most utilities/countries identified that it is the responsibility of the utility/operator, but a few indicated that the decision is made by Government.

Decommissioning strategy selection

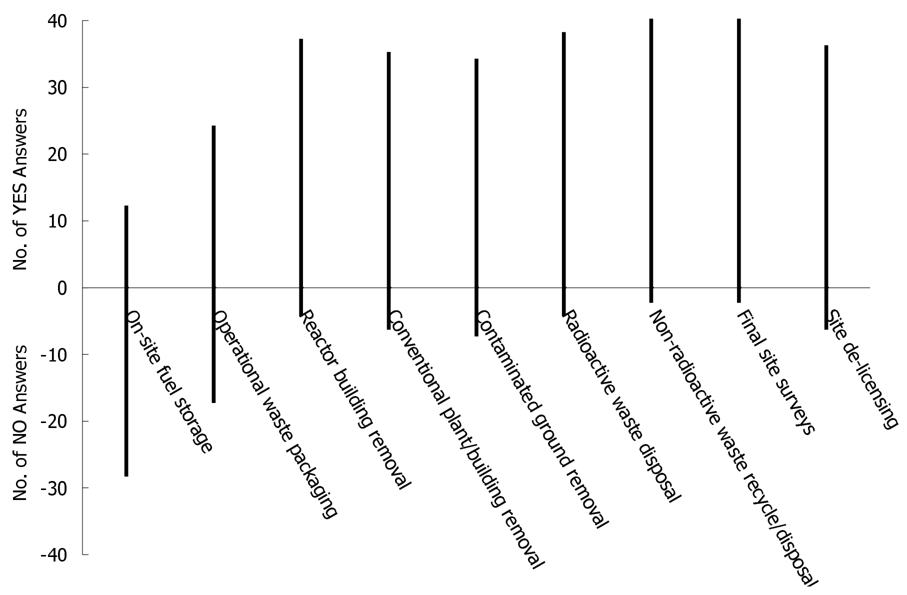
A number of questions asked in the questionnaire related to how the preferred decommissioning strategy is selected. These covered what activities were included within the assumed scope of decommissioning, which decommissioning strategy options were considered, what factors were taken into account and what process was used. The responses received are summarised below.

Assumed decommissioning scope

In order to understand the scope of decommissioning assumed by respondents they were asked to identify whether nine specific, significant activities were included within their assumed decommissioning scope. These included on-site fuel storage, removal of buildings, disposal or recycling of non-radioactive waste or material and de-licensing of the site.

Respondents were asked to answer "Yes" or "No" as to whether they included them in their scope or not. The numbers of "Yes" or "No" answers are shown in Figure 2.8. Although answers were provided for each reactor site, it was found that, understandably, the answers were generally the same for all reactor sites in a country, or, where there was some variability, the differences were between utilities in a country. Therefore the answers have been grouped into a total of about 40 utilities/countries rather than being presented in terms of all of the ~80 reactor sites covered by the questionnaire responses.

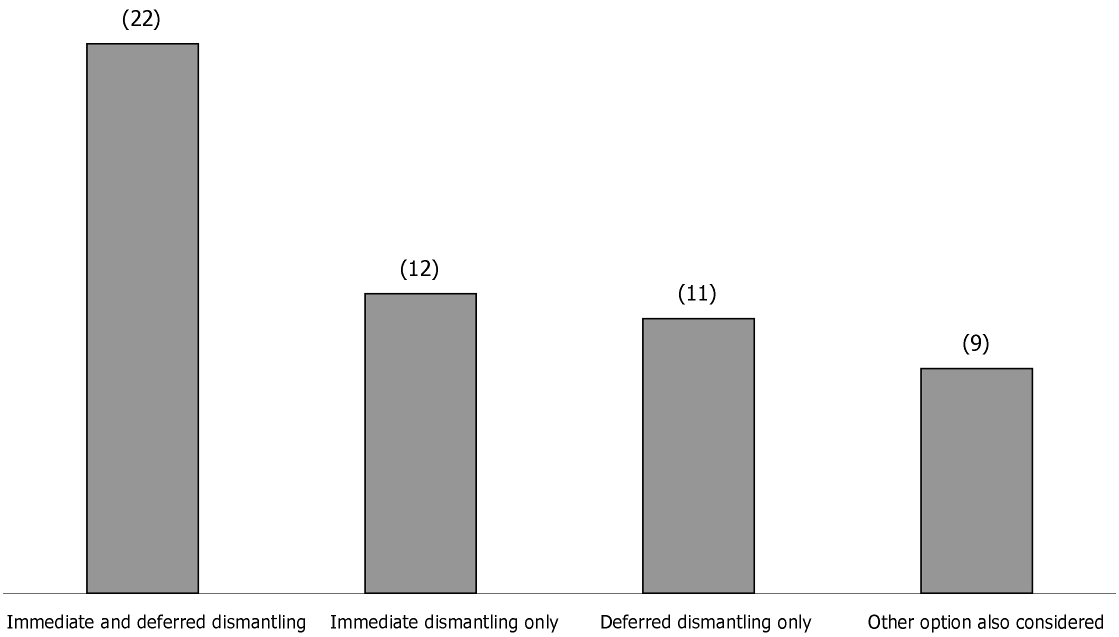
Figure 2.8. Factors included in decommissioning strategy scope



It can be seen from Figure 2.8 that most of the nine activities were included in the decommissioning scope considered by most respondents for estimating future/expected costs. The main exception to this is that most respondents did not include on-site fuel storage within their assumed scope. Also, a significant number did not include the packaging of operational radioactive waste in their scope. It should also be noted that all activities received a number of "No" responses. This shows that there is variability between utilities/countries as to what is included within the assumed scope of decommissioning. Inevitably, this will be reflected in differences on reported decommissioning costs.

Decommissioning strategy options

Figure 2.9. Decommissioning strategy options considered (number of responses)



Respondents were next asked which decommissioning strategy options they had considered: immediate total dismantling following shutdown, the deferral of some dismantling for a period, or other options. The responses are presented in Figure 2.9 which indicates that the largest number of respondents considered both strategies – immediate dismantling and deferred dismantling – while a smaller number considered either only immediate dismantling or only deferred dismantling.

Those who consider deferred dismantling were asked to indicate what deferral periods they had considered. Responses indicate that most appear to have considered only a single deferral period, ranging from 10 years in Japan to 80 years in Slovenia. However, some utilities (in France, the Netherlands and the United Kingdom) indicated that they had considered a range of deferral periods, e.g. 25 to 50 years, 40 to 100 years and 35 to 135 years.

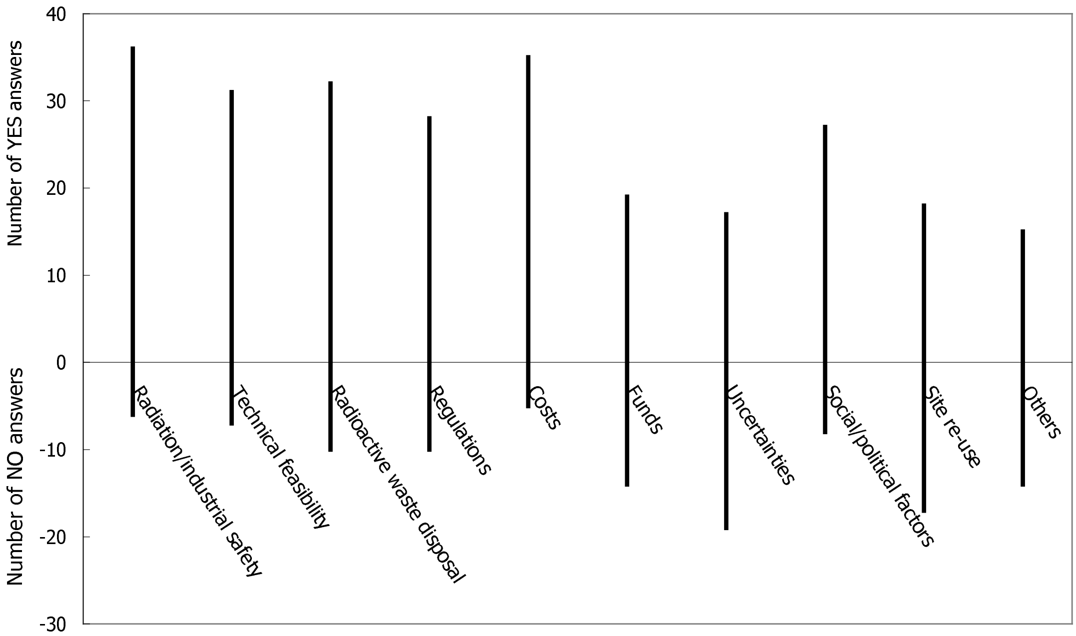
Of those who indicated that they had considered other options, "entombment" and on-site disposal were the options identified.

Selection of decommissioning strategy

In terms of how decommissioning strategies are selected, respondents identified the process used and the factors considered. Most respondents indicated that they had used some form of multi-attribute decision analysis process, although some indicated a focus on a small number of attributes, e.g. cost, safety and radiation dose reductions.

Respondents were asked to indicate whether they consider ten specific factors, including safety, radioactive waste disposal, uncertainties, social and political factors and site re-use. This was again done using a “Yes/No” format. The full list of factors and the range of responses received are indicated in Figure 2.10. An analysis of the responses, as indicated in Figure 2.10, shows that a majority of the factors were considered by most utilities/countries, but only two countries, the Czech Republic and Germany, indicated that they considered all the listed factors.

Figure 2.10. Factors considered in determining the preferred decommissioning strategy option



However, care needs to be taken in interpreting the responses as respondents were only indicating the primary factors considered in determining their preferred decommissioning strategy. For example, the fact that some indicated that they had not considered safety does not mean that they consider safety to be irrelevant to decommissioning. Safety is an inherent constraint since no decommissioning strategy would be considered that was not safe. Hence, safety is not a determining factor in selecting between decommissioning options.

The factors that were identified as not being used as determining factors varied between utilities/countries. Some of the factors received a greater proportion of “No” responses than others. The availability of funds was one of these but the majority of those not considering this factor did consider costs as a factor. This is likely to be because funds are normally determined by the costs once a decommissioning strategy has been selected and not before. Another of these factors was uncertainty (e.g. on future regulations). Those giving a “No” response to this were generally evenly distributed between those who only considered the immediate dismantling option and those who only or also considered the deferral option. Some indicated that they had not considered uncertainties separately but had done so as part of the cost factor.

Some of the differing responses can be related to specific national approaches. For example, one country (Italy) provided a "No" response to all identified factors other than "social and political factors". This is because the Italian Government policy is for immediate dismantling only and hence the utilities need not consider any of the other factors in determining the decommissioning strategy to apply. Also, some countries have identified "site re-use" as a key consideration. This reflects the intent of some countries to re-use their sites for continuing nuclear generation (France) and/or the lack of suitable alternative sites for nuclear developments (Japan).

A number of respondents indicated that they consider factors other than those specifically identified in the questionnaire. In these instances the main additional factors related to the environment, although it is to be expected that others will also have actually considered this factor, e.g. as required by National and European laws.

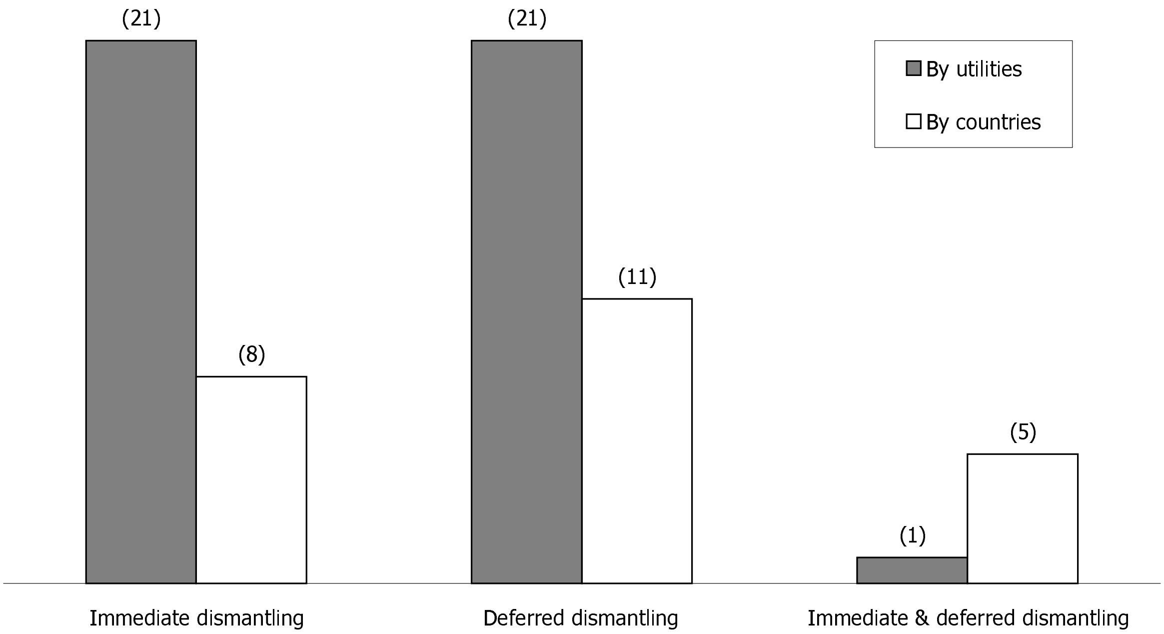
Stakeholder involvement

Respondents were also asked as to which stakeholders were consulted during the strategy decision process. The most commonly mentioned stakeholders were Governments and Regulators, followed by the public.

Decommissioning strategy used as the cost basis

A further question that was asked was which decommissioning strategy option has been selected for cost estimating purposes. The responses are indicated in Figure 2.11. This shows that 21 utilities identified the immediate dismantling option, 21 identified a deferred dismantling option and one (German utilities) retained both options. No utility or country identified any other option (such as entombment) as a lead option for cost estimates. When looking at this information on a country basis, instead of a utility basis, then only 8 countries consider the immediate dismantling option for cost estimating purposes, 11 countries consider the deferred dismantling option and 5 countries consider both immediate and deferred dismantling options.

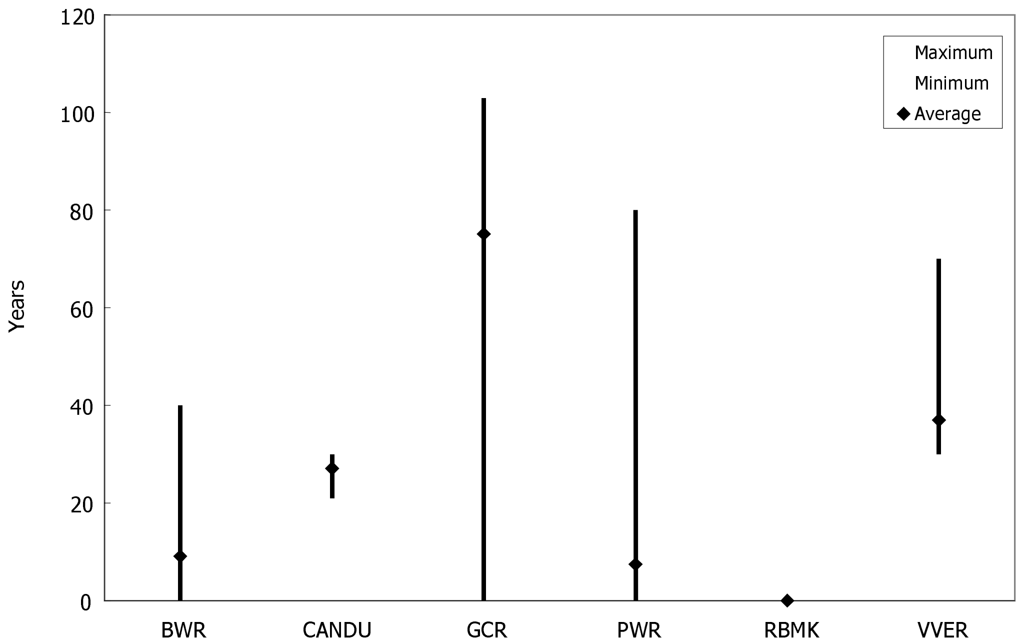
Figure 2.11. Decommissioning strategy option assumed for costing purposes (number of responses)



Deferral periods

The information provided on the length of the deferral period assumed for costing purposes is presented in Figure 2.12 by reactor types, with those considering only immediate dismantling being classified as a zero deferral period. This shows that the largest range of deferral periods, and the longest, are associated with the gas-cooled reactors. The PWRs also appear to have a large range of deferral times, however, this is dominated by two countries, Hungary and Slovenia, which assume 70 and 80 year deferral periods respectively. Generally, excluding these PWRs and the gas-cooled reactors, the range of quoted deferral times for all other reactor types is from zero to 50 years.

