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Selection of decommissioning strategies: Issues and factors

Report by an expert group

IAEA
International Atomic Energy Agency

November 2005

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FOREWORD

A comprehensive assessment of possible strategies is the key step in a decommissioning process. It should be initiated at an early stage in a facility's lifecycle and include a number of factors. The IAEA has provided extensive guidance on decommissioning strategy selection, but there are a number of cases — particularly in countries with limited resources, but not limited to them — where the selection is forced and constrained by prevailing factors and conditions.

In its role of an international expert committee assisting the IAEA, the Technical Group on Decommissioning (TEGDE) debates and draws conclusions on topics omitted from general guidance. TEGDE members met in Vienna in 2003, 2004 and 2005 to develop the basis for this publication. The views expressed here reflect those of TEGDE and not necessarily those of the IAEA. The IAEA wishes to thank all TEGDE members for their valuable contributions to the work on this publication. The IAEA officers responsible for the preparation of this publication were M. Laraia of the Division of Nuclear Fuel Cycle and Waste Technology and D. Reisenweaver of the Division of Radiation, Transport and Waste Safety.

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1. INTRODUCTION

1.1. Background

The Technical Group on Decommissioning (TEGDE) was established in 2002 with the following objectives:

(a) To provide guidance on the Agency's programmatic activities in the area of decommissioning;

(b) To assist and provide guidance to the Agency on the development of harmonized policies and strategies for decommissioning;

(c) To provide a focal point for the discussion and resolution of technical issues in the field of decommissioning;

(d) To prepare, on request, status reports on relevant issues in the field of decommissioning; and

(e) To be a forum for the exchange of information on lessons learned and on the progress of national and international programmes in this field.

It currently includes 17 members from the same number of countries and international organizations. One of the aspects where it is felt that TEGDE could provide significant added value is advice and assistance to the IAEA on pending issues in decommissioning.

Decommissioning is defined by the International Atomic Energy Agency (the Agency) as the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. The use of the term 'decommissioning' implies that no further use of the facility for its existing purpose is foreseen. The actions taken in decommissioning need to be such as to ensure the protection of the work force and continuous protection of the public and the environment. This typically includes reducing levels of residual radionuclides so that material and buildings can be safely released and reused.

Decommissioning activities need to be integrated with the full life cycle of a facility, starting with decommissioning considerations in the design and construction of the facility, decommissioning planning throughout the operational phase of the facility and the execution of the decommissioning plan at the end of the useful life of the facility.

A large number of facilities worldwide will require decommissioning in the near term and eventually all facilities that have used radioactive material will require decommissioning. These facilities range from large nuclear power reactors and complex reprocessing plants to small research laboratories and manufacturing plants. The need for decommissioning may be expected when a facility comes to the planned end of its useful life or termination of operations due to commercial and political decisions or accidents. The tasks associated with decommissioning cover a wide spectrum; for larger nuclear facilities they can include large-scale decontamination and demolition of massive concrete structures while, at the other extreme, only some modest cleaning and decontamination may be needed for radioisotope laboratories.

When selecting a proper decommissioning strategy in a specific facility, a range of general and site specific factors needs to be considered, typically, in a multi-attribute analysis. These factors include cost, health and safety issues and environmental (HSE) impact, availability of resources, stakeholder involvement, etc. In some cases the lack of a single key resource could result in the elimination of some decommissioning strategies. Good practice may not always be achieved in Member States due to constraints or overruling factors such as a lack of funds or a lack of waste management infrastructure. Constraints or overruling factors are often attributable to inadequate decommissioning planning. This in turn may be due to inadequate legal and regulatory frameworks.

Some relevant constraints and conditions have been identified in this report, and the impacts of these constraints and conditions have been evaluated by the members of the TEGDE. The objective of the evaluation was to identify key issues and to provide recommendations to Member States in which these constraints and factors prevail, in order to promote actions in support of good decommissioning practice. Good decommissioning practice is important for sustainability of the nuclear industry and nuclear applications.

1.2. Objectives

The primary purpose of this report is to provide information that will enable the policy makers and individuals of the Member States responsible for decommissioning to take note of specific decommissioning factors and constraints in order to provide support in the decommissioning strategy selection process.

It is not the intention of this report to give direct guidance on the establishment of a decommissioning strategy, but rather to enable users to analyse the identified constraints and factors, and define the key elements impacting the selection of decommissioning strategies. Some generic suggestions regarding best practices are given.

1.3. Scope

This report covers facilities that have used radioactive material in general and is not facility specific unless so indicated. It is applicable to decommissioning planning and covers preliminary and final decommissioning planning. The following constraints and conditions are evaluated:

- Insufficient decommissioning funds;
- Insufficient legislative and regulatory framework;
- Inadequate fuel and waste management systems;
- Lack of skilled human resources at the outset of the decommissioning activities;
- Social impacts associated with decommissioning;
- Specific facility/site reuse demands;
- Small facilities and limited resources.

1.4. Structure

The main text of this report is organized as follows: Section 2 describes some of the basic decommissioning factors that influence the selection of decommissioning strategies. The factors and processes that would render a decommissioning strategy ‘good practice’ are also covered. Section 3 discusses the evaluation of the impact of specific conditions and constraints on decommissioning strategies for a range of key factors, types of nuclear facility and decommissioning indicators. Section 4 lists and summarizes the main conclusions and recommendations related to the impact of specific constraints and conditions on decommissioning strategies. There is also one Appendix that provides case studies of recent decommissioning projects where some key constraints had to be considered and managed.

2. DECOMMISSIONING FACTORS

2.1. Decommissioning strategies

Three decommissioning strategies have been defined by the IAEA namely: *immediate dismantling*, *deferred dismantling* and *entombment* [1]. 'No action' is not regarded as an acceptable decommissioning strategy and therefore it will not be further discussed in this report.

Immediate dismantling commences shortly after shut down, if necessary following a short transition period to prepare for implementation of the decommissioning strategy. Decommissioning is expected to commence after the transition period and continues in phases or as a single project until an approved end state including the release of the facility or site from regulatory control has been reached.

As an alternative strategy, dismantling may be deferred for a period of up to several decades. Deferred dismantling is a strategy in which a facility or site is placed in a safe condition for a period of time, followed by decontamination and dismantling. During the deferred dismantling period, a surveillance and maintenance programme is implemented to ensure that the required level of safety is maintained. During the shutdown and transition phases, facility-specific actions are necessary to reduce and isolate the source term (removal of spent fuel, conditioning of remaining operational or legacy waste, etc.) in order to prepare the facility/site for the deferred dismantling period.

Entombment is a strategy in which the remaining radioactive material is permanently encapsulated on site. A low- and intermediate-level waste repository is effectively established and the requirements and controls for the establishment, operation and closure of waste repositories are applicable.

Although evaluation of the prevailing factors could clearly indicate one of the above-mentioned strategies, constraints and overruling factors may occur in practice, and these necessitate a combination of strategies or exclude one or more strategies from consideration (see Appendix).

2.2. General factors influencing decommissioning strategies

The factors that impact on the selection of a decommissioning strategy are generally consistent for the full range of facilities. These factors could occur as positive indicators or as constraints, e.g. whether funding is available or not. The impact of the factors also depends on country- and facility-specific conditions. The following are regarded as general factors that have an influence on the selection of decommissioning strategies:

– National Policies and Regulatory Framework

    - Policy documents that address programmes and directions of the nuclear industry on a national level;

- Legal framework covering regulatory functions and infrastructure as well as requirements and standards pertaining to decommissioning;
- Authorization/licensing processes to ensure regulation of the full lifecycle of the facility, in particular regulations for the planning and execution of decommissioning.

– Financial Resources / Cost of Implementing a Strategy

- Availability of adequate financial resources and funding mechanisms;
- Direct cost of implementing the decommissioning strategy;
- Indirect costs associated with the strategy (e.g., costs related to stakeholder involvement and social acceptance).

– Spent Fuel and Waste Management System

- National spent fuel and waste management policy and strategy;
- Availability of facility-specific spent fuel and waste management plans and facilities;
- Amounts and types of decommissioning waste.

– Health, Safety and Environmental (HSE) impact

- Safety/health risk;
- Environmental impact including impact of material/waste transportation;
- Physical status of the facility, e.g. expected integrity of buildings over time;
- Radiological and hazardous material characteristics;
- On-site industrial safety hazard impacts.

– Knowledge Management and Human Resources

- Availability of suitably qualified and experienced personnel;
- Lessons learned from previous decommissioning projects;
- Operational history and adequacy of decommissioning related information (records, drawings, etc.);
- Resources from other operating nuclear facilities either on site or in the country;
- Reasons for permanent shutdown, if not consistent with the original planning basis (economic, political, accident, etc).

– Social Impacts and Stakeholder Involvement

  - Impacts on local communities from decommissioning process;
  - Public/stakeholders concerns and perceptions;
  - Reuse options for the site.

– Suitable technologies and techniques.

Each of these general factors is described in the following subsections.

2.2.1. National policies and regulatory framework

A national policy regarding the management and regulation of the life cycle of nuclear facilities is essential for the establishment of legal tools, regulatory infrastructure, standards, and guidelines. This ensures *inter alia* that decommissioning is considered and planned throughout the life cycle of the facility.

The regulatory infrastructure generally covers the active regulation of decommissioning by requiring its consideration during design, construction, operation, and ultimately the implementation of the decommissioning strategy. All the decommissioning aspects need to be reflected in the authorization and regulatory processes.

The regulatory frameworks in Member States vary significantly and the following types of legislation can be envisaged:

(a) Regulatory framework is fully prescriptive and national legislation fully covers detailed regulation of decommissioning over the lifecycle of a facility. The regulatory framework may prescribe specific decommissioning strategies and development of a decommissioning related waste management infrastructure.

(b) Regulatory framework is prescriptive and requires early planning and progressive evaluation of possible decommissioning strategies with the final strategy being selected and justified by cost-benefit or multi-attribute analysis.

(c) Regulatory framework is performance-based, not prescriptive, and allows the operator to justify a preferred strategy in terms of factors such as safety, cost, social impacts, etc.

(d) The regulatory framework does not address decommissioning *per se*.

The regulatory framework is an important factor in the selection of a decommissioning strategy and the above-mentioned range of regulatory approaches is indicative of the variability that may exist in the selection of decommissioning strategies in Member States. An inadequate regulatory framework in terms of decommissioning may result in a lack of early decommissioning considerations and planning and is therefore undesirable.

2.2.2. Financial resources/cost of strategy

Those who have generated waste are liable for its management and disposal. In order to meet this principle the funding for decommissioning needs to be sufficient, available, transparently managed, and used only for the purpose for which the funding was established. Therefore the costs of constructing and operating disposal or management facilities for waste including spent fuel needs to be addressed either separately from decommissioning itself or, in some cases (particularly where disposal facilities do not yet exist), as part of the overall decommissioning costs. The provision of adequate funds for decommissioning and a funding mechanism forms part of decommissioning planning and is usually obligatory in terms of the regulatory framework. The level of funding is commensurate with the envisaged cost of the selected decommissioning strategy as determined by liability assessment. Insufficient levels of funding are mainly attributable to an insufficient regulatory framework. Inadequate funding creates a major constraint, which may make some decommissioning strategies impracticable.

The cost of decommissioning is an important factor that influences the selection of a decommissioning strategy. The costs of viable decommissioning strategies are compared and considered with other factors for the selection and justification of a decommissioning strategy.

2.2.3. Spent fuel and waste management system

Ideally, spent fuel and waste management systems, including final repositories for all types of waste, will be available at the time of decommissioning. If this is not the case, firm planning for these types of facilities is regarded as a priority with establishment within reasonable timescales. Meanwhile, appropriate solutions for waste processing and interim storage are required to allow for conditioned waste to be safely stored. The discussion and dialogue with all stakeholders (see Section 2.2.6.) will be strongly dependent on the availability of such facilities/plans.

During decommissioning there will be, compared to normal operation of the facilities, large amounts or even new types of waste material. These may exhibit very low levels of activity or could be readily decontaminated to achieve such levels. The amounts and types of waste created during decommissioning will be a factor in the selection of a decommissioning strategy. Radiological criteria and associated activity levels (preferably internationally harmonized guidance [2]) according to which such materials can be released from regulatory control are key factors in assessing the radioactive waste volumes. In general there are several ways of removing material and waste from a facility as follows:

(a) Clearance for unrestricted reuse or disposal;

(b) Authorized release to the environment;

(c) Reuse within the nuclear industry;

(d) Regulated disposal under controlled and monitored conditions.

2.2.4. Health, Safety and Environmental (HSE) Impact

The current and expected deterioration of structures, systems and components, and the radiological characteristics of the facility in question, may constitute a health and safety risk that could have an influence on the selection of the decommissioning strategy.

Comparative radiation and environmental assessments, based on viable decommissioning strategies and associated radiological characteristics, are key inputs to strategy selection. These evaluate the impact in terms of occupational and public exposure and safety hazards associated with the main decommissioning actions as well as environmental impacts. The selected decommissioning strategy is also subjected to review of specific methodologies and techniques in order to optimize protection of the workforce and the public.

2.2.5. Knowledge management and human resources

Knowledge of the status and history of the nuclear facility is essential for successful decommissioning planning, decommissioning strategy selection and execution from both safety and technical points of view. It is desirable to ensure that measures are taken during the entire operational phase to document the physical inventory of equipment, inventory of hazardous material and the radiological inventory.

Ideally the knowledge of the operational staff is utilized during the decommissioning phase. This might not be possible in some cases, typically for deferred dismantling. In such a situation, it is important that the knowledge accumulated by the operator of the facility is transferred to the next generation.

2.2.6. Social impacts and stakeholder involvement

During the planning stage of a decommissioning project the concerns, issues and views of the different stakeholders are taken into consideration. Environmental and social impacts play an essential role in the implementation of any large project. Therefore, to be successful a decommissioning project needs to be open, transparent and clear to all stakeholders.

For each facility, a decision is made on what the preferred end state would be after decommissioning. Different interests (ranging from the owner, the municipality, to the affected neighbors) need to be taken into consideration. The preferred end-state strategies could be to achieve a ‘green field’ situation (unrestricted use) or taking the site to a ‘brown field’ situation (reuse as an industrial facility, e.g. for new energy production). Another situation would be the use of the site for general use (housing, car-parks, etc.). The different end states call for different decommissioning strategies, different discussions with stakeholders and different regulations.

The socio-economic impact can be severe when a large nuclear facility is decommissioned. The impacts can involve factors such as employment rates, the price of housing, tax base, use of land, changes in numbers of visitors, etc. These factors will also have an impact on the public opinion about the project (e.g., the need to re-employ operational staff was a key factor in the selection of the decommissioning strategy for the Greifswald nuclear power plant, see Appendix). The most important factor to gain public acceptance might be through a procedure whereby the proposals, discussions, dialogue and decisions are brought forward in public meetings. An open and transparent process, which involves all stakeholders at a very early stage of the decommissioning project, is increasingly found to be essential.

2.2.7. Suitable technologies and techniques

The availability and use of suitable technology are important parts of decommissioning planning and can influence the selection of a strategy. Site-specific features may demand technology development and adaptation, but in many cases mature technology is commercially available.

2.3. Methodology for selection and justification of a strategy

Selection of a preferred or good decommissioning strategy is best achieved through the evaluation of the influencing factors (some of which are listed in Section 2.2) in terms of their attributes for a specific facility or site. This evaluation can benefit from the use of formal decision-aiding techniques that address the influencing factors and associated good practice indicators. A commonly used technique is discussed in this section. (It should be noted that some factors might create constraints that eliminate specific strategies, as addressed in Section 3).

Many aspects have to be addressed, the challenge being to achieve the optimal solution in a logical, structured and justified way. In general, there is a growing feeling that the quality and content of strategy studies require improvements — especially in the treatment of environmental aspects and in the rigor of the process by which a preferred strategy is selected. It is important to ensure that all three basic strategies (Section 2.1) are taken into account and evaluated for the nuclear site as a whole rather than for individual facilities (e.g. for multi-unit sites with one shutdown unit and others remaining in operation). In addition, most national regulators now demand an assessment of possible strategies and a justification of the selected strategy [1].

The process of selecting a decommissioning strategy (sometimes called 'optioneering') typically starts by collecting and assessing available data, by considering all potentially influencing factors such as applicable regulations, waste routes and associated good practice indicators. A set of possible decommissioning options is then devised together with a preliminary decommissioning plan for implementing each option. These plans can be relatively brief at this stage but are sufficiently well defined that the associated major hazards and risks can be visualized.

The next step is to perform strategy selection studies. During this process, formal decision aiding techniques and 'workshop' discussion sessions can be employed, as outlined below.

An example of a formal decision aiding technique is 'Multi-Attribute Utility Analysis' (MUA) [3, 4]. It is an effective and efficient way of showing the impact of each strategy option in terms of good practice attributes, and of reaching conclusions that address all of the influencing factors. Such techniques involve assigning numerical ratings and weightings to the factors, followed by comparison of the resultant total scores for the options. If necessary (i.e., when two options have very close scores), a sensitivity analysis can be performed to check whether or not the preferred option is a robust choice.

It should be noted that strategy selection studies (even when using formal methods such as MUA) involve aspects that are judgmental and subjective, potentially leaving the conclusions open to challenge. Increasingly this problem is being addressed by public involvement (stakeholder dialogue) in the strategy selection process.

Workshop sessions (sometimes called brainstorming sessions or decision conferences) can provide a very practical and motivating way forward. In such sessions a panel of experts (including experienced operators) agrees on the list of influencing factors and then assesses the impact of these factors on each of the decommissioning options, assisted by the use of decision aiding techniques. It is important to produce a report of the workshop sessions, describing the technique adopted, the considerations addressed and the results obtained. This report can be a valuable aid in support of the decommissioning plan and the associated safety justification.

The processes of selecting a preferred decommissioning strategy and the subsequent detailed planning are best approached by ensuring that the planning team clearly understands the underlying safety logic. This logic can be applied to each of the candidate options (at an appropriate level of detail), as part of the process of selecting a preferred option. The key point is to ensure that there is a demonstrated connection between the facility condition at shut down, the proposed decommissioning activities, the associated risks in performing these activities, the resultant safety management arrangements, and costs. For example, analysis of the risks involved logically determines the requirements for such key aspects as additional or modified equipment, staff training, procedures, work instructions, maintenance and security arrangements.