Figure 2.12. "Deferral" duration assumed for costing purposes (years)

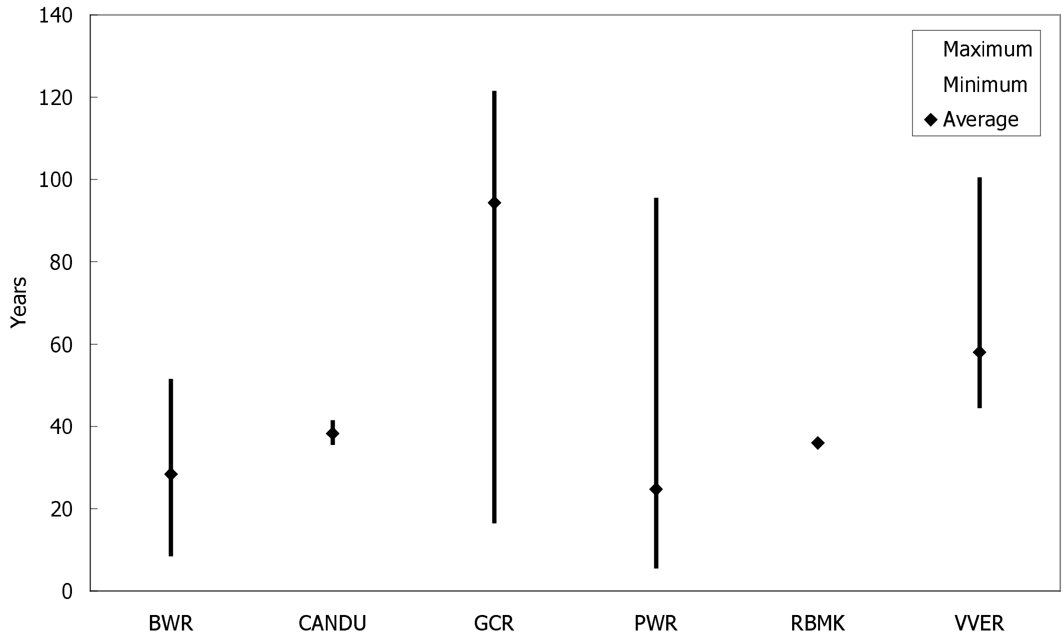


However, it has been found from the data supplied that the deferral periods quoted are not presented on the same basis for all reactors. For example, the deferral periods quoted by some utilities are for a quiescent dormancy period only, excluding any period when major decommissioning or dismantling activities are occurring. Other utilities refer to the deferral period as being the time from reactor shutdown to the start of the final dismantling period, i.e. including both a quiescent dormancy period and periods of major decommissioning activities.

These different definitions of deferral times can result in significantly different numbers being quoted for essentially the same overall decommissioning duration. For example, for some reactors where immediate dismantling is the proposed strategy, it is being indicated that it will take 30 to 40 years from the reactor shutdown date to complete all the decommissioning work. In contrast, for some reactors where a 30-year deferral period is being quoted (meaning a quiescent dormancy period only of 30 years) the overall duration from shutdown to the end of decommissioning is also predicted to be 40 years. In this example there is no difference in overall decommissioning duration between what is called an immediate dismantling strategy and what is called a deferred dismantling strategy.

In order to place the decommissioning timings on the same basis and to make a true comparison, Figure 2.13 presents the same information as used in Figure 2.12 to show the predicted range of periods from reactor shutdown to the end of decommissioning activities for each of the reactor types. This indicates a higher average "effective deferral period", considering the complete duration from reactor shutdown to the end of decommissioning, than suggested by Figure 2.12 for all reactor types. Overall, forty to fifty years for completion of decommissioning is not unusual.

Figure 2.13. Period between shutdown and complete decommissioning assumed for costing purposes (years)



It should be noted that the decommissioning strategies identified by the respondents as their preferred strategies are those assumed for costing purposes and are not necessarily firm or final decisions. For example, one utility (in the United Kingdom) has a declared strategy of a maximum of 50 years deferral for the decommissioning of a PWR but assumes, prudently, for costing purposes a significantly shorter 10-year deferral period. In some cases the declared deferral periods are quoted as maximum periods and sometimes as minimum periods (United Kingdom and Pakistan).

Decommissioning and radioactive waste management activities

A number of questions were asked about general decommissioning and radioactive waste management activities.

Dismantling techniques

The majority of the respondents indicated that the reactors, which are the most radioactive and highest radiation dose rate items handled during decommissioning, would be dismantled by fully remote means, possibly involving a degree of semi-remote operations for some parts of the reactors. Generally, the only utilities suggesting reactor dismantling using contact working were those with gas-cooled reactors who are proposing a long deferral period to allow radiation dose rates to decay before starting the reactor dismantling work. In comparison, the majority of respondents suggested that semi-remote dismantling operations could be used on primary circuit components such as steam generators and heat exchangers, with some indicating that contact working would be possible. Remote dismantling work will be more expensive than the use of semi-remote techniques, with contact working expected to be the least expensive.

Waste packaging

With respect to the degree of dismantling required, most respondents indicated that it would be necessary to size reduce reactors and primary circuit components into small pieces for packaging and disposal in a range of standard sized packages. A small number of respondents indicated that these items could be removed and disposed of whole, or in large pieces. Most respondents indicated that it would be necessary for voids in waste packages to filled with cement grout or similar. The extent of size reduction required will have an impact on the extent of work involved and hence the costs of decommissioning. Avoiding size reduction would reduce decommissioning costs but implies that waste repositories accepting large size packages are available.

Development status

Respondents were asked whether the decommissioning work was to be, or has been, performed as a research or development project. Only two respondents indicated that this was the case. All others indicated that it was or would be a fully commercial activity. This may be interpreted as a sign that the necessary techniques and processes for the dismantling do exist and are satisfactory, but opportunities for improvements are still actively investigated (in terms of costs, waste production and dose minimisation). Indeed, the IAEA Technical Report No. 395 *State of the Art Technology for Decontamination and Dismantling of Nuclear Facilities*, published in 1999, concluded that current technologies can cope with almost all the needs of decommissioning, although some techniques still need R&D to enable them to reach maturity or to reduce dose uptake or the amounts of waste generated or the costs.

Dormancy period activities

With respect to those who are proposing a period of deferral, they were asked to identify what activities were expected to be undertaken during the dormancy period. A variety of responses were received with some indicating that there would remain permanent staffing on the sites 24 hours per day. Others indicated that the sites would not be continuously staffed but that there would be continuous remote surveillance with regular site visits, i.e. in no case will sites be “abandoned” during the dormancy period. Some utilities intend to run ventilation systems whilst others do not, but in all cases monitoring and maintenance of the sites will be undertaken throughout any dormancy period.

Waste disposal

With respect to radioactive waste disposal, most respondents indicated that they were assuming that waste would be disposed of direct to a repository, with only a few indicating that some period of either on-site or off-site storage following dismantling would be necessary pending the availability of a disposal site. However, it should be noted that the responses to the policy section of the questionnaire indicated that no country as yet has suitable waste repositories for all decommissioning waste expected to arise.

The availability, or non-availability, of suitable waste repositories for decommissioning waste can be expected to have an impact on the decommissioning strategy finally implemented, and the actual timing of dismantling. This is recognised in some countries where, for example, immediate dismantling options are preferred but where their strategy declarations are qualified by statements to the effect that should a repository not be available then reactor dismantling will be delayed (Italy, Japan).

3. DECOMMISSIONING COST ESTIMATING AND FUNDING APPROACHES

In order to understand cost estimates and to analyse cost drivers in a relevant and robust way, it is important to know how, why and by whom those estimates were established. There are many techniques and approaches that can be used to estimate the cost of decommissioning. The approach taken, however, must be tailored such that the resulting cost estimate will fulfil the purpose for which it is being developed. Depending upon this purpose, the nature of the cost estimate being performed may vary significantly.

In general, decommissioning cost estimates are used for three main functions: to inform government and guide their policy for assuring that decommissioning funds will be available when needed; for utilities, to determine funding requirements and financial liabilities; and to serve as a basis for industrial strategy and decommissioning activity planning.

The present study focuses on aspects relevant for the first and second functions that are closely related. In particular a key objective of this document is to provide information so that governments can develop an appropriate understanding of decommissioning costs as input to policy and regulation development in order to assure that adequate funds are appropriately collected.

In this context, estimates are generally based on the currently agreed-upon decommissioning strategy, and will focus on the amount of money necessary as well as on the timeframe for the spending of the collected fund. Decommissioning cost estimates that are made for this purpose are thus periodically updated to reflect the current decommissioning strategy, and the state of decommissioning technology.

The third main function of decommissioning cost estimates is as a basis for planning and managing decommissioning activities. These estimates may well be more detailed than those that serve for developing an overall cost envelope for decommissioning funding purposes. This type of estimate is generally based on a detailed industrial decommissioning strategy and plan, and may be used as a basis for contracting or for solicitation of tender offers, as a starting point for establishing a project baseline for cost and schedule management, and for cost accounting and scheduling purposes during decommissioning operations.

In all cases, the elements used for assessing and managing decommissioning costs are the same, although different levels of detail will be necessary for different uses. For these reasons, among others, as it was noted earlier, the NEA, the IAEA and the EC have produced and widely distributed a document providing specific definitions for cost items and cost groups: *A proposed Standardised List of Items for Costing Purposes: Interim Technical document*, 1999. This cost matrix can be used at various levels of detail, and can thus fulfil both the primary purposes of decommissioning cost estimates described above. The cost element matrix that was developed formed the basis for the cost section of the questionnaire that was used to collect information for this report, and thus the primary elements of this matrix are described here. Some generic aspects of cost modelling and cost accounting are also described in this chapter.

Also, it should be noted that cost estimates may be expressed in different ways depending on the purpose of the presentation. For example, cost estimates may be expressed undiscounted, as an overnight capital cost. The present study focuses on cost estimates that represent the financial liabilities of nuclear power plant operators. The funding aspect raises the issue of discounting those costs, recognising that decommissioning expenses will occur in the future and that the time value of money is important. Those aspects are discussed briefly in chapter 3 related to funding mechanisms and schemes.

Finally, uncertainties in decommissioning costs have to be addressed while estimating and presenting those costs. Uncertainties may arise as a result of national policy and regulation questions (in the area of waste management for example), because some aspects of decommissioning strategy planning can not be defined *a priori* (complete plant radiological characterisation for example) and also because decommissioning activities will occur in the future and a number of cost elements and groups are known only within a range depending on assumptions on future economic conditions (e.g. wages and material costs).

To address such uncertainties, decommissioning cost estimates generally include contingencies reflecting the projected range of each cost element and group. The magnitude of the contingencies that are included in cost estimates may vary from plant to plant, from region to region, and from country to country. Furthermore, contingency estimates are influenced by the economic context and in particular by the ownership of the plant considered; in particular, private companies generally allow for a larger share of contingencies than state owned enterprises.

Elements of decommissioning cost estimates

As the decommissioning industry has matured and gained experience, it has been shown that decommissioning costs can be estimated in a reliable way and managed adequately while decommissioning activities are carried out. The experience acquired has demonstrated that the organisations responsible for decommissioning activities tend to use cost estimating methods specific for their conditions and requirements. Therefore, comparing those estimates should be undertaken with caution, as it is difficult to draw conclusions from comparisons between costs estimated within different frameworks.

It was recognised in previous international studies that valid comparisons are almost impossible to make unless there is some knowledge of which costs are included and which are excluded from cost estimates. Until 1999, because no agree-upon cost structure existed, many comparisons made were on an *ad hoc* basis. This issue was subsequently addressed by the NEA, the IAEA and the EC in a joint publication (NEA, 1999).

Based on the experience within the NEA's Co-operative Programme on Decommissioning, the work of a series of IAEA Consultant Groups, and the EC programme on decommissioning costs (EC DB COST), a series of definitions of cost groups and cost items was developed. In this context, cost items are defined as the various and specific decommissioning tasks and types of work that are generically necessary within any decommissioning programme. The full list of cost items is, in fact, a tiered list of several levels, each sub-level increasing in detail with respect to the last. Based on these considerations, eleven top-level cost items were identified:

- pre-decommissioning actions;
- facility shutdown activities;

- procurement of general equipment and material;
- dismantling activities;
- waste treatment and disposal;
- security, surveillance and maintenance;
- site cleanup and landscaping;
- project management, engineering and site support;
- research and development;
- fuel; and
- other costs.

As pointed out earlier in the report, it should be noted that fuel management costs, which are included in the above list, have been excluded from the present study mainly because they are often paid for separately and not included in the decommissioning funds.

In addition to these cost items, it was felt that costs could be grouped. Costs related to activities carried out with a similar emphasis, whether tied or not to a similar time schedule for decommissioning, are grouped, as are costs based on overall activities that cannot be categorised in a specific time period. Based on this approach, four cost groups were defined:

- labour costs;
- capital, equipment and material costs;
- expenses; and
- contingency.

In performing an international review of decommissioning policy, strategy and costs, the Expert Group agreed that a fairly detailed cost data is essential to provide a robust basis for analysing cost variability. To request this, it was agreed that the NEA/IAEA/EC Cost Structure should be used in the questionnaire, although not in its full detail. Information was requested for each of the eleven top-level cost items, and for each cost item, in each of the four cost groups. In order to further specify this information, a detailed part of the questionnaire was developed regarding which major cost-sub-items were or were not included in the reported costs (see Table C2 in Annex 2).

A significant number of respondents to the questionnaire do not use the NEA/IAEA/EC cost structure in their own estimates and they had to adapt their cost data in order to reflect the cost structure required for filling in the questionnaire. The approximations involved in such adaptations lead to inevitable inconsistencies between responses. Therefore, it is difficult to make robust and detailed comparisons between cost estimates provided by different respondents.

It is considered that the information collected provides a backdrop to decommissioning cost understanding. The data presented are intended to support an analysis of cost drivers and elements aiming at assisting policy makers in identifying reasons for cost differences, considering variability from country to country, reactor type to reactor type and taking into account the social and regulatory context in which decommissioning activities are conducted.

Approaches for estimating costs

Even given a general agreement on the elements of decommissioning cost that should be used for estimation, the approaches to estimating each element can vary significantly. Approaches can be based on assumptions, on past experience, on scaling from the decommissioning of other nuclear installations or on adaptation/extrapolation of data provided by decommissioning of non-nuclear facilities. Engineering judgement is necessary in all cases to appropriately adapt any assumptions to the specific case being considered. All approaches must be based on a model of planned decommissioning activities and time schedule, although the level of detail will vary according to the approach.