The evaluation of good practice attributes can be case-specific or can vary from one type of facility to another. One possible scheme showing the relationships between the influencing factors noted above and the associated good practice attributes is outlined in Table 1.

Table 1. Decommissioning-related factors and attributes

	Decommissioning factor	**‘Good practice’ attributes**
1	National Policies and Regulatory Framework	– Compliance with the intent of national polices – Compliance with the requirements of the regulatory framework – In the case of insufficient national policies and regulatory framework, compliance with international ‘good practice’
2	Financial Resources/Cost of Implementing a Strategy	– Adequate financial resources or financial security and funding mechanisms available for the funding of viable decommissioning strategies – Both direct and indirect costs (e.g. stakeholder involvement and public acceptance) addressed – Total cost of the viable decommissioning strategies evaluated or compared and strategies selected/eliminated in terms of main cost factors A cost-effective decommissioning strategy identified

	Decommissioning factor	'Good practice' attributes
3	Spent Fuel and Waste Management System	– Waste management system implemented in accordance with national policy and strategy or in accordance with international practice where no national policy or strategy exists· – Operational waste generation control programme in place – Spent fuel and waste management systems approved for decommissioning – Processing and storage/disposal facilities available for spent fuel and all waste streams – No unconditioned waste in storage – Implemented waste generation controls during decommissioning – Cleared waste routes maximized – Waste streams for regulated disposal minimized
4	Health, Safety and Environmental (HSE) impact	– Facility characterized: o Radiologically o Structural integrity o Non-radiological hazards o Industrial safety hazards – HSE impacts of viable decommissioning strategies known and considered in the selection of strategies; HSE impact optimized by reducing exposure of the workforce and the members of the public, and environmental impacts – The need for transportation of radioactive material is minimized

	Decommissioning factor	'Good practice' attributes
5	Knowledge Management and Human Resources	– The following information is available and considered in the selection of a decommissioning strategy: o Operating history of the facility including information on relevant incidents o Identification of all systems and equipment o Integrity of services and facilities o Prevailing radiological characteristics of facilities o Non-radiological and industrial hazards o Source term of facilities o Waste inventories of facilities – Availability of suitably qualified and experienced personnel – Consideration of lessons learned from other decommissioning projects – Reasons for permanent shutdown, if not consistent with the original planning basis (economic, political, accident, etc.) – Consideration of other operating nuclear facilities on site
6	Social Impacts and Stakeholder Involvement	– Social impact of viable decommissioning strategies discussed with stakeholders and considered in a transparent way – All stakeholders involved in the selection of a decommissioning strategy and reasonable consensus reached – Site and facility reuse options, requirements and demands considered in the development of viable strategies
7	Suitable technologies and techniques	– Necessary technologies and techniques available and adapted to suit selected strategy

3. STRATEGIC CONSIDERATION IN CASE OF SPECIFIC CONSTRAINTS AND CONDITIONS

3.1. Introduction

The choice of strategy is influenced by numerous factors. These factors have varying levels of importance and have to be considered in the selection of strategies.

Based on available information and the experience from completed projects, it is usually a straightforward procedure to establish the decommissioning strategy, taking into account the factors mentioned in the previous sections.

In some cases the real situation is much more unclear, e.g. there is a lack of money or there is no waste repository available in the near future. Obviously, in such a case, a severe constraint on the choice of strategy exists and in reality determines the choice of strategy. In other cases, e.g. if a country has a very limited nuclear programme or only research and development activities or medical installations, the infrastructure for decommissioning and the resources needed may not be available. It is also clear that the importance of such issues is dependent on the type of facility, e.g. a nuclear power plant (NPP) is quite different from a medical installation. The Appendix provides illustrations of how decommissioning strategies have been selected in the presence of significant constraints.

Looking at the present and future worldwide decommissioning activities, some important constraints and conditions that influence the strategy selection are:

- Available funds are inadequate;
- Legal and regulatory framework is limited or inadequate;
- Spent fuel and waste management systems are inadequate;
- Lack of education in the nuclear field;
- Demand for reuse of facility or site;
- Specific issues in case of small nuclear programmes and limited resources; and
- Influence of local economy and social issues.

The impact of these constraints and conditions will clearly vary when considered for the different types of facilities e.g. NPPs, research reactors, fuel cycle facilities and medical, industrial and other small facilities.

The following subsections consider the impact of these constraints, conditions and types of facility on the three fundamental decommissioning strategies (Section 2.1).

3.2. Available funds are inadequate

3.2.1. Description and credibility of the constraint

Having inadequate decommissioning funds for a large commercial NPP may be due to lack of a legal framework, early shutdown (so that insufficient funds may have been raised), devaluation of funds, their diversion for other purposes, etc.

In the case of fuel cycle facilities, research reactors and small facilities, lack of funding for decommissioning may easily occur if not enforced by a legal framework, since decommissioning fund raising is mostly associated with commercial energy production.

Regarding decommissioning of a research reactor/small facility as compared to a NPP, funding may be obtained from other sources (laboratory/university budgets, private owner funds, etc.).

In case funds are not adequate or are missing, in a regulated market government-owned facilities may receive adequate funding from the state budget. This would not be available in the case of a private facility. However, the legislative framework in the context of a deregulated market (e.g. electricity generation, isotope production, etc.) may impose restrictions on government aid, resulting in a constraint even in the case of government-owned facilities.

3.2.2. Impact on decommissioning strategies

Independently of the type of facility in question, inadequate funding limits the possibilities for decommissioning.

For government-owned facilities, funding of decommissioning activities may come from the annual government budget, under the condition that financial security to complete decommissioning can be provided. The rate at which this funding is made available may be a constraint on the rate of work that can be achieved, regardless of the choice of strategy.

3.2.2.1. Immediate dismantling

The immediate dismantling strategy imposes the largest requirements for available funds in the short term, and therefore this strategy is most likely to be negatively impacted by inadequate funding.

3.2.2.2. Entombment

Inadequate funding may also preclude or impact entombment, even if regulatory authorities accept this strategy.

3.2.2.3. Deferred dismantling

Inadequate funding generally leads to deferred dismantling by default. Transition from operation and preparation for safe enclosure; however, demands immediate financing. For the safe enclosure period, maintenance and surveillance require continuous funding. The total cost of deferred dismantling is usually comparable to immediate dismantling, but the immediate cash flow requirements may be less, because the majority of the costs have been deferred to a future date. The net present value requirements are also reduced due to the effects of discounting.

3.2.3. Key issues and possible actions

When funds are inadequate, deferred dismantling is the more likely strategy, in which case the following actions may be considered:

- Decisions are made on the collection and build-up of the funds necessary for ultimate implementing of the decommissioning plan.

- The possibility of getting financial support for decommissioning from international financial organizations (e.g. World Bank) may be explored. In such a case, technical and management support from the IAEA may be an important prerequisite to such financial aid.

- Depending on the type of facility, transition from operation to deferred dismantling and preparations for the deferred period will be planned according to regulatory requirements consistent with IAEA recommendations [5–7].

- A cost estimate of the transition from operation, preparation for deferred dismantling, and deferred dismantling itself, is important. Depending on site characteristics and surrounding population and activities, decontamination, partial dismantling, reduction of hazards and/or remediation actions may be needed, and management of the waste generated will be planned and added to the costs.

- During the deferred dismantling phase, a surveillance and maintenance programme will be put in place. A safety assessment is required to ensure acceptable public and occupational exposure levels.

- Stakeholder involvement is important to address relevant issues and concerns, and is an increasingly important part of the decision-making process.

3.3. Legislative and regulatory framework is limited or inadequate

3.3.1. Description and credibility of the constraint

Some Member States have a well-developed legal framework on decommissioning. Inadequate legal and regulatory frameworks addressing decommissioning activities may be found in Member States where no facilities using radioactive material have been decommissioned yet. In some instances, small facilities are inadequately covered in existing legal frameworks with regard to decommissioning.

When no actual decommissioning experience has been gained in a country, the regulatory framework on decommissioning may be restricted to general considerations, similar to those in Article 26 of the Joint Convention [8].

The legal and/or regulatory framework may become obsolete during the operational phase of the facility, mainly due to international developments. There is a worldwide tendency towards stricter regulations. A logical evolution of regulations occurs once the need for decommissioning has been established in a Member State, and international guidelines and experience are consulted.

Criteria for clearance of material and release of sites may be lacking in some Member States, and more restrictive application of regulations is to be expected in the future.

3.3.2. Impact on decommissioning strategies

3.3.2.1. Immediate dismantling

Immediate dismantling, if possible, may be the preferable strategy. However, when the legal and/or regulatory framework is inadequate, immediate dismantling may face important delays, due to the need by the regulatory bodies for establishing regulations covering all the phases of decommissioning. For example if regulations on clearance of material are not available initial cost estimates may be incorrect.

3.3.2.2. Entombment

Entombment requires a robust regulatory/legal framework. The lack of international experience on entombment and its regulatory complexity may make this strategy the least desirable to Member States having an inadequate legal and/or regulatory framework.