The most precise and detailed cost estimates will be based on bottom-up activity-based models of the specific site being decommissioned. They may be more difficult to perform but are likely to be the most robust and accurate. While such estimates are based on the specific plant design, judgement will be necessary in assuming various work parameters, such as time required and equipment needs. If the necessary judgement is based on first-hand, on-site decommissioning experience, as a result of work that has been recently completed, or work that is currently underway, reasonably accurate estimates can be obtained.

Reliable estimates may be obtained even when site-specific experience is not available but more engineering judgement will then be needed. In that case, decommissioning cost estimates may be based on the decommissioning of a different nuclear installation (e.g. similar reactor type on a different location) or even on a non-nuclear facility (e.g. chemical plant).

Many cost elements can be extrapolated from site to site. For example decommissioning labour costs can be based upon labour time, productivity factor for the region and local unit labour costs. Obviously, consideration must be given to the possible differences in hourly rate for nuclear-qualified workers and for workers not qualified to work in contaminated and/or radioactive work environments.

Decommissioning cost estimates from sites of different sizes may be used as a basis and scaled up or down. In that case, the estimated amounts of material arising from decommissioning activities can be scaled relatively accurately in a generally linear fashion but other scaling models may be needed for such cost elements as man-hours. Factors such as waste conditioning requirements may also result in differences, when, for example, a small reactor element may be disposed of in one piece, while the same element scaled up may require significant cutting and conditioning before it is accepted at a national waste repository.

An important issue to be considered when extrapolating cost estimates from one site to another is the contamination history that vary significantly from facility to facility. In cases where histories differ, more engineering judgement will be necessary to extrapolate cost estimates from one site to another.

When national experience does not exist, decommissioning cost estimates from other countries may be used as a basis for preliminary estimates. Depending upon the accuracy necessary for the final use of the cost estimate, the elements from cost estimates performed in another country can be tuned to reflect national practices. While carrying out such adaptation, many cost elements require tuning to appropriately reflect local, case-specific aspects. For example, labour costs, waste repository availability and waste disposal costs have to be adapted to national and local circumstances.

Funding aspects

Since some decommissioning expenses will be incurred long after a nuclear power plant is shut down, decommissioning costs constitute a future financial liability. Since the early development of nuclear energy, it was recognised that consideration should be given to ensuring that funds will be available to cover future decommissioning expenses when needed. For this purpose, decommissioning costs should be estimated in a reliable way and transparent accounting principles should be applied to establish and maintain an adequate decommissioning fund.

The State and the owners/operators of nuclear power plants have their respective responsibilities regarding decommissioning liability funds. While the State has to ensure that the consequences of its energy policy will not harm present or future generations, in nearly all countries, the owners/operators of nuclear power plants are responsible for fully covering the costs of decommissioning. Specific issues that may be raised by national policy decisions, such as premature shut-down of nuclear power plants resulting from a phase-out of nuclear energy, must be addressed by each country on an *ad hoc* basis.

Technical and managerial measures have to be taken to regulate the use of radioactive materials, safety, radiation protection, and the protection of man and its environment; similarly, policy actions have to be undertaken to guarantee that economic liabilities foreseen in the future can be discharged with money provided during operation of nuclear power plants. The establishment of a fund and guaranteeing of its availability when needed can be seen as compliant to the "Polluter Pays Principle".

How is the liability accounted for?

The detailed methods for calculating and reporting liabilities differ from country to country and sometimes between operators in a given country. In practice, two main methods – current value and net present value – and sometimes variations of these are generally used for calculating future financial liabilities associated with decommissioning. In both methods, the value of the liability is adjusted periodically as the cost estimates evolve owing to technology progress, regulatory changes and inflation, as applicable.

The current value method evaluates the financial liability based upon what decommissioning would cost today if the expenses were incurred at present. In that case, the value of the liability is equal to the decommissioning cost estimate and does not depend on the timing of decommissioning activities; it is independent of the time at which the expenses will occur. Costs calculated using the current value method are often referred to as undiscounted or overnight costs.

The net present value method evaluates the liability based upon the discounted decommissioning costs, taking into account the expected expense schedule. The estimate requires a discount rate to be assumed and depends on the timing of decommissioning activities and the associated expenses. The later the expense will be incurred the lower its net present value. Costs calculated using the net present value method are often referred to as discounted costs.

The main differences between the two methods are that the net present value accumulates the funds more slowly and is more sensitive to assumptions on expense schedule and rate of return on capital set aside. In the current value method, since the provisions are set up faster the interest generated by the accumulated provisions is higher and, if the provisions are tax deductible, the charge for the owner/operator is alleviated.

In eleven countries – Bulgaria, Finland, France, Germany, Japan, the Russian Federation and Slovenia – the decommissioning funds are based on overnight, undiscounted costs. In yet another twelve countries, e.g. Brazil, Canada, Hungary, the Netherlands, Pakistan, Spain, Switzerland, and the United Kingdom, the decommissioning funds are based on the net present value and the discount rate usually ranges between 2 and 4%. In a few countries, no specific policy exists.

For the purpose of the present report, as noted in Chapter 1, decommissioning costs were reported and are presented undiscounted, to serve as a basis for a transparent analysis. While it is legitimate to recognise the time value of money, discounting raises specific issues in cases, such as decommissioning activities, where expenses are spread over several decades or more.[8]

Who pays?

In nearly all countries, the operator/utility is responsible for the decommissioning costs. However, in cases where nuclear power plants are state-owned, the responsibilities may be distributed between the operator and the state as owner. For example, in Armenia, the government is responsible for decommissioning liabilities. In Hungary, where the nuclear power plant is state-owned, the responsibility is shared by the government and the operating organisation. A similar situation exists in Lithuania.

In the United Kingdom, at the time the surveys were carried out, the government was directly responsible only for the decommissioning liabilities of the non-commercial reactors, owned by the UKAEA (United Kingdom Atomic Energy Authority), but there were plans for major changes in the future management of nuclear liabilities.

In Switzerland, the owners of the nuclear facilities are required to make financial contributions to a joint decommissioning fund which is under the supervision of the government. The board of the joint fund is responsible for ensuring that the contributions are adequate to cover decommissioning costs in due course.

When do decommissioning funds have to be provided?

Regulatory requirements and options available to plant owners/operators regarding the accumulation of decommissioning funds very from country to country. In about half of the responding countries, the accumulated funds should cover total estimated decommissioning expenses at the time of plant shut down. In some countries, the regulator requires that the owner/operator provide guarantees to cover decommissioning expenses if a unit must close before the foreseen earning period or if the fund is not sufficient at shutdown. In some countries, the regulator allows the owner/operator to chose between alternative options.

The following examples illustrate various regulations and options in place in different countries. In Belgium, Brazil, Finland, Germany and Sweden the funds must equal the total estimated decommissioning costs 25 to 30 years after the start of the nuclear power plant. In Italy, where the four nuclear power plants closed before the operators could accumulate sufficient funds, extra funds are to be raised during the decommissioning period. In Canada, a financial assurance for the current value of the full decommissioning costs is required before the regulator (CNSC) issues an operating licence. In the United Kingdom, the government pays the decommissioning costs of the reactors for which it is

8. See for example, the series of OECD reports on projected costs of generating electricity (last issue: IEA and NEA, Projected Costs of Generating Electricity: Update 1998, OECD, Paris, 1998).

responsible as they arise. For the Karachi nuclear power plant in Pakistan, the total fund for decommissioning is planned to be accumulated five years ahead of permanent shutdown.

How are decommissioning funds required to be raised, held and managed?

In nearly 60% of the countries, the funds are collected by a charge included in the electricity price. This is also the case in Armenia, Lithuania and the Slovak Republic but in these countries, additional means are used and part of the funds is collected by compulsory fees as well as contributions from donor organisations. In Finland, Pakistan, and Sweden compulsory fees are used to raise the decommissioning funds.

In nearly 50% of the countries, the operator holds the funds. The Government holds the decommissioning fund in five countries. In eight countries, decommissioning funds are held by another, specially designed body. In the United Kingdom, this is true for the privatised commercial utility operating nuclear power plants while the non-privatised commercial utility hold its own funds.

Regardless of whether the Government, the operator or another body holds the decommissioning funds they are nearly always managed as a segregated fund, i.e. separately from other assets of governmental body or company. In the Czech Republic and Ukraine, the funds are managed within a separate account.

Adequacy of decommissioning funding

In many countries, independent review and audit systems exist. Sometimes, as in Japan, Spain and Sweden, the licensee's cost estimates are reviewed and approved annually. In Switzerland, the decommissioning costs are subject to revision every third year today and every fifth year in the future. In the United Kingdom, the Health & Safety Executive in consultation with the Environmental Agencies performs a review of the operator's decommissioning strategy, including a limited analysis of financial provisions every five years.

4. DECOMMISSIONING COST DATA

The cost data upon which this report is based are summarised below. Responses to the questionnaire were received from 26 countries, including nine non-OECD countries participating in the study under the IAEA umbrella (see Annex 1 for the detailed list of responding countries and experts). Decommissioning cost data were provided by 24 countries (Pakistan and Romania did not report on costs). The 53 cost data sets received cover different reactor types with sizes ranging from less than 10 MWe to more than 1 000 MWe. Two countries, Germany and Spain, provided data for a reference plant, representative of the units in operation in their respective countries. France provided one cost data set for the decommissioning of all the French PWRs in operation in the country and another cost data set related to all the French plants already shut down. The United Kingdom provided cost data for a typical Magnox two unit plant. Other cost data provided refer to a specific power plant on a particular site, e.g. Bruce A in Canada or Paks in Hungary.

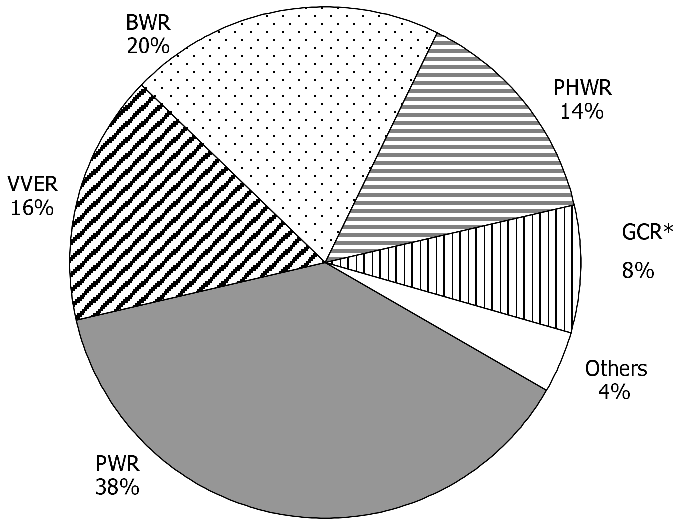
The large number of responses received provides a broad base for cost data analysis. Even with market deregulation raising some confidentiality issues, responses that included cost estimates were received from more countries than was the case for previous studies. The cost analysis in the 1986 NEA study [NEA, *Decommissioning of Nuclear Facilities: Feasibility, Needs and Costs*, OECD, 1986] was based upon responses from 6 countries. For the 1991 NEA study [NEA, *Decommissioning of Nuclear facilities: An Analysis of the Variability of Decommissioning Cost Estimates*, OECD, 1991] 16 responses from 9 countries were received. It should be noted, however, that the increasing number of respondents in the present study is partly due to the participation of non-member countries through the IAEA Secretariat.

All the responses received were compiled and reviewed by the Expert Group and the Secretariat and have been used in the analyses provided in the present report. However, it was decided to exclude from the reporting and detailed cost analysis cost data sets, related to SGHWR in the United Kingdom, and Saxton and Big Rock Point in the United States. This was because they were not considered by the Expert Group as representative of decommissioning costs of current commercial nuclear power plants. The Dodewaard BWR, in the Netherlands, although very small – 58 MWe – was kept in the analysis because it was a commercial power plant; however, its cost data are not reported in Figure 4.4 because they are too high for the scale adopted.

In the graphs and tables of this chapter, as well as in the rest of the report, the German and Spanish data for representative PWRs and BWRs, and the British data for a typical Magnox are considered as one cost data set each. Similarly, the French data for PWRs are considered as one data set and the French data for shut down units, i.e. 6 GCR, 1 PWR, 1 HWGCR and 1 FBR, are considered as another data set.

The German and Spanish cost data sets can be considered representative of the entire fleet of nuclear units in both countries. Similarly, the British data set can be considered representative of all Magnox reactors in the country. Therefore, the total capacity covered by the cost data reported and analysed in the present study represent around one third of the nuclear power capacity in operation world-wide.

Figure 4.1. Distribution by reactor type of the cost data sets provided and analysed



* See tables 4.1 and 4.2 for details on the GCR cost data sets provided for the study

Reactor types and sizes

Figure 4.1 displays the distribution by reactor type of the 50 cost data sets that were provided and which have been included in the analyses carried out within the present study. The figure shows that more than a third of the cost data provided and analysed refer to PWR (38%); BWR represent 20% of the data, VVER (PWR of Soviet design) 16%, PHWR/Candu 14% and GCR 8%. The "Others" category includes one RBMK (Ignalina, in Lithuania) and one unit representative of the mix of French reactors already shut down. This distribution reflects rather well the variety of nuclear power plants in operation at present in the world.

Table 4.1 shows the distribution by country, reactor type and size of the cost data sets reported and analysed. Four size intervals were adopted within the range covered by responses: below 250 MWe; 250 to 500 MWe; 500 to 1 000 MWe and more than 1 000 MWe. Only 4 cost data sets refer to reactors in the size category below 250 MWe, 14 cost data sets are in the reactor size category between 250 and 500 MWe, 21 cost data sets in the category between 500 MWe and 1 000 MWe and 11 cost data sets in the category above 1 000 MWe. In addition to the size of the reactor, the questionnaires also asked for the number of units on the site that may have a significant impact on decommissioning costs, especially in the case of twin units (see Table 4.2).

Reactor history and decommissioning schedule

The information provided on the start of commercial operation and shutdown dates of the units, excluding the reference plants, is summarised in Table 4.2 which also gives more details of the nuclear power plants corresponding to the cost data sets reported. The dates for starting commercial operation vary between the early 60s (most Italian reactors) and 2001 (for Angra-2 in Brazil). For cost data sets referring to units already shut down, reported shutdown dates range between 1972 and 1998. For cost data sets referring to units still in operation, the shutdown dates decided, expected or assumed for costing purpose range between 2002 (expected for Kozloduy in Bulgaria) and 2030 (assumed for costing purpose for Angra-2 in Brazil). Table 4.2 does not cover those cost data sets, which referred to reference, average or illustrative units.

Table 4.1. Distribution by reactor type and size of the cost data sets provided and analysed

Country	Gross capacity			
	< 250 MWe	**250-500 MWe**	**500-1 000 MWe**	**> 1 000 MWe**
PWR (19 data sets)				
Belgium			1 [twin units]	1
Brazil			1	1
France				1 [58 units]
Germany*				1 [Reference]
Italy		1		
Japan				1
Netherlands		1		
Slovenia*			1	
South Africa			1	
Spain			1 [Reference]	
Sweden				1
Switzerland		1 [2 units]		1
United States			2	2
VVER (8 cost data sets)				
Armenia		1		
Bulgaria		1		
Czech Republic		1		
Finland		1 [2 units]		
Hungary		1		
Russia		1		
Slovakia		1		
Ukraine			1	
BWR (10 cost data sets)				
Germany*			1 [Reference]	
Finland			1 [2 units]	
Italy	1		1	
Japan				1
Netherlands	1			
Spain		1 [Reference]		
Sweden			1	
Switzerland		1		1
CANDU (7 cost data sets)				
Canada			7	
GCR (4 cost data sets)				
Italy	1			
Japan	1			
Spain		1		
United Kingdom		1 [twin units]		
Others (2 cost data sets)				
France [-]		1 [9 units]		
Lithuania [RBMK]				1
Total number of cost data sets	**4**	**15**	**19**	**12**

* Cost estimates provided for 2 decommissioning options, immediate and deferred.