3.3.2.3. Deferred dismantling

An inadequate legal and/or regulatory framework may force a deferred dismantling strategy. However, this option requires that regulatory requirements for the safe enclosure phase be established at the outset.

3.3.3. Key issues and possible actions

When the legal and regulatory framework is inadequate, immediate dismantling in compliance with international practice may be chosen as a strategy. Deferred dismantling may also be an option under these circumstances, while entombment may be less favorable. In the case where the regulatory/legal framework is inadequate the following actions may be considered:

- Backup or alternative solutions may be needed in order to limit the impact of changes in legislation and regulations. This is particularly important in the case of deferred dismantling, as during the deferral period these changes are most likely to occur.

- Delaying any tendering or contracting process until all relevant licensing requirements and criteria exist. Contracts may include flexibility in the case of changes in regulations.

- The regulatory body may be developing the licensing approach as the project advances; early discussion and resolution of issues will help the regulator and will expedite the project.

- Promoting public involvement in defining and developing the project and the regulatory framework. Stakeholder involvement is desirable in the decision-making process at an early stage.

- The IAEA may be a reliable source of international experience on typical regulatory frameworks that might be enforced for decommissioning purposes.

3.4. Spent fuel and waste management systems are inadequate

3.4.1. Description and credibility of the constraint

It is assumed that no storage/disposal facilities are available for decommissioning waste or spent fuel, and that they will not be available during the period of transition from operation to decommissioning.

As the facility to be decommissioned has been operational, it is assumed that on-site storage of operational waste has been available until final shutdown. No assumption is made on the capacity for storing radioactive waste arising from the transition phase. For the same reason, in the case of power or research reactors it is assumed that some on-site storage facility for spent fuel is available. It is also assumed that the spent fuel storage facility has room for the fuel that is still in the reactor core.

Even Member States having well-established waste management systems may have difficulties accommodating the large waste quantities and new waste types associated with decommissioning. Large quantities of slightly contaminated waste may be generated (e.g. building rubble), which may require an ad-hoc authorized disposal route.

Nuclear programmes that started as early as the 1950's were later either discontinued or reduced in scope and in some cases neither spent fuel storage/disposal facilities nor waste management systems were established to deal with decommissioning waste.

In the case of small facilities, it may be that a waste management system to deal with the usually small volumes of operational waste is in place. Once the facility is permanently shutdown, it may happen that this system is unable to deal with much larger amounts of decommissioning waste, especially if there has been widespread contamination of equipment or buildings.

3.4.2. Impact on decommissioning strategies

3.4.2.1. Immediate dismantling

When no adequate decommissioning waste management system is in place, immediate dismantling may not be possible unless waste storage is established.

3.4.2.2. Entombment

Entombment, that is transforming the facility into an on-site radioactive waste repository for disposal of radioactive materials, may be chosen as a strategy if waste management systems are inadequate.

3.4.2.3. Deferred dismantling

In most cases, deferred dismantling will be the adopted strategy when there is no decommissioning waste management system in place.

3.4.3. Key issues and possible actions

The following actions may be considered in the case of entombment:

- The activity concentration of long-lived alpha radionuclides needs to be considered with regards to the suitability of such waste to be disposed in a near surface configuration [9].
- Public consultation in order to obtain acceptance for a waste repository.

The following actions may be considered in the case of deferred dismantling:

- Development of a waste management system.
- Enlargement of the on-site capacity for operational waste storage in preparation for deferred dismantling.

3.5. Lack of education in the nuclear field

3.5.1. Description and credibility of the constraint

The numbers of trained nuclear engineers and nuclear technology/safety specialists have declined in many Member States.

The ‘lack of skill’ scenario is realistic. There are many reasons why a Member State, while still having nuclear facilities, may have discontinued formal training in nuclear technology and safety. Reasons include the following:

- Lack of interest in these subjects.
- Discontinuation of nuclear activities due to economic or political reasons.
- Absence of indigenous capability to teach these subjects.
- Discontinuation of training abroad in nuclear technology and safety, due to economic or political reasons.

3.5.2. Impact on decommissioning strategies

3.5.2.1. Immediate dismantling

To take advantage of the existing knowledge and human resources immediate dismantling is the preferred strategy.

3.5.2.2. Entombment

Entombment is a strategy that requires technical and safety expertise. However, under the assumed scenario, entombment might be feasible if the following conditions are met:

- Shortage of skilled workers can be compensated for by using the operations personnel;
- Participation of foreign organizations in entombment planning, execution and management can be obtained, as well as IAEA assistance. Responsibility for post-entombment continuing oversight remains of course to the Member State.

3.5.2.3. Deferred dismantling

Deferred dismantling is not preferred in this case, as the number of trained staff will likely decrease in the future.

3.5.3. Key issues and possible actions

In terms of human resources the following actions may be considered:

- Maximize the use of operational staff;
- Ensure participation of foreign organizations in decommissioning planning and management;

- Take action to reduce the radiation levels at the facility (e.g. decontamination, removal of active components) as soon as possible after shutdown;
- Update and preserve technical information on the design and operation of the facility;
- Effect radiological characterization of the facility using operational experience and facility history;
- Assign responsibility for completion of decommissioning.

3.6. Demand for reuse of facility or site

3.6.1. Description and credibility of the condition

Specific demands on the reuse of the site pose a realistic scenario, which might be a result of the following:

- Shortage of possible sites in Member States (e.g. due to public opposition against new sites);
- Use of a licensed site for a new facility may simplify regulatory and legal procedures;
- Reuse of the site may compensate for the negative socio-economic impact of the facility being shut down;
- Some systems and utilities of the old facility may be reused in a new one;
- Reactor buildings, workshops or laboratories may be required for non-nuclear activities.

3.6.2. Impact on decommissioning strategies

3.6.2.1. Immediate dismantling

Immediate dismantling is the logical strategy when the site is to be reused.

3.6.2.2. Entombment

Reuse of the site is generally not compatible with entombment.

3.6.2.3. Deferred dismantling

Reuse of the site is generally not compatible with deferred dismantling.

3.6.3. Key issues and possible actions

The only viable strategy in the case of reuse demand is generally immediate dismantling, in which case the following may be considered:

- Actions and criteria to release material, structures and the site to allow for eventual reuse of the site for either nuclear or non-nuclear purposes;
- The possibility of interference between the construction of the new facility and the dismantling and demolition of the old one is important to consider.

3.7. Specific issues in case of small nuclear programmes and limited resources

3.7.1. Description and credibility of the condition

A situation may exist where a Member State has a small nuclear programme, and limited human, technical and economic resources. This scenario may also be associated with inadequate funding for decommissioning and/or inadequate waste management systems. A further complicating factor may be that the facility is operated by a private owner that eventually leaves business (or goes bankrupt) and abandons the site.

3.7.2. Impact on decommissioning strategies

3.7.2.1. Immediate dismantling

Under the assumed conditions, immediate dismantling is the preferred strategy, as in this case no legacy is left for future generations.

3.7.2.2. Entombment

Entombment does not seem to be a realistic alternative under these conditions.

3.7.2.3. Deferred dismantling

Deferred dismantling may be forced by the prevailing circumstances.

3.7.3. Key issues and possible actions

In the case of small programmes and limited resources the following may be considered:

- International involvement and cooperation will be useful, in order to provide support in defining an adequate decommissioning strategy, planning to obtain resources and eventually performing transition and decommissioning tasks;
- Under these circumstances, immediate dismantling is the preferred strategy.

In the case of small facilities the number of people with knowledge of the facility is limited. It is crucial in this case to maximize the utilization of existing operational personnel to get the facility into a safe state and to provide essential information for decommissioning.

3.8. Influence on local economy and social issues

3.8.1. Description and credibility of the condition

Impact on local economy and unemployment are the key factors considered in this section.

The impact on the local economy of decommissioning of a large nuclear facility will be more acute if no other large nuclear facilities remain operational on the site. This impact can be significant when the site is isolated or in an area of depressed economic activity. Political/economic pressures may call for reuse of the site. On the other hand, the impact on local economy of decommissioning of a research reactor or small facility will be generally insignificant, as its personnel are numerically small.

The impact on the local economy may affect many stakeholders and covers many aspects such as employment rates, tax base, cost of housing, number of visitors, etc.

Member States with limited nuclear activities may expect a more severe impact of facility closure, as relocation of personnel within the nuclear realm will be less practicable.

A recent publication on financial aspects of decommissioning contains more detailed information on socio-economic impacts of decommissioning [10].

3.8.2. Impact on decommissioning strategies

3.8.2.1. Immediate dismantling

When the impact on local economy and employment is an important issue, immediate dismantling might be the preferred decommissioning strategy. This strategy may result in the opportunity to remedy the negative social effects while continuing to stimulate the local economy and provide employment for the local work force. Later on, the opportunity for reuse of the site may create long-term positive socio-economic impacts.

3.8.2.2. Entombment

With respect to impact on the local economy and employment, most of what has been said regarding immediate dismantling can be equally applied to entombment.

The main difference with entombment is that the site becomes a radioactive waste repository. This implies that a reduced work force will remain on site, with some long-term positive effect on the local economy. However, reuse of the site for other purposes becomes less likely.

3.8.2.3. Deferred dismantling

In the transition phase between operation and safe enclosure, the differences in the socio-economic effect on the economy between immediate and deferred dismantling are less pronounced. However, during the safe enclosure phase only a small number of personnel will remain on site for maintenance and surveillance. If spent fuel remains stored on site, operation of the facility and safeguards will also imply some kind of activity, e.g. during inspections.

3.8.3. Key issues and possible actions

The following may be considered in regards to socio-economic impacts:

- Involvement of the different stakeholders is the key point for the identification and management of social issues. Social issues need to be considered in decision-making and incorporated into decommissioning planning. Local economy and social factors become more relevant when the facility is one of the major employers in the area.

- Local economy and social issues may also play an important role in defining the decommissioning objective and strategy.

- Socio-economic impacts associated with decommissioning of a facility are site and region specific. It is difficult to predict which strategy will have the minimum impact. An evaluation of the socio-economic impact of each of the viable decommissioning strategies is an important consideration in strategy selection. If unemployment of the NPP personnel is an important issue, the decommissioning work may be a way of smoothing its negative effects, regardless of the decided strategy. This approach will usually require a culture change from operations to decommissioning which may be accomplished with extensive training and incentives. International examples exist where re-employment of the operational staff was a key factor in deciding for immediate dismantling (e.g. Greifswald NPP, Germany) [11].

- Public involvement through discussions, public meetings, and open dialogue is essential and may improve public acceptance of the adopted strategy.

4. CONCLUSIONS AND RECOMMENDATIONS

The following general conclusions may be drawn from the evaluation:

- All the identified major factors influence decommissioning strategies to a greater or lesser extent. The selection of a decommissioning strategy needs to be based on the evaluation of all relevant factors. Techniques may be used such as multi-attribute analyses that would consider all the relevant factors, constraints and conditions, their interactions and weights to select the appropriate strategy. Other conditions and constraints may exist, which are not dealt with in this report, and are important to include in site specific evaluations.

- The constraints associated with funds, the waste management system and human resources could limit the strategies for decommissioning to deferred dismantling independent of other factors. If this is the case, decommissioning strategies that are not necessarily 'good practices' may be forced.

- Deferred dismantling caused by the above-mentioned overwhelming constraints is generally attributable to lack of decommissioning planning which is in turn due to insufficient legal or regulatory framework. Authorization of facilities that use radioactive material needs to include decommissioning considerations from the design phase to operational and shut down phases.

- When the forced decommissioning strategy is deferred dismantling, the problems associated with decommissioning are only delayed and in some cases exacerbated.

- Legal and regulatory infrastructures related to decommissioning need to be established as soon as practicable.

- When constraints occur, management has to proactively take steps to remove the constraints or, if that is not possible, to eliminate or minimize their impacts.

If deferred dismantling is forced due to overwhelming constraints, active retrospective activities are required to cover such items as:

- Essential actions in the transition period to render the facility 'safe' for the extended storage period;

- Management of the deferred dismantling phase;

- Interim management of waste and spent fuel;

- Updating and preservation of the facility history and technical information on radiological surveillance, design and operation;

- Programmes to ensure planning and execution of final decommissioning.

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APPENDIX I.

EXAMPLES OF PRACTICAL EXPERIENCE

I.1. INTRODUCTION

In practice it is often found that a decommissioning strategy for a particular facility has to be selected in the context of a very complex set of influencing factors — as discussed in this report. Furthermore, the nature of this complexity tends to evolve with time, such that adjustments have to be made to the selected strategy or to important aspects of its implementation.

In many cases, the basic lesson learned is that if the initial strategy has been well chosen (taking comprehensive account of all relevant issues), then it can be adapted to deal with changing circumstances. Sometimes, it has even been possible to adapt a strategy to deal with a potentially severe constraint.

The following examples are set out as case studies, enabling the reader to appreciate the overall context in which the decommissioning strategy was selected and to understand why particular measures were taken when implementing the strategy. Key aspects from these case studies are summarized below.

I.2. DECOMMISSIONING STRATEGIES FOR THE KOREAN RESEARCH REACTORS KRR-1 AND KRR-2

The initial pressure was for immediate dismantling (the reactor site had already been sold for other uses). Then it became apparent that the problem of sanctioning a national waste repository was not likely to be resolved in the short term, so it seemed that the strategy would have to be changed to deferred dismantling (safe enclosure). This approach also allowed time for the development of some necessary technologies.

Some time after the decommissioning project had commenced (based on deferral), an operational date for a waste repository was established. This created an opportunity to revise the decommissioning strategy further, leading to a way forward that was somewhere between immediate and deferred dismantling.

The solution was to adopt a compromise time frame (2008) for the completion of the decommissioning project. This compromise offered the possibility of completion in the shortest practicable time consistent with the need to reuse the site, the expected earliest availability of a waste repository and the need to ensure that enough time was still available for the required technology developments. In addition, the project team had to deal with a lack of facility history and records, together with a lack of staff having experience operating these reactors.

I.2.1. Introduction

I.2.1.1. Site

Both Korean research reactors #1 and #2 are located at Gongnung-dong, Seoul. The site was formerly used by the Korea Atomic Energy Research Institute (KAERI) before it was sold to the Korea Electric Power Corporation (KEPCO). The total area of the site is 48 000 m^2 and the buildings occupy 7800 m^2.

I.2.1.2. Main characteristics of the reactors

The construction of the first research reactor, Korean Research Reactor #1 (KRR-1) was started in July 1959 and the reactor became critical on March 19, 1962. The KRR-1 was a TRIGA Mark II type and had an open pool and a fixed core. The reactor was utilized for the education and training of the students of nuclear engineering and basic tests on nuclear characteristics. It had been operated for 36 000 hours until it was shut down on January 1995. The total energy generation during the operation was 3700 MWh and the maximum neutron flux was $1x10^{13}$ n/cm^2 sec. The fuel was 20% enriched uranium in a chemical form of Zr-UH.

Korean Research Reactor #2 (KRR-2) came into operation in 1972 and enabled research on nuclear characteristics, radioisotope production and production of labeled compounds for medical applications. It generated a total energy of 69 000 MWh during the 55 000 hours operation till it was shut down in 1995 at the same time as KRR-1. It was a TRIGA MARK-III type with an open pool and a movable core. The fuel was 70 % enriched uranium in a chemical form of Zr-UH. Water was used as a moderator, coolant and reflector, (whereas graphite was used as a reflector for KRR-1).

I.2.2. Decommissioning projects

I.2.2.1. Reasons for decommissioning

In 1996, it was concluded that KRR-1 and KKR-2 would be shut down and dismantled. The main reason for decommissioning was that the condition of the facilities had deteriorated and the relevant regulations had become stricter. The surrounding areas became urbanized and the number of inhabitants had rapidly increased near the reactor site. Furthermore, high cost was expected for the modification and restart of the operation. Another reason was the start of the operation of a new research reactor, HANARO, which is located at the Daejeon site. It was expected that the new reactor could satisfy all the domestic needs of research reactor utilization in Korea for a long time.

I.2.2.2. Decommissioning plan

A project was launched for the decommissioning of the reactors in January 1997 with the goal of completion by 2008. The project was divided into 5 steps namely:

(1) Preparation (Jan. 1997–Dec. 2000): establishment of the decommissioning strategies, engineering, preparation of detailed procedures, and licensing;

(2) Dismantling of the auxiliary facilities of the KRR-2 (Jan. 2001–Dec. 2002): dismantling the laboratories, lead hot cells and concrete hot cells of the KRR-2;

(3) Dismantling of the reactor hall of the KRR-2 (Jan. 2003–Dec. 2004): dismantling of the internals in the pool including the core, and bio-shielding concrete;

(4) Dismantling of the KRR-1 (Jan. 2005–Dec. 2007);

(5) Final evaluation of the residual radioactivity and de-licensing (2008).

I.2.2.3. Strategies for decommissioning

The following strategies were decided upon at the beginning of the preparation phase:

(1) Dismantling time: immediately after the licensing;

(2) Final state of the site: clearance of the site and buildings after the removal of all the radioactive material;

(3) Waste: minimization of the radioactive waste, which will be packed into 200-liter drums and 4 m^3 containers and temporarily stored at the site until transportation to the national repository facility in 2008;

(4) Technologies: development of the technologies directly required for the dismantling of the KRR-1 and -2 during the project, and for any future demands in connection with the project;

(5) Preparation of the next projects: participation of private companies for a joint development and technology transfer.

I.2.3. Factors influencing the strategic decision

I.2.3.1. Legal conditions

Under the Atomic Energy Act (concerning the decommissioning of power reactors and related facilities) and the Enforcement Regulations (concerning the application for approval of the decommissioning), the licensee for an operation, with an intention to decommission a power reactor, should submit a decommissioning plan and obtain approval from the Ministry of Science and Technology (MOST). The provisions for the decommissioning of power reactors were extended to research reactors.

The Act also determined that a decommissioning plan should include the following:

(1) Methods for the dismantling of power reactors and associated facilities, and a work schedule;

(2) Methods for the removal of the radioactive material and for decontamination;

(3) Radioactive waste treatment and disposal;

(4) Necessary counter measures against radioactive hazards;

(5) Assessment of the environmental impacts and the measures for their minimization;

(6) Quality assurance programme.