Table 4.2. Starting and shutdown dates of plants included in the study*

Country	Plant Name	Commercial Operation	Shutdown	Comments on Shutdown Date
Armenia	Metsamor 1-2	1977/1980	1989/-	Actual/Not decided
Belgium	Doel 1-2 [twin units] Tihange 1	1975 1975		Not decided Not decided
Brazil	Angra-1 Angra-2	1985 2001	2014 2030	Assumed for costing purpose Assumed for costing purpose
Bulgaria	Kozloduy 1-2 [2 units]	1974/1975	2002	Expected
Canada	Bruce A [4 units] Bruce B [4 units] Darlington [4 units] Gentilly 2 Pickering A [4 units] Pickering B [4 units] Point Lepreau	1977-1979 1985-1987 1990-1993 1983 1971-1973 1983-1986 1983	2017-2018 2024-2027 2030-2033 2010 2011-2013 2023-2025 2008	Assumed for financial planning Assumed for financial planning Assumed for financial planning Assumed for costing purpose Assumed for financial planning Assumed for financial planning Assumed
Czech Republic	Dukovany [4 units]	1985-1987	2015-2017	Assumed for costing purpose
Finland	Loviisa [2 units] Olkiluoto [2units]	1977/1981 1978/1980	2022/2026 2018/2020	Assumed for costing purpose Assumed for costing purpose
Hungary	Paks [4 units]	1983-1987	2013/2017	Assumed for costing purpose
Italy	Caorso Garigliano Latina Trino	1981 1964 1963 1965	1986 1978 1987 1987	Actual Actual Actual Actual
Japan	Tokai 1 Tokai 2 Tsuruga 2	1966 1978 1987	1998	Actual Not decided Not decided
Lithuania	Ignalina 1-2 [2 units]	1984/1987	2005/2010	Expected
Netherlands	Borssele Dodewaard	1973 1969	2007 1997	Assumed for costing purpose Actual
Russia	Novovoronez 1-2 [2 units]	1964/1970	1988/1990	Actual
Slovakia	Bohunice 1-2 [2 units]	1980/1981	2006/2008	Government decision
Slovenia	Krsko	1983	2023	Expected
South Africa	Koeberg [2 units]	1984/1985	2021	Assumed for costing purpose
Spain	Vandellos 1	1972	1990	Actual
Sweden	Oskarsham 3 Ringhals 2	1985 1975	2010 2000	Assumed for costing purpose Assumed for costing purpose
Switzerland	Beznau 1-2 [2 units] Goesgen Leibstadt Muehleberg	1969/1971 1979 1984 1972	2009 2019 2024 2012	Assumed for costing purpose Assumed for costing purpose Assumed for costing purpose Assumed for costing purpose
United States	Hadddam Neck Maine Yankee Trojan Zion 1-2 [2 units]	1968 1972 1976 1973/1974	1996 1997 1992 1998	Actual Actual Actual Actual

* Reference or average plants are not listed in the table.

Two countries, Germany and Slovenia, provided cost estimates for immediate and deferred dismantling. Including these multiple responses, 27 decommissioning cost estimates were provided for immediate dismantling and 30 for deferred dismantling. The deferral periods range between 5 and 80 years, but more than 80% of the responses indicate a deferral period of 25 to 50 years.

Cost data reporting and conversion

According to the information provided in response to the questionnaire, most cost estimates were calculated using a standard or specific engineering cost model and input data corresponding to the unit considered. A few responses refer to a feasibility study or actual cost data. In most responses cost estimates were expressed in national currency unit of 1st July 2001, as requested by the questionnaire. However, some cost estimates were provided in national currency of another date or in other currencies (e.g. Slovenian data were given in DM). In those cases, the Secretariat used the Gross Domestic Product (GDP) index of the country and official exchange rates to adjust the costs. The adjustment factors used are given in Annex 3, *Exchange Rates and Currency Adjustment Factors*.

In order to facilitate the analysis, the Secretariat converted all the costs into USD of 1st July 2001, using the official exchange rates of that date (see Annex 3). Such cost conversions are intended to facilitate the overall presentation of results in the report. They should not be considered as providing a reliable and robust basis for comparing costs across borders in the light of the issues raised by adjusting and converting cost estimates using GDP indexes and exchange rates.

Other OECD publications, in particular the 1998 IEA/NEA report *Projected Costs of Generating Electricity: Update 1998*, caution on methodological difficulties and limited relevance of aggregated GDP indexes and exchange rates for converting costs related to electricity generation, including nuclear energy. In the case of decommissioning the importance of labour, domestic products and services in the total cost enhances the difficulty to establish a common costing basis without analysing costs item by item and group by group.

The cost sections of the questionnaire were based upon the standardised list of cost items proposed in the 1999 joint publication of EC, IAEA and NEA *Nuclear Decommissioning, A proposed Standardised List of Items for Costing Purposes*. Respondents were asked to provide cost estimates disaggregated into 11 cost items and 4 cost groups (see Annex 2, Questionnaire, and Table 4.3 below) and, if possible, to provide further disaggregated costs (see Annex 2, Table C2) at the level of sub-items within each of the 11 cost items.

Thirty seven responses provided costs by items in Table C1 but several of the respondents adapted the cost items to national regulations, accounting practises and contexts (e.g. merging 2 or more items in one cost figure and/or modifying the scope of some items). Data on cost groups, i.e. labour, capital, expenses and contingency were given in 15 responses provided by 6 countries.

In 12 of the 50 cost data sets used in the analysis, Table C2 was not completed at all while in 14 responses, provided by 6 countries, Table C2 was fully completed and in 24 responses it was indicated for each sub-item of Table C2 whether it had been included in or excluded from the aggregated total decommissioning cost estimates provided.

Table 4.3. Format of the cost data requested in the questionnaire

COST ITEM	COST GROUP [2]					TOTAL
	Labour		Capital	Expenses	Conting.	TOTAL
	(hours)	(NCU)	(NCU)			(NCU)
Pre-decommissioning						
Facility shutdown						
Procurement						
Dismantling						
Waste treatment and disposal						
Security, surveillance and maintenance						
Site cleanup and landscaping						
Project management, engineering and site support						
R&D						
Fuel						
Others						
TOTAL						

Summary presentation of cost data

The total undiscounted decommissioning cost estimates, converted by the Secretariat in USD of 1st July 2001, and expressed in USD and USD per kWe, are shown in Tables 4.4 to 4.7, grouped by reactor type and according to the option adopted, i.e. immediate or deferred, for starting decommissioning activities.

Although it is recognised that the cost estimates provided and presented below are not fully consistent, the number of data sets collected is large enough to support some statistical analysis. This analysis, however, is intended to highlight trends and not as an attempt to draw robust conclusions on decommissioning costs variability and structure.

As a preamble to the following analysis, it should be noted that it is well known since a long time that nuclear power plant decommissioning cost is not directly correlated to the capacity of the plant especially for low-rated plants. This is due to the fixed costs that are nearly independent of the size of the plant, such as plant survey, guarding, security, engineering, project management and equipment for waste characterisation, and therefore are relatively higher for smaller plants.

Table 4.4. Decommissioning cost estimates for PWRs

Country	Name of the plant	Capacity (MWe gross)	Total cost	
			MUSD	USD/kWe
Immediate dismantling				
Belgium	Doel 1-2 (twin units)	412 x 2	280	340
	Tihange 1	1 009	213	212
Germany	Germany_PWR	1 200	315	262
Italy	Trino	270	245	909
Slovenia	Krsko	707	332	479
South Africa	Koeberg	944 x 2	317	168
Spain	Spain_ref.PWR	1 000	166	166
Sweden	Ringhals 2	917	85	93
Switzerland	Beznau [2x 380]	380 x 2	259	341
	Gösgen	1 020	238	234
United States	Haddam Neck	587	452	769
	Maine Yankee	900	379	421
	Trojan	1 155	296	256
	Zion	1 085 x 2	904	417
Deferred dismantling				
Brazil	Angra 1	657	198	301
	Angra 2	1 350	240	178
France	Average_PWR	1 070 x 58	13 973	225
Germany	Germany_PWR	1 200	331	276
Japan	Tsuruga 2	1 160	470	405
Netherlands	Borssele	481	168	348
Slovenia	Krsko*	707	152	216

* Deferred by 80 years.
** Entombment after 150 years.

Table 4.4 shows that specific decommissioning costs of PWRs vary within a rather narrow range, around 200 to 500 USD/kWe, if the extremes (3 out of 22 data sets reported) are excluded. The two highest cost estimates, for Trino in Italy and Haddam Neck in the United States, correspond to reactors that were commissioned in the 60s. The lowest cost figure, for Ringhals 2 in Sweden, may be explained to a certain extent by the lower waste management and disposal cost assumed/reported in that country.

Statistical analysis has limited value if consistency checking of the data is not possible owing to differences in scope, accounting framework and overall economic conditions assumed by each respondent. However, the average values and standard deviations given below are of interest for benchmarking further studies. Taking into account all the data sets reported, the average value of decommissioning cost for PWRs is around 320 USD/kWe with a standard deviation of around 195 USD/kWe.

As far as the decommissioning schedule is concerned, the data provided suggest that deferring the dismantling has no significant impact on the overnight decommissioning cost. It will, however, have an impact on the discounted cost: this may be a driving factor in the choice of a strategy option by utilities.

According to the eight data sets reported for VVERs, the costs of decommissioning for this reactor type remain in the range 200 to 500 USD/kWe. The low value reported by Finland results from the strategy approach adopted that reduces waste cutting, packaging and transport costs; the activated internal metallic pieces of the reactor core are kept inside the vessel that is disposed of in a repository located on the reactor site.

Table 4.5. Decommissioning cost estimates for VVERs

Country	**Name of the plant**	**Capacity** (MWe gross)	**Total cost**	
			MUSD	USD/kWe
Immediate dismantling				
Finland	Loviisa	510 x 2	166	162
Slovakia	Bohunice	430 x 2	273	317
Deferred dismantling				
Armenia	Metsamor	408 x 2	225	276
Bulgaria	Kozloduy	440 x 2	377	429
Czech Republic	Dukovany	440 x 4	383	218
Hungary	Paks	467 x 4	740	396
Russia	Novovoronezh	288 x 2	291	506
Ukraine	Ukraine_1 000	1 000	319	319

The average value of specific decommissioning costs for VVERs is around 330 USD/kWe with a standard deviation of around 110 USD/kWe; those values are not very different from the values found for PWRs. It might be noted that decommissioning costs are not systematically higher in OECD countries than in non-member countries although unit labour costs generally are higher in OECD countries. This might be due to the fact that high labour costs provide an incentive to replace manpower by machinery such as remote handling equipment in order to reduce costs.

Like for PWRs, the immediate and deferred dismantling options seem to lead to similar decommissioning costs.

The information provided for BWRs shows, similarly to PWRs, a few data points very far from the average reported data. The cost values provided for Garigliano in Italy and Dodewaard in the Netherlands are three to four times higher than the next highest value, for Caorso in Italy. Both reactors are small as compared to other commercial BWRs and were put into commercial operation in the 60s. The cost values provided for Olkiluoto in Finland and Oskarsham 3 in Sweden are three to four times lower than the next lowest value, for Leibstadt in Switzerland.

Excluding those four data sets, the decommissioning costs for BWRs range between some 300 and 550 USD/kWe. The range for BWRs does not differ significantly from the ranges indicated for PWRs and VVERs. The average value of BWR decommissioning costs, excluding the four data sets identified above, is around 420 USD/kWe with a standard deviation of some 100 USD/kWe. Even more than in the case of PWRs, it should be stressed that the relevance of statistical analysis based upon seven data sets is limited.

Table 4.6. Decommissioning cost estimates for BWRs

Country	Name of the plant	Capacity (MWe gross)	Total cost	
			MUSD	USD/kWe
Immediate dismantling				
Germany	Germany_BWR	800	362	453
Italy	Caorso	882	480	544
	Garigliano	160	263	1 644
Spain	Spain_ref.BWR	500	147	294
Sweden	Oskarshamn 3	1 200	124	104
Switzerland	Leibstadt	1 200	344	282
	Mühleberg	372	178	479
Deferred dismantling				
Japan	Tokai 2	1 100	436	396
Finland	Olkiluoto	870 x 2	132	76
Germany	Germany_BWR	800	375	469
Netherlands	Dodewaard	58	133	2 300

Decommissioning costs of BWRs do not show any significant variation between the immediate and the deferred dismantling option.

Table 4.7. Decommissioning cost estimates for PHWRs/Candus – deferred dismantling

Country	Name of the plant	Capacity (MWe gross)	Total cost	
			MUSD	USD/kWe
Canada	Bruce A*	825 x 4	906	275
	Bruce B*	840 x 4	904	269
	Darlington*	935 x 4	1 289	345
	Gentilly 2	680	294	432
	Pickering A*	542 x 4	830	383
	Pickering B*	540 x 4	858	397
	Point Lepreau	680	295	433

* multi-units, 4 stations.

The cost estimates provided for PHWR/Candu reactors are all related to Canadian nuclear power plants, for the deferred dismantling option and based upon financial guarantee assumptions. Therefore, it is not surprising that the range of value is narrower than for other reactor types. The decommissioning cost estimates reported range between 270 and 435 USD/kWe with an average value of around 360 USD/kWe and a standard deviation of less than 70 USD/kWe.

Table 4.8. Decommissioning cost estimates for GCRs and others

Country	Name of the plant	Capacity (MWe gross)	Total cost	
			MUSD	USD/kWe
GCR immediate dismantling				
Italy	Latina	160	520	3 248
GCR deferred dismantling				
Japan	Tokai 1	166	742	4 470
Spain	Vandellos	500	360	721
United Kingdom	Magnox	265 x 2	1 409	2 658
Others immediate dismantling				
France	All_others	411 x 9	2 534	685
Lithuania	Ignalina	1 300 x 2	701	270

For gas-cooled reactors (and others), the number of data sets provided is too small to support a statistical analysis. The low cost value reported for Vandellos results from the exclusion of waste management costs.

Figures 4.2 to 4.6 provide graphical representations of total decommissioning costs, expressed in USD of 1st July 2001 per kWe of capacity versus reactor capacity, showing with a different symbol the estimates corresponding to the immediate and deferred dismantling options.