Detailed standards and guidance were not defined in the Act and its Enforcement Regulations, but internal guidance from the Korea Institute of Nuclear Safety (KINS) was issued for the safety evaluation of the decommissioning plans of the research reactors and fuel cycle facilities. The Act and the internal guidance from the KINS defined only the procedures and safety requirements, not the criteria or the methods for the selection of the decommissioning strategies. The implementer was expected to choose the optimum strategy and technologies, and ensure safety of the selected strategy. This means that the legal system does not have any influence on the selection of the strategies for the decommissioning of the research reactors.

I.2.3.2. Funding

The Korean Research Reactors #1 and #2 were constructed and operated by KAERI, funded by the Korea government. The government provided all the financial resources for the construction and operation of the research reactors. KAERI obtained approval on a master plan from the MOST and started a project for the decommissioning of the research reactors. According to the project plan, the government guaranteed all the decommissioning funds, including waste disposal and research and development. This financial support was also expected if deferred dismantling was selected. Thus funding was not an important factor in the selection of the decommissioning strategies.

I.2.3.3. Waste management system

The total amount of the radioactive waste, to be generated during the decommissioning of the research reactors was estimated at 168 m^3 from the KRR-1 and 453 m^3 from the KRR-2. The radioactive material could be classified into activated material and those contaminated by ^{60}Co and ^{137}Cs. All the spent fuel was returned to the United States, the country of origin. Most of the contaminated material was expected to be decontaminated by chemical or physical-chemical methods to clearance levels.

At the initial stage of strategy development and before the commencement of detailed engineering, all the waste management systems, including the storage facilities, were moved to the Daejeon site from the Seoul site where the reactors were located. The transportation of the radioactive waste to the Daejeon site required funding. By law, public consultation was not required since the Daejeon site is an institute and not a waste repository. Since the plan for the construction of a repository facility by the Korea Hydraulic and Nuclear Power Company (KHNP) was not clear at that time, a deferred dismantling strategy seemed the preferred strategy. The research reactors could be safely enclosed for several years until the plan for disposal of the waste could be established. The target date of 2008 for an operational waste repository was established after the decommissioning project commenced.

I.2.3.4. Reuse of the site and buildings

The site on which the reactors operated was already sold in 1985 to KEPCO. The section of the site and facilities of the research reactors were leased to the KAERI. A contract required that the site be returned as soon as possible after decommissioning and the removal of all the radioactive material. KEPCO planned to use the entire site as a training centre for its staff and had already started to use the remainder of site before the commencement of the decommissioning project. Under these conditions an immediate dismantling strategy seemed essential. The transfer of all the radioactive waste was not possible before 2007 and the project was prolonged for the development of the technologies for decommissioning and the minimization of radioactive waste. The target date of 2008 was finalized for the completion of the decommissioning project and the return of the site.

I.2.3.5. Local economy and social issues

The research reactors were located in Seoul, whose economic scale was too large to be influenced by the decommissioning project of small research reactors. The annual budget for the decommissioning was also very small, when compared with the total research and development budget of KAERI. KAERI had the funds to perform the decommissioning project. The project was not expected to impact significantly on the local economy. Funding was therefore not a factor in the selection of a decommissioning strategy.

According to the KEPCO plan, many trainees whose qualifications were not nuclear science and/or engineering were expected around the decommissioning site. The surrounding areas also became urbanized with high population density. Generally Koreans are opposed to nuclear facilities close to their houses, especially if they appear to be in an uncontrolled state. The strategy of deferred dismantling was expected to be less acceptable to the inhabitants around the site than immediate dismantling even if stretched over a somewhat longer period.

I.2.3.6. Human resources

Even though the same worldwide trend of a decreasing number of students in the nuclear engineering departments of universities had also appeared in Korea, the nuclear industries remained proactive. It was expected that more than 23 nuclear power plants would be operated in the near future in Korea and nuclear fuel cycle facilities such as fuel fabrication plants would continue their operations according to the nuclear power production. Research and development in nuclear science was also stipulated by a long and medium term plan, funded by the government at a fraction of the electricity fee. Thus a lack of suitably qualified human resources was not expected in the future, especially during the decommissioning of the research reactors and even in the case of deferred dismantling for several tens of years.

After the shut down of the KRR-1 and -2, most of the operational staff of the reactors and the auxiliary facilities such as the hot cells, moved to the Daejeon site for the operation of the new research reactor and some of them retired. No staff with experience in the reactor operations were part of the decommissioning project team except for some retired manpower that were utilized on a contract basis.

A major problem was the lack of facility history and records. For example, there were many items with a high radioactivity in the concrete hot cells, but there were no records of them. Before dismantling, each item in the hot cells had to be identified and operational experience helped to reduce the cost and time required for the identification. For deferred dismantling, detailed documents on the status of the facilities are to be prepared on the basis of the operator’s experience and preserved for later dismantling. This preparation of the documents would require additional funding.

I.2.3.7. Others

In 1997 when the decommissioning project of the research reactors was started, there was no expertise, technologies and experience on decommissioning in Korea. The options for the execution of the project were to use a foreign company with its technologies or to develop technologies within KAERI. It was decided that in house development of technologies would be desirable to prepare for future decommissioning of the many research facilities, fuel manufacturing facilities, power reactors and small facilities for medical uses at KAERI.

A timely supply of the necessary technologies seemed to furnish a key for the success of the project. Many technologies were required even at the planning stage for which limited development time existed. A longer transition period was required to allow for the development of the required technology.

I.2.4. Decision on the strategies

Some major factors that impacted on the selection of a decommissioning strategy and planning are summarized in the table below and discussed from the viewpoint of their strengths and weaknesses. The factors are considered for three categories namely; immediate and deferred dismantling and no influence. Generally it seems that the funding and waste management systems are the most important factors, because in the case of no funding and/or no waste management system, an immediate dismantling strategy is not possible. But for KRR-1 and KRR-2, immediate dismantling was selected because the return of the site was very urgent, deferred dismantling was expected to be difficult from a public acceptance perspective and a national repository facility was expected in the near future (Table A-1).

The selection of the immediate dismantling for KRR -1 and -2 meant that the negative impacts from the lack of a waste management system and the required technologies had to be considered and managed.

Table A-1. Influence of factors on decommissioning strategies for Korean reactors

Factors	Immediate dismantling	Deferred dismantling	No influence
Legal conditions			X
Funding			X
Waste management systems		X	
Reuse of site and buildings	X		
Local economy/social issues	X		
Human resources	X		
Local technology/expertise		X	

For the decommissioning of the KRR -1 and -2, a new waste management system, including classification, decontamination, packing and temporary storage, was established by considering the following requirements.

- Treatment of all the liquid waste by a membrane process and solar evaporation since no discharge of liquid waste was legally possible at the reactor site;
- Decontamination of the solid waste as far as possible by the equipment and technologies developed;
- Classification, storage and packing of the wastes according to their activities and their properties.;
- Temporary storage of the radioactive waste in the reactor hall of the KRR #2 after being packed in 200-litre drums and $4m^3$ containers until transportation to the national repository facility is possible.

A foreign company was contracted for the development of technologies required at an early stage of planning of the decommissioning project. It was however decided that the technologies required for the decommissioning of the hot cells and reactors would be developed in house. The lack of the technologies can be overcome, but the decommissioning period has to be extended to over 10 years.

I.2.5. Conclusions

Some major factors that played important roles on the decision of the decommissioning strategy for the KRR -1 and -2 were discussed. Two factors, funding and legal conditions, did not have any significant influence on the strategy selection. Factors like reuse of site/buildings, local economy/social issues and human resources supported an immediate dismantling strategy. The lack of a waste management system and technological factors did not support an immediate dismantling strategy but their negative impact seemed to be surmountable by the implementation of specific counter measures.

I.3. Kozloduy Nuclear Power Plant decommissioning case study—selection and updating of the decommissioning strategy

I.3.1. General

Kozloduy Nuclear Power Plant (NPP) is the only Bulgarian NPP. It was constructed in three stages and until 2002 six power units generated 3760 MWe total capacity. Units 1–4 are the WWER-440/V-230 model, the Russian-design equivalent of a PWR. Units 5 and 6 are the WWER-1000 type.

The first feasibility study showed that both immediate decommissioning and deferred dismantling were viable strategies. However it was soon realized that more detailed work would be needed, in order to confirm the best solution (including undertaking a material inventory and cost estimates). A second study was therefore undertaken, addressing immediate decommissioning, entombment and three variants of deferred dismantling.

Account had to be taken of some very significant influencing factors (i.e., no specific regulations dealing with decommissioning; no specific mechanisms had been in place for the collection of decommissioning funds and the agreement to ship spent fuel back to the country of origin had been suspended). In addition, the socio-economic and cultural situation was rapidly evolving. There was also a technical consideration, in which the reactors at the NPP were due to reach the ends of their design lives at different times – and they shared some key systems.

The resulting conclusion was that dismantling of the radioactive parts of the NPP should be deferred for 70 years. However, an agreement was later reached with the European Commission concerning early shut down and decommissioning at Kozloduy. The deferral strategy was therefore reviewed; leading to a revised solution in which the deferral period was shortened from 70 to 35 years.