Figure 4.2. Total Decommissioning Cost (USD 1st July 2001/kWe) – PWRs

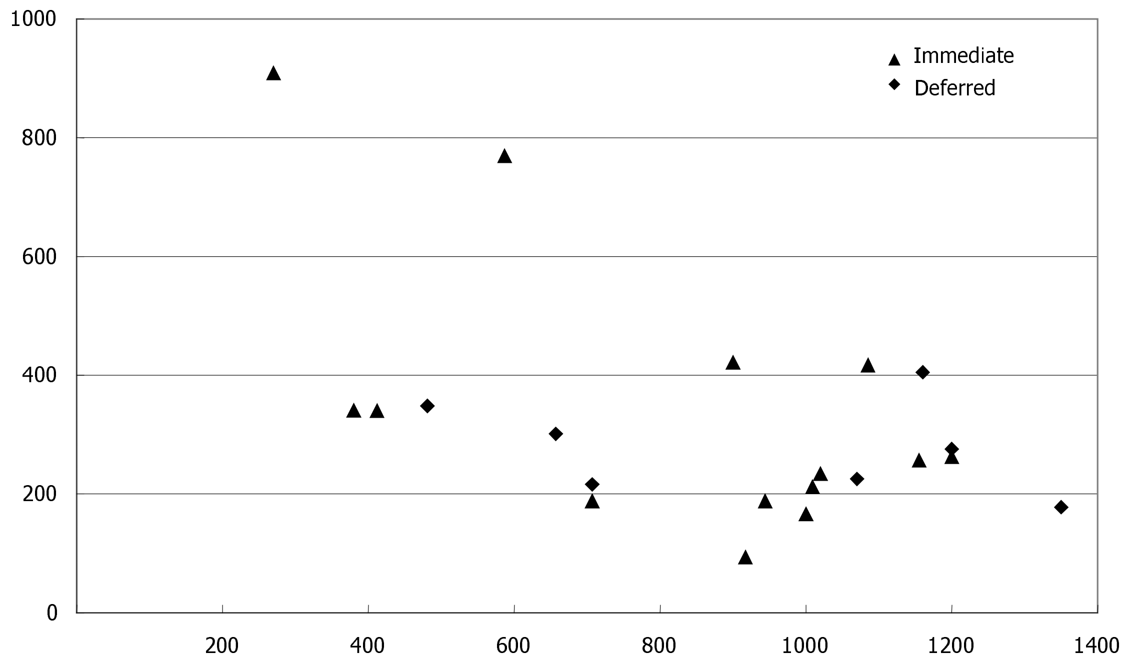
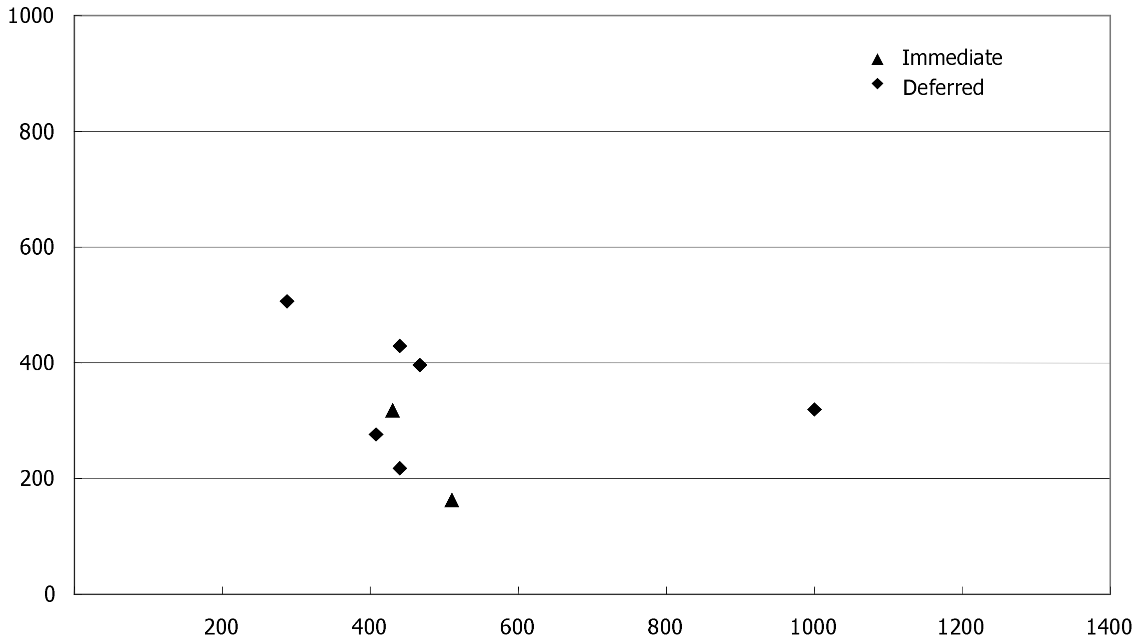
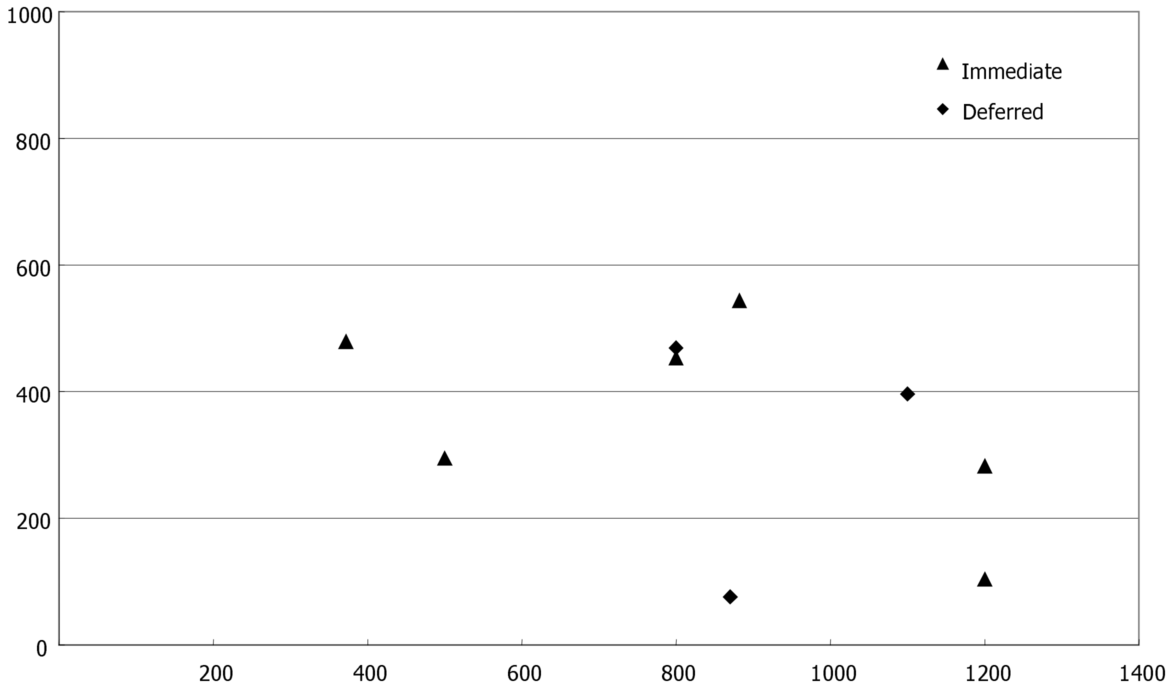


Figure 4.3. Total Decommissioning Cost (USD 1st July 2001/kWe) – VVERs



Reactor capacity MWe

Figure 4.4. Total Decommissioning Cost (USD 1st July 2001/kWe) – BWRs



Reactor capacity MWe

Figure 4.5. Total Decommissioning Cost (USD 1st July 2001/kWe) – PHWRs

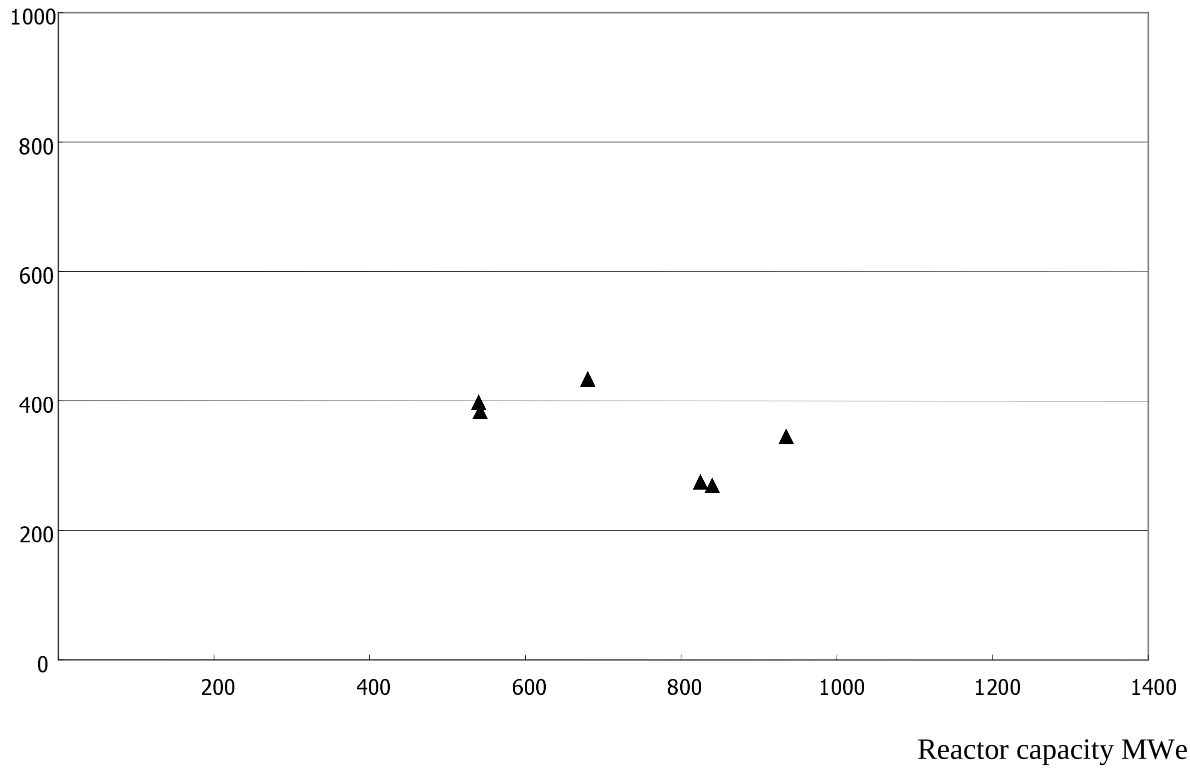
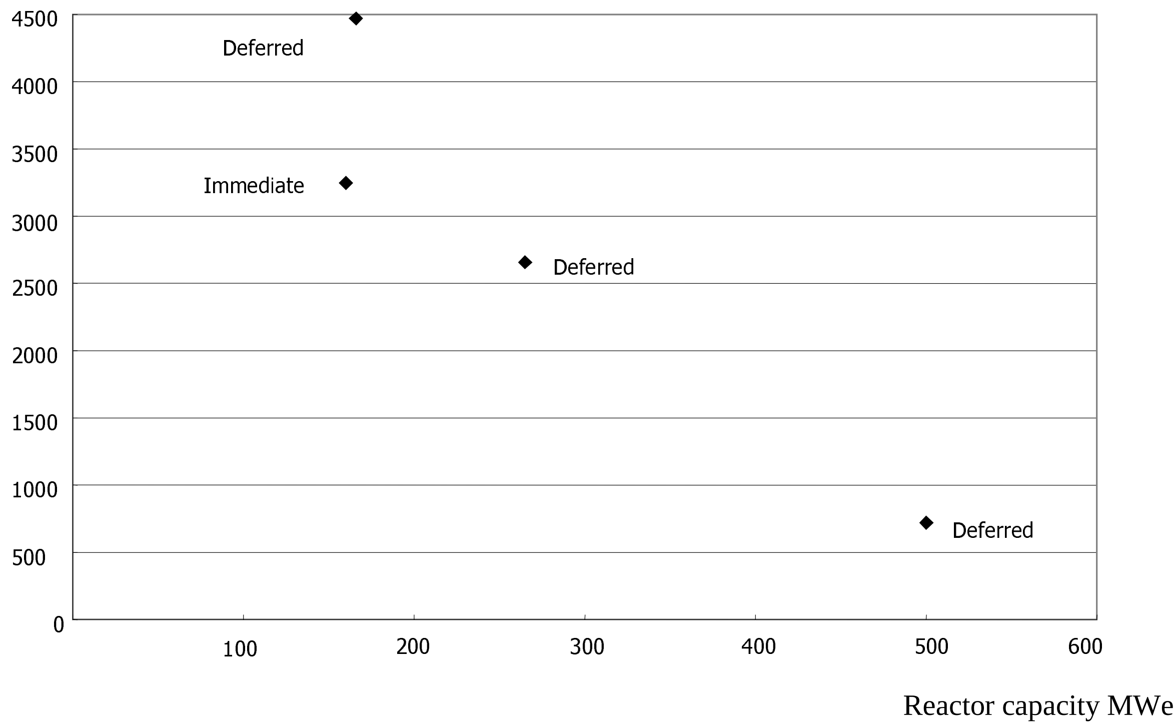


Figure 4.6. Total Decommissioning Cost (USD 1st July 2001/kWe) – GCRs



If data sets for all reactor types are considered, specific costs (expressed in USD per kWe) show a slight decreasing trend with increasing capacity. However, this trend is dominated by the high specific costs reported for gas-cooled and small size reactors. If the analysis is limited to water-cooled reactors with capacities higher than 200 MWe, the decreasing trend of specific costs with increase reactor capacity is less significant and the correlation is less robust.

In general, respondents who filled in Table C2 with numbers generally provided higher costs (in USD/kWe) than respondents that entered only “Yes” or “No” in Table C2 and respondents who did not fill in Table C2 at all generally reported lower cost estimates. Generally, estimates based on actual decommissioning projects, ongoing or completed, or on detailed modelling lead to higher costs. For example, high cost values reported in the case of BWRs by Italy (Garigliano) and the Netherlands (Dodewaard) have been evaluated with a bottom-up activity-based modelling approach.

This may be because detailed estimates are more likely to cover the entire scope and to have recognised potentially expensive difficulties and because when decommissioning activities are ongoing the work has been more fully scoped and precisely scheduled.

For the forty data sets which provide a decommissioning cost structure as requested in the questionnaire, the two cost elements representing a significant share (one fourth to one third, each) of the total in most cases are dismantling and waste treatment and disposal. Dismantling reaches up to 60% of total decommissioning cost in some cases but in average by reactor type its contribution ranges between 25 and 34% (see Table 5.1). Waste treatment and disposal represents average shares ranging from 17% to 43% depending on the reactor type but may exceed 65% in some cases.

Three other cost elements represent generally around 10% each of the total cost: security, survey and maintenance; site cleanup and landscaping; and project management, engineering and site support. In average by reactor type, security, survey and maintenance represents 8 to 13% of total costs, site cleanup and landscaping 5 to 13% and project management, engineering and site support 5 to 24%. The other cost items do not exceed 5% of the total decommissioning cost.

Table 4.9. Average contributions of major cost items to total decommissioning costs for each reactor type

Reactor Type	Dismantling (%)	Waste treatment and disposal (%)
BWR	33	23
PWR	30	23
VVER	25	17
PHWR	34	43
GCR	25	43

The findings tentative presented above are drawn from responses to the questionnaire and, therefore, do not cover all the cost data sets analysed in the study since some respondents did not provide a detailed cost structure. Moreover, many responses indicate some inconsistencies between national cost breakdown (accounting framework) and the list of cost items defined by the NEA/EC/IAEA document (NEA, 1999) used as reference in the questionnaire.

5. ANALYSIS OF COST DRIVERS

There is a wide variability between countries, utilities and reactor sites in a number of areas related to decommissioning, as shown by the information provided for this study in the questionnaire responses and by data reported in other international documents includes:

- *The Decommissioning and Dismantling of Nuclear Facilities: Status, Approaches, Challenges*, OECD/NEA 2002.
- *The Decommissioning and Dismantling of Nuclear Facilities in OECD/NEA Member Countries: A compilation of national fact sheets*, OECD/NEA 2002.
- *Today's Measures for Future Decommissioning of Swiss Nuclear Power Plants*, H. Achermann, von Gunten A. et al, 2002.
- Review of selected cost drivers for decisions on continued operation of older nuclear reactors, IAEA-TECDOC-1084, May 1999.
- *Decommissioning of Nuclear Facilities: An Analysis of the Variability of Decommissioning Cost Estimates*, OECD/NEA 1991.

Although some of the differences are physical (such as the type and size of reactors), others relate to different approaches (such as decommissioning strategies) and different conventions (such as what is included in decommissioning cost estimates and what is included elsewhere) applied by different countries and utilities. These go some way towards explaining why there are differences in decommissioning cost estimates between utilities and countries, even for similar facilities.

Currency conversion, while necessary for presentation purpose, may introduce some distortions that has to be recognised when trying to draw findings and conclusions from the cost information collected. Although not a cost driver *per se*, the assumed currency conversion rates do affect the costs presented in the present report and make comparisons between countries more difficult. This is especially important when comparing costs in North America with costs in Europe as the exchange rate between the US dollar and the Euro varied significantly over time.

Furthermore, the questionnaire asked for overnight, or undiscounted, cost estimates expressed in national currency at a given date and any assumed escalation rates necessary to obtain those costs also have an impact on the data provided and thereby on the variability of costs reported in this document. Another element that may increase the variability of reported cost is the scope of decommissioning costs in terms of taxes and insurance premium.

Type of reactor

There are quite a number of different reactor types in use (7 types are considered in this report) and there are have significant physical differences between them. For example, light water reactors tend to be compact in size whereas gas-cooled reactors tend to be physically much larger. Some reactors use water as a moderator and others use graphite, and some use liquid metal as a coolant rather than water or gas. Some reactor designs are replicated on a number of sites whereas others are unique thus requiring individual decommissioning plans. The extent of auxiliary systems and "conventional plant", and the extent to which this becomes contaminated with radioactive substances, varies between reactor types. For example, boiling water reactors have steam turbines that are contaminated with radioactive substances whereas other reactor types do not.

Light-water reactor vessels, as well as being compact in size, are designed so that the top can be fully removed giving direct access to the full diameter of the reactor and allowing all fuel to be removed in a short period of time. As a consequence, de-fuelling at the end of life tends to be considered to be a final operational activity and not a decommissioning activity that needs to be included in the decommissioning costs. The reactor internals in light water reactors are also designed to be removable. This ready access into the reactor vessels assists decommissioning activities. In contrast, gas-cooled reactors are not only large but have a non-removable top to the reactor vessel with only limited access designed into the reactor vessels for fuelling and de-fuelling purposes via small diameter penetrations. This means that reactor de-fuelling at the end of life can take a number of years and effectively means that it is sometimes classified as part of decommissioning and hence included within the decommissioning costs. Also, the lack of a readily removable top to the reactor vessel means that reactor dismantling is more difficult, time consuming and costly.

Size of reactor

There is a large variability in reactor sizes, not just in physical terms but also in power output. For example a modern pressurised water reactor of 1 200 MWe output has a reactor vessel internal diameter of 4.4 m whereas that of an older 150 MWe gas-cooled reactor has a reactor vessel diameter of 20 m. The sizes of the reactors, in combination with the types of reactor and materials of construction, dictate the quantity and nature of the radioactive waste that results from decommissioning, as well as the scale of dismantling required. The levels of radioactivity remaining in reactor materials at the end-of-life relate to the reactor size, output and material composition. More modern, high output but compact reactors, such as light water reactors using predominantly stainless steel materials, will have much higher residual radioactivity levels than will lower output, physically larger reactors such as gas-cooled reactors constructed from mild steel and graphite. This can affect the complexity of dismantling activities, and the potential for natural radioactive decay beneficially to reduce radiation levels. For example, radiation levels within gas-cooled, graphite moderated reactors are predicted to reduce to allowable personnel access levels within about 70 to 90 years after shutdown but in the more compact light water reactors the decay period would need to be very significantly longer. There is therefore less benefit to be gained by deferring the dismantling of light water reactors as compared to gas-cooled reactors.

Number of units on the site

As indicated in this report, the number of reactor units on individual sites can vary from one to eight. This can have an effect on decommissioning costs when considered in terms of costs per unit. The more units there are on a single site the more the supporting infrastructure facilities, including those during a decommissioning period, are shared. Hence and the site operating costs are lower when considered on a per reactor unit basis.

If some units remain operational while others on the site are shutdown and being decommissioned, this can reduce decommissioning costs. For example, if dismantling is being deferred on a reactor unit whilst others on the same site remain operational, then the care and maintenance costs for the shutdown reactor unit during the dormancy period will only be a marginal cost on top of the costs of continuing to operate the other reactors. For a fully shutdown site the full costs of maintaining that site would be attributable to decommissioning and would therefore be more significant.

Operating history

The operating history of a reactor can have an impact on decommissioning. This could be the case if there had, for example, been an accident or incident on the site that resulted in damage or contamination spread requiring different or more extensive decommissioning effort. However, this is a very infrequent occurrence and does not apply to the power plants considered in this report.

Other history related issues that might affect decommissioning costs include fuel leakage and water chemistry events as well as the reactor operating load factor during its lifetime. Fuel leakage events can result in the dispersion of alpha-emitting radionuclides within the primary circuit that will complicate the decommissioning and dismantling process. Water chemistry control problems can result in excessive spread of various radionuclides, especially ^{60}Co, in piping scale and hot spots. Water chemistry control also can have an effect on fuel leakage.

Some reactors have experienced relatively low load factors over their lifetime whereas others have had high ones. This can have an effect on the residual radioactivity levels at shutdown. Also, some plants have undergone refurbishment or replacement programmes during their lifetime. This may have resulted in more materials contaminated with radioactive substances being stored on the site, e.g. redundant heat exchangers, which then have to be included within the decommissioning plans, thus increasing the overall costs.

Scope of decommissioning activities

The assumed scope of decommissioning, including the assumed starting point and end point of decommissioning, will have a marked effect on decommissioning costs. The assumed scopes, starting and end points, identified in this report have been found to be very variable. Activities that some utilities include in their assumed decommissioning scope, and hence include in their decommissioning costs, but which others exclude, are:

- de-fuelling;
- on-site fuel storage;
- retrieval and packaging of accumulated operational waste;
- on-site storage of radioactive waste;
- radioactive waste transport and disposal (all costs);
- removal of conventional plant;
- removal of non-radioactive structures above ground level;
- removal of non-radioactive structures below ground level;
- contaminated ground remediation; and
- landscaping and site de-licensing.

Although some of these activities are not included within some utilities decommissioning scope and costs, it does not mean that these activities are not considered by them. For example, some utilities treat de-fuelling as operational and not decommissioning activities.

Decommissioning strategy options

The decommissioning strategies assumed for costing purposes have been found in this study to vary. Although the assumed strategies tend to be classified as either "immediate dismantling" or "deferred dismantling" there is quite a variability within these two categories. For example, some utilities are proposing what could be considered to be "rapid" immediate dismantling, with all work being completed in about 10 years, while others are considering a more prolonged dismantling period of 20 to 40 years, but still classifying this as immediate dismantling.

Under the deferred dismantling option a variety of deferral or dormancy periods is being considered which results in dismantling being completed in periods ranging from about 40 to around 100 years. There is also a variability in the extent of plant for which dismantling is to be deferred. On some sites it is effectively the dismantling of all plants and buildings that is deferred. On others, it is only the dismantling of plants and structures significantly contaminated with radioactive substances, such as the reactors, that is deferred, with all other plants and buildings being dismantled on an 'immediate' basis. Also, for those following a deferral strategy, the extent of work and on-site staffing assumed during the dormancy period, and hence the costs, is variable, e.g. some assume 24 hour on-site staffing is required and others that some measure of remote surveillance is allowable. Some utilities consider that, following a deferral period, radiation levels will have reduced sufficiently to allow simpler reactor dismantling technologies to be used, e.g. that fully remote operations will not be required. This is particularly the case for gas-cooled, graphite moderated reactors.

Site re-use

The assumptions as to how the site is to be re-used at the end of decommissioning can vary and affect the extent of decommissioning required, and hence affect the costs. Some countries that are committed to the continued use of nuclear power intend to re-use their existing sites. This may mean that they will select an immediate dismantling strategy, but the extent of dismantling need not be as extensive as on a site that is not to be re-used. For example, it might be possible to re-use some plant and buildings and it will not be necessary to undertake what can be extensive monitoring and remediation of the site to allow the nuclear site licence to be rescinded.

Where sites are not to be used for continuing nuclear purposes, the alternatives could be, for example, to use the sites for other non-nuclear industrial purposes or to return them back to nature. Such options will affect the extent of decommissioning required. For example, at Fort St Vrain in the USA where decommissioning is considered to be complete and the nuclear site licence has been rescinded, only the radioactive materials were removed. The non-radioactive reactor building shell remains on the site and the conventional plant, such as the turbine hall, has been re-used as part of a re-powering of the site using gas as the fuel.

Plans for the re-use of the site clearly affect the scope, schedule and end point of decommissioning, and hence affect the decommissioning costs.

Clearance and classification levels

The allowable clearance levels at which materials can be categorised as non-radioactive vary from country to country. This will inevitably have an impact on the quantity of material resulting from decommissioning that will need to be classified as radioactive waste. In some countries the material which is cleared from nuclear sites can be recycled or re-used without additional controls and hence can generate some income and, more importantly, reduce waste disposal costs. In other countries there are greater restrictions on cleared waste that lead to higher volumes of radioactive waste for disposal, thus incurring extra costs.

In addition, there are different classifications for material which is considered to be radioactive, i.e. above clearance level. These also vary from country to country and determine what happens to such material. For example, some countries allow lightly radioactive materials to be recycled in a controlled manner within the nuclear industry whereas others require the disposal of such material. Also, some radioactive waste may be disposed of in near-surface repositories in some countries whereas other countries will require the same material to be disposed of, more expensively, at a deep geological facility. These differences will result in variations in decommissioning costs.

Regulatory standards

Clearance levels, as mentioned above, are one example of "regulatory standards" that are relevant to decommissioning. Cleanup, as the final decommissioning criterion is most likely a major cost driver. There are other regulatory standards that could affect decommissioning activities and costs, and which vary from country to country, including allowable radiation doses for workers and the public, and allowable radioactivity and chemical discharges from sites. Regulations may also include environmental controls, for example on noise, dust and traffic. All these regulations will require extensive documentation to be prepared, assessed and approved, e.g. safety cases and environmental statements. There may also be some element of public consultation as part of these regulatory processes. These will all have a cost impact.

Amount of waste

The quantity of radioactive waste resulting from decommissioning can vary significantly from site to site as indicated in Chapter 2. This can, for example, be affected by the type and size of reactors, the extent of supporting plant and the allowable clearance levels. The type of drum used for immobilisation of the waste has an impact also on the final volume to be disposed of. As well as the quantity of radioactive waste, the material types will also vary. For example, some reactors use materials that may require special treatment, handling or disposal, e.g. heavy water, liquid metal coolant and graphite. Also, some reactor sites have accumulated operational waste on the site that will require retrieval, processing and packaging during the decommissioning period. These will all add to the costs of decommissioning.

In addition to radioactive waste, there will be a variability in the quantity and types of non-radioactive waste that result from decommissioning. Some of this waste may require special treatment. This is the case for asbestos, for example, which was used extensively as an insulating material on the older reactor sites, but not on the more modern ones. Lead, contaminated or not, also will require special handling if it is classified as waste for disposal. This again will affect the cost comparisons between different sites.

Availability of radioactive waste repositories

Decommissioning produces significant quantities, and different types, of radioactive waste that will ultimately require disposal in a suitable repository. The availability of such repositories can have a significant impact on the decommissioning strategy selected, particularly the timing of dismantling. Most utilities are assuming that repositories will be available when they plan to start decommissioning, even though all the necessary repositories are not yet available or planned. Should they not be available then dismantling may need to be deferred longer than presently intended, or interim waste stores will need to be provided.

The assumed design and location of repositories varies, with some being near-surface and some being deep geological facilities, some being close to or actually on the reactor site and some being a significant distance away. The acceptance criteria will also vary from repository to repository, e.g. in terms of allowable activity levels and radiation dose rates and package sizes. Some repositories will be able to accommodate large packages, including whole reactor vessels, others will only accept much smaller packages. These will all affect the extent of dismantling and packaging work required. All these factors will have an impact on costs.

As well as the differences between assumed repository types, there is also a variability in what proportion of the expected disposal costs are included within the quoted decommissioning cost estimates. Some utilities include the full cost of radioactive waste disposal, including those for accumulated operational waste as well as decommissioning waste, within their decommissioning cost estimates. Other utilities only include part of the disposal costs within their decommissioning cost estimates whereas others do not include them at all. Where the disposal costs are not included, or only partially included, in the decommissioning cost estimates it is generally because they are accounted for separately and included in a different fund to that directly associated with decommissioning.

Uncertainties and uncertainty treatment

The confidence levels in decommissioning cost estimates inevitably vary. For example, utilities actually undertaking decommissioning works should have a higher confidence in their cost estimates than those for whom decommissioning activities are contemplated in some years. This is borne out by the tendency for cost estimates to increase the closer the utility gets to starting work, and to completing it, an experience that relates to all major developments, not just nuclear power plant decommissioning.

The uncertainties associated with decommissioning costs, some of which will not be fully resolved until the decommissioning work is complete, have been recognised by the nuclear industry. A number of approaches are implemented to address such uncertainties. One common approach is to include a contingency allowance in the decommissioning cost estimate. Another, related to uncertainties in waste arisings, is to include a contingency allowance in the assumed waste quantities.

As well as the likely variability in approach to uncertainties there will also be variability in the level of any such contingency allowance included. Various levels of contingency are applied to various work elements depending on the experience in the field. Furthermore, risk allowances may be used to reflect the possibility that additional scope of work will be added as a result of changes in decommissioning policy. This variable treatment of uncertainties will inevitably have an impact on overall cost estimates and result in differences when comparing cost estimates between different utilities and countries.

Labour costs

Decommissioning can be a labour intensive activity and labour costs may be a significant component of total decommissioning costs. Therefore, the assumed unit cost of labour will have an impact on decommissioning cost estimates. Labour costs vary widely from country to country and depend on the skill level required for carrying out decommissioning activities that also may vary from country to country according to national regulatory frameworks. Differences in work productivity from country to country may also impact decommissioning labour costs.

On the basis of cost data sets provided for the present study, decommissioning costs do not seem to be significantly higher in countries where labour costs are high. Recognising that manpower is an important component of decommissioning costs, in countries where labour costs are high, operators may be relying more on automated equipment and less on manual intervention in the expectation that this will reduce their overall decommissioning costs. In reality, the skill levels required to develop, operate and maintain automated equipment may lead to costs that are higher than manual intervention.

Social and political factors

Social and political factors need to be taken into account and can have a significant impact on decommissioning strategy, plans and hence costs. For example, nuclear sites tend to be at remote locations and they are often the major employers in the vicinity. The social responsibilities to the local communities therefore need to be considered in determining decommissioning proposals. This has resulted at some sites in a plan to proceed with early decommissioning to maintain local employment levels.

Similarly, political factors are relevant and a necessary consideration which can affect plans and costs. For example, national political decisions may imply a mandatory immediate dismantling while a deferred strategy would have been chosen otherwise by the operators of nuclear units. Also, the overall nuclear energy policy of a country, e.g. moratorium on new nuclear units, accelerated phase-out or continued deployment, has an impact on decommissioning strategies and costs.

6. CONCLUSIONS

This report is based on responses from 26 countries (including 9, which contributed under the IAEA umbrella) to a questionnaire and on the work of a group of experts in the field of decommissioning. The information collected and analysed by experts provides some understanding of national decommissioning policies and of utility strategies together with commercial nuclear power plant decommissioning costs. The analysis provides some indication of the influence of policy and strategy on these costs. Previous chapters have presented the data, as given in responses to the questionnaire by official country representatives, and findings drawn by the Expert Group. The present chapter summarises qualitative and quantitative conclusions that can be derived from the information provided and the analyses of the experts.

Although the Expert Group decided to develop a comprehensive questionnaire, it was recognised up-front that the study will not include detailed analyses of decommissioning cost structure nor in-depth reviews of differences between the various cost data provided by respondents. The rationale for collecting detailed data was to support by some quantitative examples the analysis of impacts from policy and strategy choices on various cost items and on cost structure.

Decommissioning policy and strategy

Analysis of data provided by the questionnaire shows wide variations in many aspects of national decommissioning policy. For example, of the 26 countries that responded, only half have a national definition of decommissioning and just over half have a defined end point for the decommissioning process. Only seven countries have a mandatory time-scale to complete reactor decommissioning and only a third have a defined start point.