I.3.1.1. Description of WWER-440 units

The WWER-440 reactors are a Russian (former Soviet Union) design. They are water-cooled, water-moderated with boron control of the reactivity. The thermal output is 1350 MWt and the electrical output is 440 MWe.

The primary coolant system consists of 6 loops with horizontal steam generators and main isolation valves. Each reactor has two turbine-generators with a capacity of 220 MWe. The units are of so called ‘twin’ type with a lot of common systems, and also systems common to all four units. Units 5 and 6 are completely separate with only few exceptions.

I.3.1.2. History of the WWER-440 units

Units 1 and 2 were put into commercial operation in 1974 and 1975 respectively. After successful operation, both units were finally shut down at the end of 2002, following a government decision. They were shut down during the 23rd fuel cycle for Unit 1 and the 24th for Unit 2. During this entire operational time, only one event with significant radiological impact occurred, namely the rupture of one fuel assembly during the first refueling outage of unit 1.

Units 3 and 4 were commissioned in 1980 and 1982 respectively. They are in operation in the 20th and 19th fuel cycle, respectively.

I.3.2. Decommissioning studies

I.3.2.1. Feasibility studies

The first feasibility study was performed in 1993-94 by a US company. The aim of the study was to define possible strategies for decommissioning Units 1 and 2, based on the existing experience and knowledge. The main outcome of the study from a technical viewpoint was confirmation of the acceptability of both immediate dismantling and deferred dismantling. The choice of a particular scenario should be through the consideration of other factors – funds, radioactive waste management programme, etc.

I.3.2.2. Cost estimation

During the period 1994-95, a comprehensive study was performed by a Bulgarian company in close cooperation with its affiliates in Russia and Slovak Republic. The study aimed at making a precise material inventory of the units and also to make a preliminary cost estimation of their decommissioning. The results have been compared with the similar studies in countries operating WWER-440 reactors and good correlations have been noted. The overall results are presented in [A-1].

I.3.2.3. Comparative study of different strategies

A study was performed in 1996 that compared five different strategies:

- Immediate dismantling;
- Entombment;
- Deferred dismantling with the following variants:
  - Deferred dismantling of the entire facility;
  - Deferred dismantling of the radioactive objects;
  - Deferred dismantling of the reactor cavity.

The strategy of deferred dismantling of the radioactive objects was recommended as most relevant to the current situation.

I.3.3. Selection of strategy

The following were identified as factors that would impact on the selection a decommissioning strategy:

I.3.3.1. Regulatory framework

In this period only general provisions existed in the Nuclear Law [A-2] in force. No specific regulations with regards to decommissioning existed and only radioactive waste management was addressed to some extent.

I.3.3.2. Funding

Taking into account the fact that the plant was unconditionally state owned up to the early 1990s, no specific provisions were made for establishing the mechanism for the collection of decommissioning funds. It was assumed that the State would provide decommissioning funds as and when needed. Only in 1995, through an amendment of the Nuclear Law, was the National Decommissioning Fund established. However, the fund really began functioning in 2000 after governmental approval of the specific regulation and administration of the fund. Since the beginning, a relatively high rate for payments by the nuclear operators has been set at 8% of the income from selling electricity. Later, the rate was increased even further.

I.3.3.3. Spent fuel and radioactive waste management

I-3.3.3.1. Spent fuel

Since the beginning of NPP operation, a clause existed for shipping all the spent fuel back to the former Soviet Union free of charge. This clause remained in force until the late 1980s. Following the political and economical changes in both countries and in particular the collapse of Soviet Union, Russia suspended the agreement. In the meantime, an on-site interim storage facility was constructed and put into operation with a conditional and limited license by the Bulgarian Nuclear Regulatory Authority (BNRA). The full license was issued in 2001.

The facility is a pool type for underwater storage with limited capacity, which is why steps have been taken for the construction of a new facility for the dry storage of spent fuel. For various reasons, the procurement process was delayed and the dry storage facility is now expected to be operational in 2009.

I-3.3.3.2. Radioactive waste

Currently, a super-compactor is in operation along with a process for liquid waste cementation. An on-site interim waste storage facility was constructed. These were placed in operation in the period 2001–2003. The interim storage capacity is based only on operational waste.

A preliminary study for site selection for a near surface repository for low and intermediate level waste was completed in 2003.

I.3.3.4. Human resources

Taking in account that Kozloduy NPP is a multi-unit plant with the expected operation of the last units until 2030-2035, it was considered that personnel with specific nuclear knowledge and skills would be available at the start of dismantling activities.

I.3.3.5. Social impact

Due to the above reasons (see A-3.3.4 above) it was initially considered that the negative impact on the personnel and the region would be minimal. But it was soon realized that this consideration had to be revised due to the rapid change of the economical situation in the country in general, and in the region in particular. The high rate of unemployment and very low amount of functioning industry requires the implementation of special measures. The first step was to establish the Center for Regional Development in cooperation with institutions of the United Kingdom.

I.3.3.6. Others

Some specific features of the Kozloduy NPP site having impact on the decommissioning were considered. The major one is the existence of six power units with significant differences in design life. Considering the full 30 calendar years, the end of design life for Units 1 and 2 is 2004–2005 and for Units 3 and 4 it is 2010–2012. This fact, as well as complexity and commonality of systems for all units, makes the strategy of immediate dismantling of Units 1 and 2 difficult.

Based on an evaluation of the above factors, a 70 year deferred dismantling period of the radioactive parts of the units was selected.

I.3.4. Strategy development and updating

I.3.4.1. Regulatory development

In the beginning of 2001, BNRA issued a specific regulation (No. 10) on “Safety during decommissioning of nuclear facilities” [A-3]. This regulation defines, in detail, the requirements for maintaining a high level of safety during the implementation of decommissioning activities.

In July 2002 a new Law on Safe Use of Nuclear Energy [A-2] was promulgated and during the following two years the secondary legislation has been updated to reflect the requirements of the new law. In particular, the Regulation on “Issuing Licenses for Safe Use of Nuclear Energy” [A-4] was approved and effective since May 2004. This regulation describes in details the licensing process, including licensing for decommissioning.

The updating of Regulation No. 10 [A-3] is underway.

I.3.4.2. European Union accession process

The 19th of November 1999 was a key date for the decommissioning of Units 1 and 2. On this date an agreement between the Bulgarian government and the European Commission was signed. The Bulgarian government took a firm commitment to shut down and initiate the decommissioning of Units 1 and 2 before 2003. Bulgaria has committed itself [A-5] to the definitive closure of Units 3 and 4 in 2006 and to the subsequent decommissioning of these Units. Through 2006, the European Commission will provide a total financial commitment of

€ 340 million in support of the closure and decommissioning of Units 1 through 4 of the Kozloduy Nuclear Power Plant. The assistance covers not only the decommissioning of the Units but also measures for environmental upgrading, and the modernization of the conventional energy production, transmission and distribution sectors in Bulgaria. It also includes measures to improve energy efficiency, enhance the use of renewable energy sources and improve security of energy supply. Additionally, for the period 2007–2009 an additional assistance of € 210 million is foreseen for the same purposes.

I.3.5. Decommissioning planning

I.3.5.1. Conceptual planning

In line with the commitments taken by the Government, a conceptual design for the decommissioning of Units 1 and 2 was developed, and was completed in 2000. An international consortium prepared the conceptual design. The conceptual design suggested keeping the general strategy for deferred dismantling but shortening the deferred dismantling period from 70 to 35 years as limited benefit from the radioactive decay occurs after 35 years.

I.3.5.2. Detailed design

Based on the conceptual design, a detailed design was developed in 2001 by the same consortium. The detailed design consisted of three major parts.

- Technology and cost assessment, including planning;
- Decontamination and radioactive waste management;
- Licensing documentation, including safety assessment report, environmental impact assessment, quality assurance programme and radiation protection plan.

This detailed design reflected a broad spectrum of aspects, including those that impacted on the selection of the decommissioning strategy. This also allowed for the facility to take the necessary actions for addressing issues not originally addressed or resolved in the process of strategy selection. Some examples are:

- Increasing the rate of payment into the national decommissioning fund from 8% to 15% of income from electricity sales in order to provide for the collection of necessary funds in a shorter time frame;
- Supply of facilities and equipment for the decontamination of plant components and radioactive waste treatment to complement existing capabilities;
- Construction of new dry spent fuel interim storage facility to address the spent fuel issue; and
- Development of a special programme for human resource management for softening the negative impact of the units’ closure.

Additional financial support will be provided by the European Commission through 2009. The funds will be allocated for:

- Support of decommissioning;

- Implementation of projects for improving energy efficiency countrywide; and
- Regional development for the Kozloduy surrounding region.

I.3.6. Conclusions and lessons learned

It seems that there are very few cases when all the factors relevant to the selection of a decommissioning strategy are manageable and all problems solved. The major lesson learned from our experience is that an early selection of the decommissioning strategy and identification of the problems to be solved will help the owner / operator of a facility in addressing the issues. The proper way might be not to wait until all problems are satisfactorily solved, but to select the general strategy and then to develop and implement an action plan for the activities necessary to achieve a satisfactory status for the implementation of that strategy.

I.4. Greifswald WWER decommissioning project: strategy selection

I.4.1. Greifswald site and initial situation

A combination of political and economic factors lead to the final shut down of the 8 reactors at Greifswald. This situation prevailing at shutdown presented major socio- economic problems for the workers at the plant (and supporting research groups), combined with an overall culture change (including new legal and regulatory systems and a new social framework, based on free market).

Due to the unexpected shutdown, there had been no preparatory decommissioning planning and no final waste disposal facility was likely to be available. Also it was necessary to achieve decommissioning while, at the same time, paving the way for industrial and economic recovery at the site, there being little prospect of alternative work locally [A-1].

The solution was to set up a new decommissioning management company for Greifswald, organized in such a way that it could deal with decommissioning in the presence of all the challenges created by the new socio- economic situation. Within this broad and complicated context, an immediate dismantling strategy was adopted, together with the construction of on-site interim stores for the resultant radioactive waste and spent fuel.

The decision to go for immediate dismantling was based on detailed project planning and cost assessments as well as on broader issues — thereby providing a sound justification for that strategy. These planning and assessment activities showed that immediate dismantling was cheaper, produced less waste and resulted in lower radiological doses than had been estimated for deferred dismantling.

There are a total of 8 reactors of the Russian pressurized water reactor type (WWER 440-213) at the Greifswald site. The Units 1–4 are of the model 230 and the Units 5–8 are a more recent model. A wet storage facility for spent fuel; a hot workshop and additional buildings for the treatment and storage of radioactive waste are also available on site.

Immediately after the reunification of Germany in 1990, the 4 operating Units 1–4 were shut down and the trial run of Unit 5 and the construction of the Units 6–8 were stopped. Investigations with regard to the upgrading and refurbishment of some units indicated no acceptable economic solutions. Finally, in 1990 the decision was taken to decommission

Units 1–4, followed by the same decision for Unit 5 in 1991. The Energiewerke Nord GmbH (EWN) was established as the new owner, with the sole shareholder being the German government (Ministry of Finance).

In 1991 there were around 5000 employees on site and approximately a further 1000 in research groups in Berlin, Rossendorf and Leipzig. Some 8000 construction workers had already left the site. This high number of employees can only be appreciated within the context of the previous socio-economic system. The site is also located in a basically agricultural region without any major industries, which made job relocation very difficult if not impossible.

After Germany's reunification the society had to be transformed from a centrally planned economy to a free market one. The legal system was completely changed and renewed, including the nuclear licensing authority and authorized expert system. The local residents and plant employees had to adapt the new social surroundings. It was also necessary to introduce "Western" planning and management methods. Thus, it can be understood that the execution of a major project with such boundary conditions was a challenging task.

I.4.2. Situation analysis and key decisions

Decommissioning projects are multi-faceted and the following main issues had to be addressed:

- Personnel;
- Decommissioning strategy;
- Waste/material management;
- Licensing;
- Site reuse scenarios; and
- Project management.

These issues are interrelated and had to be resolved in an integrated and iterative manner. The financing of the overall project is secured by the German Ministry of Finance. EWN, as a legal private company, has to apply the financial practices accordingly.

Due to the unexpected shutdown there had been no preparatory decommissioning planning and it was necessary to establish the planning basis for the overall project and to define the company objectives. First of all, a strategic analysis of the company was performed, considering all prevailing boundary conditions, technical, legal, economical, political and social, in order to:

- Establish an overall decommissioning strategy;
- Establish an organizational structure fit for the decommissioning project;
- Establish a business plan for the company; and
- Determine personnel and competency requirements.

As a result of this analysis, the following key decisions were taken:

- Construct a large interim storage facility for all waste and spent fuel arising from the decommissioning to achieve flexibility and independence of external boundary conditions;
- Perform as much as possible of the work with existing personnel responsible;
- Reuse the site to create new jobs; and
- Convert the operation license into a decommissioning license.

On the basis of these decisions the project objectives and the company tasks were clearly defined, and it was possible to introduce an adequate project structure and to begin with the planning work of the decommissioning in a well defined manner.

I.4.3. Basic strategies

Based on the key decisions taken, the strategies in the different main areas mentioned above could be developed and integrated into the overall project plan.

I.4.3.1. Personnel

Initially, measures had to be taken to reduce the number of employees, which was much too high for the decommissioning task. Due to the decision to use existing personnel as far as possible, major contractors were excluded. A retirement scheme was implemented and after careful evaluation all possibilities of privatization and outsourcing were performed. Furthermore, EWN improved the chances of a number of employees on the free labor market by training and education, while others received appropriate financial support.

In this way EWN was able to reduce the personnel in a socially acceptable manner from approximately 5000 to 1800 during the first 3 years. Based upon the more detailed project planning, the number of staff had to be reduced further and it was about 1250 in 2003. Thus, the remaining personnel became the decommissioning workforce that was required for an effective project.

I.4.4. Decommissioning strategy

Parallel to resolving the personnel issue it was necessary to decide on the decommissioning strategy, i.e. immediate or deferred dismantling. In order to resolve this main issue, a complete project planning and cost assessment for both alternatives was performed. The result showed that the immediate dismantling is about 20 % cheaper, produces less radioactive waste and results in a lower dose commitment. These results are mainly due to the limited lifetime of the buildings and the lack of containment. Obviously, the immediate dismantling strategy also has a positive influence on the job situation on site and the knowledge of the operating personnel can be effectively used in the project.

In order to reduce the overall project time and personnel doses, the plant sections had to be dismantled in as large parts as possible and transported to an interim storage facility on site. In this way, the further handling and processing of the dismantled material could be performed at an optimal date independent from the dismantling activities in the facilities.

I.4.5. Waste/material management

Material handling and waste management need to be thoroughly planned on the basis of radiological characteristics, technical and practical considerations such as waste classes and availability of waste processing and disposal facilities.

Due to the expected lack of a final radioactive waste disposal facility in Germany in the near future, the Interim Storage North (ISN) facility was planned and erected on site. It serves as an independent, integrated treatment and storage centre for radioactive waste and dismantled material, as well as storage for spent fuel in CASTOR casks. In this way, sufficient buffer and intermediate storage capacities were established and high flexibility in logistics and waste management was achieved.

To obtain clear boundary conditions for the dismantling activities, the spent fuel was removed from the reactors and the cooling ponds into the wet interim storage on site. The fuel will be loaded in dry CASTOR casks and transported to the ISN in the future.

I.4.6. Licensing

Since the temporary license ended on 30 June 1995, and as a result of the legal transition between both German states in 1989/1990, it was sought to obtain a license for the largest part of the decommissioning project at an early stage and to complement the licensing provision with further license applications as deemed necessary. In this way, the consistent use of human resources, continuous work planning and continuity in the licensing procedures and in-process control could be ensured.

It was furthermore agreed with the regulatory authority, that no public hearing was required in view of limited public concern. The importance of informing the public of progress and development on the project is, however, well recognized and was achieved through a liaison committee with representatives from government, nongovernmental organizations and the public who meet regularly.

I.4.7. Site reuse

During the initial personnel reduction phase it was possible to establish a number of small and medium sized enterprises on site. In total, slightly less than 1000 jobs were created. After the initial key decisions, all efforts have been taken to keep the site as an industrial and energy producing site and investors have been found for the construction of gas fired power plants (total capacity 2400 MWe). Thus, despite the rather isolated location of the site, it has been possible to create new industrial activities. The efforts in this area are continuing and the infrastructure is being improved. A major element here is the establishment of a harbor area at the cooling water outlet channel allowing the entry of normal size Baltic transport and container ships [A-6].

I.4.8. Project management

To cover all necessary activities, a project management organization was introduced at an early stage. On the basis of the company analysis, a technical concept was worked out and the overall project was broken down to the working package level. The project was optimized from the cost and personnel perspective in order to avoid fluctuations in the personnel requirements in the different qualification groups. For the project management, special software tools have been developed, which technical planning, work preparation planning and the tracking and control of dismantled material and radioactive waste, etc. Actual data from the dismantling operations are registered, evaluated and fed back into the system [A-7].

I.4.9. Conclusions and lessons learned

After initial difficulties caused by massive personnel reduction combined with the introduction of a market economy and West German regulatory framework, EWN has succeeded in restructuring the company to arrive at a size suited to the decommissioning task. The immediate dismantling of the Russian WWER type reactors do not pose specific technical problems. However, the size of the project and the resulting material mass flow is extraordinary.

It can be concluded that dismantling of facilities is basically not a technical problem but a challenge to project management and logistics; once the legal, economical and waste management related boundary conditions have been clarified. In order to achieve a safe and cost effective project, it is necessary that all stakeholders, i.e. operator/owner, government, regulatory authority, authorized experts, and the public achieve positive co-operation.

The lessons learned for decommissioning strategy selection are:

- Development of a comprehensive inventory is a necessary prerequisite for all decommissioning strategies;
- Social aspects and psychological effects are important;
- A clear licensing structure is essential — one licence is preferable if the project is not too large;
- Clear and realistic requirements from licensing authority are crucial;
- The overall project requires planning, i.e. from shut down to final disposal;
- Establish a project structure and integrate all site activities;
- The dissemination of open public information is a key activity to achieve a consensus on the selected strategy;
- Consider simple and sturdy tools/equipment; mock-up tests are useful if new or complicated technology is envisaged;
- The optimization principle needs to be strictly applied and be considered as a requirement from the planning phase on.

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