Many countries have a well-developed system for de-licensing nuclear sites, with 80% of the responding countries requiring a specific decommissioning license for this phase of the power station life cycle. However, only 60% of countries have defined exemption levels for radioactive waste.

According to the information provided, there are fewer variations in decommissioning strategy. The scope of decommissioning, with the exception of fuel storage and operational waste management, is generally broadly similar as are the factors considered in determining the preferred decommissioning strategy. Only eight countries use immediate dismantling as the sole cost base. Where deferral periods are assumed they generally range up to 50 years, except for the GCRs. This is probably mostly due to the absence of possibility to work underwater in a GCR and to the presence of large amounts of graphite.

These national and utility variations in policy and strategy inevitably lead to variations in decommissioning costs.

Cost variability

The analyses of the data supplied carried out within the present study have confirmed that cost comparisons, both international and national, are a useful input to many types of government and industry decisions. However, interpreting numerical differences between costs is complex and caution must be applied when drawing conclusions from those differences. Besides variations in national regulations and decommissioning policy, national radioactive waste management infrastructure, variants in the scope of decommissioning activities and accounting methods may all be responsible for broadening the range of costs reported by various countries for various reactor types. A complete understanding of cost differences between countries and reactor types is unlikely to be possible without a level of data verification and assessment beyond the scope of the present study.

In most countries where nuclear power plants are in operation, decommissioning costs are estimated and analysed on a regular basis. The purposes of decommissioning cost estimates vary from project management to establishment and monitoring of funding provisions. Such cost estimates are well understood by various stakeholders, and are well accepted by government and industry for the purposes for which they are intended.

Decommissioning cost estimates are based on a series of hypotheses reflecting industrial strategy choices or assumptions, national regulations and policy, and economic and social situations corresponding to the power plant concerned. Methodologies and tools used for decommissioning cost estimate calculations are robust and reliable. In most countries, cost estimates are carried out by those responsible for decommissioning activities and their financing. These are monitored and controlled by independent bodies generally reporting to the government.

It should be noted that all cost estimates provided for the study are based upon a strategy including final disposal of all radioactive waste, and assume a cost for this final disposal, although no country reported that final repositories exist at present for all types of radioactive waste. However, contingency margins and data collected on existing repositories and laboratories provide a reasonable certainty that the estimated costs are realistic.

Cost is only one of the parameters considered in the choice of decommissioning strategies. As reported in Chapter 2 (see Figure 2.10), many other factors are taken into consideration when deciding on a specific approach and scheduling of decommissioning activities. This reflects the complexity of the process of selecting a decommissioning strategy. While, especially in a deregulated market, cost will remain a key criterion for strategy selection, other criteria are as important and may even play a more significant role. Key aspects affecting strategy choices include: radiation protection and industrial safety; radioactive waste management and disposal options available; technical complexity; regulations; political factors; and social acceptance.

Except for gas-cooled reactors (GCRs), the type of reactor does not seem to affect significantly decommissioning costs on a unit cost per kWe installed basis. For all water reactors for which data were provided and analysed in the study, including PWRs, VVERs, BWRs and PHWRs/CANDUs, the decommissioning cost per kWe installed appears reasonably independent of the reactor type. The capacity effect, although noticeable, is not significant according to the data collected. The data indicate a low correlation between capacity and specific decommissioning costs and a rather slow decrease of this cost as the capacity of the reactor increases. The average cost per unit of capacity is usually lower for power plants with several reactors sharing common services.

This observation may reflect the fact that dismantling techniques are fairly universal and apply to any reactor type. Also, the total volume of work needed to decommission a water reactor, including cutting, demolition, grinding, waste conditioning, waste characterisation and so on, does not depend on its specific type but is common to all large metal and concrete nuclear facilities.

In this context, differences in labour costs, plant operating histories, waste conditioning requirements, and waste disposal costs probably explain most of the spread in reported costs. These variables are largely independent of the type or size of the unit being considered.

Gas-cooled reactors are, in general, more expensive to decommission than water-cooled reactors of any type. This is likely to be due to such key factors as the large physical size of GCRs, and the need to dispose of large amounts of graphite. As a result, the volume of work necessary to dismantle a GCR is larger than that needed for water reactors and the volumes of waste and materials to be managed are higher.

Although a rather wide range of decommissioning cost estimates were reported, those estimates remain below 500 USD/kWe for nearly all water reactors considered within the study. On the other hand, for the GCRs considered within the study, for which total decommissioning cost estimates were provided, they exceed 2500 USD/kWe.

Table 6.1 provides average values and standard deviations for decommissioning cost data reported in this study relative to each reactor type considered.

Table 6.1. Average decommissioning costs and standard deviations

Reactor type	Decommissioning costs (USD/kWe)	
	Average	Standard deviation
PWR	320	195
VVER	330	1 150
BWR	420	100
PHWR/Candu	360	70
GCR	> 2 500	–

The information provided on cost structure can be summarised as follows for the cost elements that contribute most to total decommissioning costs:

Dismantling	25-35% of total
Waste treatment and disposal	17-43% of total
Security, survey and maintenance	8-13% of total
Site cleanup and landscaping	5-13% of total
Project management, engineering and site support	5-24% of total

The above percentage ranges represent average by reactor type, the values vary more broadly from reactor to reactor.

In the responses that provided labour cost estimates, including sixteen plants in eight countries, labour represents between 10 and 70% of total decommissioning costs with most responses lying in the range 20 to 40%. The data provided are insufficient to assess whether or not this percentage is affected by the type of reactor considered but indicate clearly, as expected, that it differs from country to country, e.g. around 65% in Switzerland as compared to around 20% in Italy.

Effect of decommissioning strategy on cost

The decommissioning strategy options assumed for cost estimate purposes are more or less evenly split between immediate and deferred decommissioning options. Moreover, the detailed schedules of decommissioning activities provided by respondents indicate that “immediate” and “deferred” may not be very different. Indeed, in some immediate decommissioning strategies decommissioning activities would start several years after shut down while in some deferred strategies they would start no later than five years after shut down.

The choice between immediate and deferred dismantling may be influenced by the availability, or not, of waste disposal facilities. For example, in the United States, some units have been decommissioned immediately because space was available for the disposal of large reactor components.

The average total duration of decommissioning that has been assumed for the purpose of estimating decommissioning costs, including deferral period plus dismantling time, is approximately 40 years for all types of water reactors (PWR, BWR, VVER, CANDU) and is longer for GCRs. This may be due to the fact that, for GCRs, the radionuclide mix resulting from operation will decay significantly in about 100 years because they are built mainly from carbon steel, which is not the case in water reactors. This makes it worthwhile, in terms of reduced radiation dose and easing of working conditions, to defer decommissioning.

The overnight decommissioning cost estimates provided show no significant impact on the schedule (i.e. immediate or deferred decommissioning) on the cost for any type or size of reactor. This may be due to the fact that, for either immediate or deferred dismantling, the volume of work to be performed for a given size of plant does not change to any great extent given a similar end point. In such cases, only the assumption of when the work will be carried out changes, but this will have limited effect on the overnight costs, although the longer the deferral period the higher the care and maintenance costs during dormancy.

For the deferred option, some cost variations may appear as a result of facility maintenance over extended periods, depending on the type of “safe-store” strategy assumed. Also, the characteristics and status of the site has a significant impact on the costs of surveillance during safe-store. If other nuclear units continue to be operated on the site, the surveillance cost will represent only a marginal increase on the operation and maintenance costs of the operating units. If there is no further nuclear energy related activity on the site, surveillance of the shut down unit may become a significant component of the total decommissioning cost.

The option assumed, immediate or deferred, does affect the discounted cost of decommissioning because of the time value of money. This in turn may affect the amount of money to be accumulated in the decommissioning fund. The discount rate adopted is a key factor in this calculation. In most countries the nominal real discount rate assumed for the purpose of accumulating the decommissioning fund varies between 2% and 4%.

Waste volumes, management and disposal

None of the 26 countries that responded to the questionnaire has facilities to dispose of all the radioactive waste arising from reactor decommissioning. This could have a significant effect on the proposed timing of reactor dismantling and makes this cost element more uncertain.

The quantity of waste arising from decommissioning activities, as reported in responses to the questionnaire, varies within a broad range depending on the type and size of the reactors considered and on the responding country. In general, the weight of waste per installed capacity of reactor is considerably higher for GCRs than for other types of reactors while PWRs and BWRs are in the lower part of the range.

For most PWRs and BWRs and CANDUs considered in the study, the weight of radioactive waste arising from decommissioning activities is below 10 tonnes per MWe. For VVERs this mass is slightly higher around 17 tonnes per MWe. For GCRs the mass of radioactive waste is nearly ten times higher than in the case of water reactors, around 100 tonnes per MWe. A summary of the information reported for this study on radioactive waste weight is given below:

Reactor type	Radioactive waste weight (t/MWe)
PWR	10
BWR	10
PHWR/CANDU	13
VVER	17
GCR	100

The mass of material arising from decommissioning activities is clearly related to the physical size of the unit being decommissioned. The results of this study therefore are in agreement with the expected size effects since GCRs are physically larger than CANDUs, which in turn are generally physically larger than the new generation of LWRs.

A large number of responses provided some elements of cost structure and in particular the absolute value or share of waste management and disposal cost. According to those responses, waste management and disposal represents in average by reactor type between 17 and 43% but may as low as 5% or as high as 65% of total decommissioning cost for individual reactors, with most responses remaining in the range 10 to 30%.

As noted above, waste disposal costs may be among the more uncertain data provided for this study since no country reported that it has existing waste repository facilities for all types of decommissioning waste. However, extensive research in the economics of repositories means that uncertainties in waste disposal cost estimates may now be within a reasonable range.

Overall concluding remarks

A complete understanding of decommissioning cost variability is beyond the scope of the present study and could not be achieved with the working method adopted. Differences in decommissioning work breakdown structures and scope between countries and operators made fully consistent responses difficult to obtain, even though great care had been taken in this study to produce a detailed and explicit questionnaire.

However, the analysis of the data contained in the responses indicates trends and ranges of costs and helps to identify major aspects of national policy and industrial strategy that affect decommissioning costs. The observations and tentative conclusions drawn from the data supplied should provide useful and relevant input to discussions of and decisions on national policy, national regulation and industrial strategy for decommissioning nuclear power plants.

Lastly, it is pleasing to note the increase in international co-operation in assessing decommissioning policies, strategies and costs. The present study contains contributions from 26 countries (including 9 non-OECD countries that participated under the IAEA umbrella). The 1991 study contained data supplied by only 9 countries. Continued international co-operation, together with exchange of experience and lessons learned, will help ensure that the current generation of nuclear power plants world-wide is decommissioned safely and cost-effectively.

Annex 1

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Annex 2

QUESTIONNAIRE

General Information

The present questionnaire is largely based upon previous work carried out in particular within the framework of the Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD). However, the Expert Group has adapted and simplified the CPD questionnaire in the light of the specific objectives and scope of the study on "*Decommissioning Strategies and Costs*" undertaken under the leadership of the NDC as described above.

In order to avoid duplication of national efforts and to take advantage of the wealth of information already available within the international community and in particular to the NEA, a copy of the responses received from representatives of your country to previous questionnaires are attached to this document for your information. This includes responses to the CPD questionnaire (entire or non-confidential parts of it if applicable) and responses to the questionnaire on decommissioning costs of VVER-440 that have been sent to the IAEA.

Practical Instructions

This questionnaire has been sent as "read only file" (pdf) and paper version. Respondents are encouraged to respond **on paper**; however, an electronic file (MicrosoftWord97) may be provided upon request. Please note that each question is numbered so thank you for referring to the number whenever you need to add text outside of the space/box allocated in the questionnaire. For multiple answers to the same question (e.g. several waste repositories), please make copies of the questions as needed. For many questions, the answer is Yes or No, please circle your response, e.g. Yes.

PART I

Country:

Co-ordinator details:

[Please specify below the contact details of the person responsible for co-ordinating the responses within the country and for returning the questionnaire to the Secretariat; contact details of the experts/project managers who filled in the questionnaire for different plants/facilities, are to be provided in Part II of the questionnaire.]

Co-ordinator:

Name:

Affiliation (i.e. company, organisation):

Department:

Mailing address:

Telephone:

Facsimile:

E-mail:

Decommissioning Policy

Decommissioning policy, in the context of this project, is intended to include all governmental (national or regional) requirements, as described in laws, regulations, standards and other mandatory rules that will influence the framework within which decommissioning activities must take place. In order to cover the main issues, please answer questions QP1 to QP21 below.

If your country sent a response to the questionnaire used for preparing the NEA "decommissioning fact sheets", it is attached to the present questionnaire and you may refer to it whenever appropriate and/or modify/complement it with emphasis on issues relevant for the present study.

If you wish to provide descriptive text covering additional key elements of the decommissioning policy in place in your country relevant in connection with decommissioning strategies and costs and/or references to documents containing policy statements and legal frameworks, please insert the corresponding text at the end of your answer, under the heading "Decommissioning policy".

QP1	Is there a national definition of decommissioning? If yes, please provide the definition.	Yes	No
QP2	Is there a required starting point of decommissioning? If yes, please describe the starting point.	Yes	No
QP3	Is there a required end point of decommissioning? If yes, please describe the end point (e.g. "green-field", removal of radioactive materials only, site available for unrestricted use, site available for nuclear use or for other industrial use).	Yes	No
QP4	What are the conditions that need to be achieved to be able to de-license a site, i.e. to enable all nuclear regulatory restrictions and controls to be removed? [*Please indicate if these conditions lead to unrestricted release of the site and whether operators are liable for the cost of managing any radioactivity discovered after the de-licensing process is complete*].		

QP5	Is there a mandatory time scale by which the end point of decommissioning described in QP2 must be achieved?	Yes	No
	If yes, please indicate the time scale (number of years after shut down).		
QP6	Are utilities/operators required to perform a broad-based strategy optimisation before selecting a decommissioning strategy?	Yes	No
	If yes, is guidance provided on how to perform this optimisation?	Yes	No
	If yes, please describe the guidance provided.		
QP7	Are specific strategy options/alternatives required to be included in the selection process mentioned above?	Yes	No
	If yes, please describe them.		
QP8	Are final repositories available for all radioactive waste types arising from decommissioning (other than spent fuel)?	Yes	No
	If no, please indicate what is the national approach adopted to manage the waste types for which there is no repository available today.		
QP9	Please provide the following information for each radioactive waste repository available for decommissioning waste (including on-site disposal if applicable): [Please copy and fill in for each available repository] Location: Opening date: Anticipated closing date: Characteristics of the waste limiting acceptability: Maximum activity level [*please specify*]: Maximum dose rate at contact [*please specify*]: Maximum size of the package [*please specify*]*:* Maximum weight of the package [*please specify*]:		
	Is geographic location (e.g. distance from decommissioning site) a limit to use this repository?	Yes	No
	Are there specific materials, e.g. graphite, which are not accepted at this repository?	Yes	No
	If yes, please specify.		

QP10	Are new repositories planned for radioactive waste arising from decommissioning?	Yes	No
	If yes, please provide the following information for each planned repository. [please copy and fill in for each planned repository] Location: Opening date: Anticipated closing date: Characteristics of the waste limiting acceptability: Maximum activity level [*please specify*]: Maximum dose rate at contact [*please specify*]: Maximum size of the package [*please specify*]: Maximum weight of the package [*please specify*]:		
	Is geographic location (e.g. distance from decommissioning site) a limit to use this repository?	Yes	No
	Are there specific materials, e.g. graphite, which are not accepted at this repository?	Yes	No
	If yes, please specify.		
QP11	What is the national policy regarding: Hazardous non-radioactive waste from decommissioning? Mixed waste (i.e. radioactive waste co-disposed with hazardous non-radioactive materials)?		
QP12	Are there specific clearance levels and/or procedures for categorising decommissioning waste as non-radioactive or for making such materials exempt from regulation?	Yes	No
	If yes, please describe them		
QP13	Is a specific license, different from the operating license, required to shut down a nuclear facility?	Yes	No
QP14	Is a specific license, different from the operating license, required for decommissioning a nuclear facility?	Yes	No
QP15	What documents must be submitted to gain consent to proceed with decommissioning [*e.g. safety case, environmental assessment*]?		

QP16	Who is responsible for the decommissioning costs?		
	Government	Yes	No
	Utility/Operator	Yes	No
	Other [please specify]**:**		
QP17	When do total decommissioning funds have to be provided?		
	By shutdown of the plant	Yes	No
	Within years of commissioning of the plant	Yes	No
	Within years of shutdown of the plant	Yes	No
	Other [please specify]:		
QP18	Are decommissioning funds required to be based on:		
	Overnight/undiscounted decommissioning costs	Yes	No
	Net present value/discounted decommissioning costs If yes, please specify the discount rate and reference date of discounting	Yes	No
	Other [please specify]**:**		
QP19	On what basis does the government assure itself that the decommissioning funding levels are adequate?		
QP20	How are decommissioning funds required to be raised?		
	By a charge included in electricity price	Yes	No
	By a tax	Yes	No
	By Governmental/compulsory fees	Yes	No
	By other means [*please specify*]		
	No specific requirement	Yes	No

QP21	How are decommissioning funds required to be held?		
	By the government	Yes	No
	By the utility/operator	Yes	No
	By another body [*please specify*]		
	No specific requirement	Yes	No
QP22	How are decommissioning funds required to be managed?		
	As a segregated fund	Yes	No
	By the utility/operator within its own assets	Yes	No
	By the utility/operator within a separated account	Yes	No
	By the utility/operator as a segregated fund	Yes	No
	Other [please specify]	Yes	No
	No specific requirement	Yes	No

PART II

[Please fill in this part of the questionnaire for each plant/facility for which cost data are provided].

Respondent:

Name:

Affiliation (i.e. company, organisation):

Department:

Mailing address:

Telephone:

Facsimile:

E-mail:

Decommissioning Strategy and Costs

Decommissioning strategy, in the context of this project, is intended to include all technical, logistic and scheduling aspects proposed by the operators to their national regulatory authorities when requesting the authorisation to proceed with decommissioning projects. Topics to be covered include: permitted or expected re-use of the site; socio-economic context of the site/region; public acceptance issues; specific factors affecting the company strategy regarding decommissioning; possibilities for recycling materials; possibility of one piece removal; driving factors and priorities, e.g. dose to workers minimisation, cost minimisation, waste volume or activity minimisation.

In order to cover the main issues, please answer questions QS1 to QS18 below. If you wish to provide additional information, please insert the corresponding text at the end of your answer under the heading "Decommissioning strategy".

QS1	**Plant details**
	Name
	Location
	Category [e.g. commercial, prototype, research reactor]
	Type [e.g. PWR, BWR, LMR]
	Type of reactor pressure vessel [*e.g. steel, concrete, pressure tube*]
	Number of units on the site
	Capacity on the site [MWe net, if applicable indicate heat production capacity]
	Number of units/capacity for which decommissioning cost data are provided
	Date of commissioning
	Date of shutdown [please specify whether the date is: actual, expected, assumed for costing purpose]

QS2	**Weight of residual materials and radioactive waste from decommissioning**		
		Materials (tonnes)	**Radwaste** (tonnes)
	Reactor and biological shields:		
	Metals		
	Concrete		
	Graphite		
	Other materials		
	Other primary circuit components [*e.g. steam generators, pipes*]		
	Other contaminated components/materials [*e.g. fuel handling, effluent treatment*]		
	Conventional buildings included in decommissioning scope		
	Total		

QS3	**Please provide information on the history of the plant relevant for decommissioning cost purpose, e.g. extended shut down, incidents, accidents, and major refurbishment?**		
QS4	**What was/is expected to be the dose rate inside the reactor vessel at shutdown?**		
QS5	**Is the responsibility for decommissioning transferred from the utility/ operator to another body?**	Yes	No
	If yes, please specify.		
QS6	**What was included in the assumed scope of decommissioning when the strategy was developed?**	Yes	No
	On-site storage of fuel	Yes	No
	Packaging of accumulated operational waste, e.g. sludge, ion-exchange resins	Yes	No
	Removal of reactor building	Yes	No
	Removal of conventional plant/buildings, e.g. turbine halls	Yes	No
	Removal of contaminated ground	Yes	No
	Disposal of radioactive waste	Yes	No
	Disposal or recycling of non-radioactive waste	Yes	No
	Final site surveys	Yes	No
	De-licensing of the site	Yes	No

QS7	**Which decommissioning strategies were considered?**		
	1. Immediate dismantling	Yes	No
	2. Deferred dismantling	Yes	No
	If yes, please indicate the deferral period years		
	3. Other (please specify)	Yes	No
QS8	**Which decommissioning strategy has been assumed for calculating the cost data provided?** [please refer to strategy numbers given in QS7 and indicate the key stages of the assumed strategy, the main activities undertaken at each stage and the duration (years) for each stage]		
QS9	**What process was used to determine and select the decommissioning strategy?** [*e.g. multi-attribute decision analysis*]		
QS10	**Which stakeholders were consulted during the process?** [*e.g. Government, Regulators, public*]		
QS11	**What were the main factors considered in adopting the strategy?**		
	Radiation protection and industrial safety	Yes	No
	Technical feasibility	Yes	No
	Radioactive waste disposal	Yes	No
	Regulations	Yes	No
	Costs	Yes	No
	Funds	Yes	No
	Uncertainties (on future regulations and/or other factors)	Yes	No
	Social and political factors	Yes	No
	Site re-use	Yes	No
	Others If yes, please specify.	Yes	No
QS12	**Who selected the decommissioning strategy?**		
	Utility/operator	Yes	No
	Regulator	Yes	No
	National Government	Yes	No
	Regional Government	Yes	No
	Joint decision If yes, please name the parties involved	Yes	No
	Other [if yes, *please specify*]	Yes	No

QS13	**How is reactor dismantling to be done?**		
	Fully remotely (with no direct worker access to or contact with reactor components)	Yes	No
	Semi-remotely (with restricted worker access to or contact with reactor components)	Yes	No
	Contact working (no significant restriction on worker access or contact)	Yes	No
	Other [please specify]		
QS14	**How is primary circuit component dismantling be done?**		
	Fully remotely	Yes	No
	Semi-remotely	Yes	No
	Contact working	Yes	No
QS15	**How are reactor vessel and primary circuit components to be disposed of?**		
	Single piece removal and disposal	Yes	No
	Large piece removal and disposal	Yes	No
	If yes, please indicate the size of pieces		
	Small piece removal, packaging and disposal	Yes	No
QS16	**Is it assumed for cost data that the void remaining in waste packages has to be filled with cement grout or similar?**	Yes	No
QS17	**What are the plans for the radioactive waste resulting from decommissioning?**		
	To be disposed of directly to a waste repository	Yes	No
	To be stored on-site pending the availability of a waste repository	Yes	No
	To be stored off-site pending the availability of a waste repository	Yes	No
	Other If yes, please specify	Yes	No
QS18	**Is decommissioning to be, or has it been, performed as a research or development project, i.e. not a fully commercial activity?**	Yes	No
QS19	**If there is a dormancy or deferral period before decommissioning, what will be the conditions and operations carried out during that time?** [*e.g. permanent site staff in attendance 24 hours a day, active cooling/ventilation*]		

Cost Data

Cost data are expected to be reported as overnight/undiscounted costs expressed in constant national currency unit (NCU) of 1st July 2001. Whenever another approach is adopted (e.g. discounted costs, NCU of another date or any other currency), please specify and provide details (under QC1 or as separate text under the heading "Determination of cost data").

Respondents are invited to refer to the interim technical report entitled "A Proposed Standardised List of Items for Costing Purposes" (OECD/NEA, IAEA, EC, 1999) for definitions of cost items and categories. All Members of the Expert Group should have received a copy at the first meeting of the Group and additional copies may be obtained from the NEA Secretariat upon request.

Detailed decommissioning cost estimates, if they are provided, should be reported according to the structure/breakdown recommended in the interim technical document. If only total decommissioning cost estimates are reported, the response should specify whether or not each of the standardised cost items listed in the questionnaire are included in the total.

Similarly, detailed cost categories, if they are provided, should be reported according to the four standardised cost groups defined in the interim technical document (OECD/NEA, IAEA, EC, 1999), i.e. labour, capital, expenses and contingency. If only total decommissioning cost estimates are reported, the response should specify whether or not each of the four standardised cost groups (are included in the total.

QC1	**When were decommissioning cost data determined?**		
	If not in 2001, please specify how the costs were adjusted to 1st July 2001 NCU		
QC2	**How were decommissioning cost data determined?**		
	Actual cost (i.e. project completed or nearly completed)	Yes	No
	Extrapolation based on another completed project	Yes	No
	If yes, please specify the type and size of the plant		
	Standard cost model	Yes	No
	Detailed site/plant specific cost estimates	Yes	No
	Other [please specify]	Yes	No
	Site re-use	Yes	No
QC3	**Please fill in Table C1 [and C2 if data are available]**		
	See following page.		

Table C1. Aggregated decommissioning cost data [1]

	COST GROUP [2]						
COST ITEM	Labour		Capital	Expenses	Conting.	[3]	TOTAL
	(hours)	(NCU)	(NCU)				(NCU)
Pre-decommissioning							
Facility shutdown							
Procurement							
Dismantling							
Waste treatment & disposal							
Security, surveillance & maintenance							
Site cleanup & landscaping							
Project management, engineering & site support							
R&D							
Fuel							
Others							
TOTAL							

[1] If you wish to provide disaggregated cost data, please fill in tables C1 and C2.

[2] If you do not provide data for each cost group, please indicate, in the respective cell in each line, if the group is included in (**Y**), or excluded from (**N**), the total decommissioning cost data given in the last column of that line.

[3] If you do not provide cost data for each cost item, please indicate in this column if the item is included in (**Y**), or excluded from (**N**), the total decommissioning cost.

Table C2. Disaggregated decommissioning cost data

COST ITEM	[4]	Cost (NCU)
Pre-Decommissioning		
Decommissioning planning		
Authorisation		
Radiological surveys for planning and licensing		
Hazardous material surveys and analyses		
Prime contracting selection		
Facility Shutdown Activities		
Plant shutdown and inspection		
Removal of fuel and/or nuclear-fuel materials		
Drainage and drying or blowdown of all systems not in operation		
Sampling for radiological inventory characterisation after plant shutdown, defuelling and drainage or blowdown of systems		
Removal of system fluids (water, oils, etc)		
Removal of special system fluids (D_2O, sodium, etc)		
Decontamination of systems for dose reduction		
Removal of waste from decontamination		
Removal of combustible material		
Removal of spent resins		
Removal of other waste from facility operations		
Isolation of power equipment		
Asset recovery: Resale/transfer of facility equipment and components as well as surplus inventory to other licensed (contaminated) and unlicensed (non-contaminated) facilities		
Procurement of General Equipment and Material		
General site dismantling equipment		
General equipment for personnel/tooling decontamination		
General radiation protection and health physics equipment		
General security and maintenance equipment for long-term storage		

Dismantling Activities		
Decontamination of areas and equipment in buildings to facilitate dismantling		
Drainage of spent fuel pool and decontamination of linings		
Preparation for dormancy		
Dismantling and transfer of contaminated equipment and materials to containment structure for long-term storage		
Sampling for radiological inventory characterisation in the installation after zoning and in view of dormancy		
Site reconfiguration, isolating and securing structures		
Facility (controlled area) hardening, isolation or entombment		
Radiological inventory characterisation for decommissioning and decontamination		
Preparation of temporary waste storage area		
Removal of fuel handling equipment		
Design, procurement, and testing of special tooling/equipment for remote dismantling		
Dismantling Activities (cont.)		
Dismantling operations on reactor vessel and internals		
Removal of primary and auxiliary systems		
Removal of biological/thermal shielding		
Removal of other material/equipment from containment structure and all other facilities, or removal of entire contaminated facilities		
Removal and disposal of asbestos		
Removal of pool linings		
Building decontamination		
Environmental cleanup		
Final radioactivity survey		
Characterisation of radioactive materials		
Decontamination for recycling and reuse		
Personnel training		
Asset recovery: Sale/transfer of metal or materials, and salvaged equipment or components for recycling or reuse		

Waste Processing, Storage and Disposal		
Waste processing, storage and disposal safety analysis		
Waste-transport feasibility studies		
Special permits, packaging, and transport requirements		
Processing of system fluids (water, oils, etc) from facility operations		
Processing of special system fluids (D_2O, sodium, etc) from facility operations		
Processing of waste from decontamination during facility operations		
Processing of combustible material from facility operations		
Processing of spent resins from facility operations		
Processing of other nuclear and hazardous materials from facility operations		
Storage of waste from facility operations		
Disposal of waste from facility operations		
Processing of decommissioning waste		
Packaging of decommissioning waste		
Transport of decommissioning waste		
Storage of decommissioning waste		
Disposal of decommissioning waste		
Site Security, Surveillance and Maintenance		
Site security operation and surveillance		
Inspection and maintenance of buildings and systems in operation		
Site upkeep		
Energy and water		
Periodic radiation and environmental survey		
Site Restoration, Cleanup and Landscaping		
Demolition or restoration of buildings		
Final cleanup and landscaping		
Independent compliance verification with cleanup and/or site reuse standards		
Perpetuity funding/surveillance for limited or restricted release of property		

Project Management, Engineering and Site Support		
Mobilisation and preparatory work		
Project management and engineering services		
Public relations		
Support services		
Health and safety		
Demobilisation		
Research and Development		
Research and development of decontamination, radiation measurement and dismantling processes, tools and equipment		
Simulation of complicated work on model		
Fuel and Nuclear Material		
Transfer of fuel or nuclear material from facility or from temporary storage to intermediate storage		
Intermediate storage		
Dismantling/disposal of temporary storage facility		
Preparation of transfer of fuel or nuclear material from intermediate storage to final disposition		
Dismantling/disposal of intermediate storage facility		
Other Costs		
Owner costs		
General, overall (not specific) consulting costs		
General, overall (not specific) regulatory fees, inspections, certifications, reviews, etc		
Taxes		
Insurances		
Overheads and general administration		
Contingency		
Interest on borrowed money		
Asset recovery: Resale/transfer of general equipment and material		

[4] Please specify if the item is included (Y) or excluded from (N) the total decommissioning cost data provided in table C1

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Please insert below any additional text that you wish to include in your response.

Annex 3

EXCHANGE RATES AND ADJUSTMENT FACTORS [1]

Currency Exchange Rates (USD per national currency units on 1st July 2001)

Belgium	0.0209
Canada	0.6573
Czech Republic	0.0251
European Union	0.8447
Germany	0.4319
Hungary	0.0035
Japan	0.0080
Slovak Republic	0.0201
Sweden	0.0919
Switzerland	0.5556
United Kingdom	1.4085

GDP Deflators (Index)

Canada	1.0056	[2000 to 1st July 2001]
Czech Republic	1.2187	[1997 to 1st July 2001]
European Union	1.039	[1999 to 1st July 2001]
	1.0009	[March 2001 to 1st July 2001]
Germany	1.038	[1995 to 1st July 2001]*
	1.0078	[December 2000 to 1st July 2001]
United States	1.082	[1997 to 1st July 2001]**
	1.05	[January 1999 to 1st July 2001]**
	1.03	[January 2000 to 1st July 2001]

* Used for data provided by Slovenia in DM.
** Used for data provided by other/non-US countries in USD.

1. Source: OECD Main Economic Indicators

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