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RADIOACTIVE WASTE MANAGEMENT COMMITTEE

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Working Party on Decommissioning and Dismantling (WPDD)

SELECTION OF STRATEGIES FOR DECOMMISSIONING OF NUCLEAR FACILITIES

A status report prepared on behalf of the WPDD by its Task Group on Strategy Selection

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Selection of Strategies for Decommissioning of Nuclear Facilities
A Status Report

Prepared on behalf of the WPDD by its Task Group Strategy Selection
8 February 2006

This status report reflects the viewpoints and materials of a Seminar on "Strategy Selection for the Decommissioning of Nuclear Facilities" held in Tarragona, Spain 1-4 September, 2003. The report also reflects the sharing of experiences within the WPDD, which represent operators, regulators, R&D and policy specialists from countries with advanced nuclear infrastructure that have considerable experience in the field of decommissioning.

FOREWORD

The Working Party on Decommissioning and Dismantling (WPDD) brings together senior representatives of national organisations who have a broad overview of decommissioning and dismantling (D&D) issues through their work as regulators, implementers, R&D experts or policy makers. The WPDD addresses the current views of NEA member states and is intended to be of service to them with the goal to strengthen overall visibility of decommissioning as an activity that is attracting growing attention.

WPDD keeps under review the policy, strategic and regulatory aspects of decommissioning of phased-out nuclear installations in view of the ultimate goal of releasing facilities and sites from regulatory control. The intention is to examine commonalities and differences and identify a common basis for a way forward.

The WPDD held an international seminar on “Strategy Selection for the Decommissioning of Nuclear Facilities” in Tarragona, Spain, 1-4 September 2003. The seminar proceedings can be obtained from the OECD/NEA Bookshop. In particular the following subjects were examined during the sessions: (a) International stocktaking; (b) Strategy selection by type of plant, e.g. light water reactors and other fuel cycle facilities; (c) National strategies; and (d) Social aspects.

A task group was established at the WPDD meeting in November 2004 to prepare a Status Report on strategy selection based on the Tarragona seminar. The task group that included D. Metcalfe, V. Massaut, D. Orlando, J.L. Santiago, E. Warnecke (chair), A. Duncan and C. Pescatore drafted the report in the following year and submitted it to the WPDD at its meeting in November 2005 for approval.

Status reports of the WPDD are intended to summarise the existing knowledge and experience on a given subject in order to provide concise and “digested” information to those who are interested in obtaining a quick overview over a subject without reading through an extensive number of specialized papers from conferences, seminars or other type of meetings. Status reports are not only addressed to decommissioning experts, e.g. regulators, implementers and R&D experts, but also to an interested audience, including politicians, decision makers and the general public.

This status report on “Selection of Strategies for Decommissioning of Nuclear Facilities” is based on the viewpoints and materials of the Tarragona seminar and the experience of the WPDD. It identifies, reviews and analyses factors influencing decommissioning strategies and addresses the challenges associated with balancing these factors in the process of strategy selection. It gives recognition to the fact that in addition to technical characteristics, there are many other factors that influence the selection of a decommissioning strategy and that cannot be quantified, e.g. policy, regulatory and socio-economic factors and aspects that reach far into the future. Uncertainties associated with such factors are a challenge to those who have to take decisions on a decommissioning strategy.

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1. SUMMARY OF KEY POINTS

The OECD/NEA Working Party on Decommissioning and Dismantling (WPDD) developed a Status Report on “Selection of Strategies for Decommissioning of Nuclear Facilities” which is based on an international seminar held in Tarragona, Spain on 1-4 September 2003. The following key points were developed from this report.

There are three main strategies for decommissioning of nuclear facilities.
The three main decommissioning strategies are “immediate dismantling”, “deferred dismantling”, also called “safe enclosure”, and “entombment”. In the first case, a facility is dismantled right after the removal materials and waste from the facility. In the second case, after the removal of materials and waste, the facility is kept in a state of safe enclosure for 30–100 years followed by dismantling. In the third case a facility is encapsulated on site and kept isolated until the radionuclides decayed to levels that allow a release from nuclear regulatory control. No further consideration is given to entombment which is a near surface disposal option. The present trend is in favour of immediate dismantling.

Many factors have to be taken into account when decisions on strategy selection have to be made.
The large number of factors to be taken into account can be grouped into the following three categories: (a) Policy and socio-economic factors; (b) Technological and operational factors; and (c) Long-term uncertainties. The assessment of these factors is a challenge, in particular in cases where long time periods are involved. Most of these factors are not of a quantitative nature and need subjective assessment. Taking also into account that policies differ in many instances it is not surprising that different strategies are selected for similar facilities.

Policy and socio-economic factors are dominated by the national and/or the local situation.
National policies on nuclear matters vary considerably from country to country and with time. Policies may range from increasing nuclear power generation to continued operation of existing nuclear power plants and to phasing out of nuclear power generation.

The judgement, for example on the availability of qualified staff, is strongly policy dependent. It is an argument for immediate dismantling in a phase out situation. The lack of availability of a repository for decommissioning waste may be an argument for the deferral of decommissioning and keeping a nuclear facility in safe enclosure until a repository is available.

Implementing appropriate legislation and regulation, in particular regarding the definition of an end state for decommissioning and the cost/funding arrangements are important national policy issues. Decommissioning end states are defined by providing clearance levels and establishing levels for the release of sites. International recommendations for clearance levels were published by the IAEA. Funding arrangements must ensure that funds will be available when needed. This includes careful cost assessments, a collection of funds during operation and setting up a funding system to ensure a proper management of the funds until they are needed.

The closure of a nuclear facility and its subsequent removal has a major impact on local employment and economy. Immediate dismantling is more likely associated with a smooth transition and could ease local implications. In the local public opinion immediate dismantling often has the better acceptance as deferral might result in an abandonment of the facility and a failure to ensure continuing safety.

Although decommissioning technology is available, technological and operational factors will influence the choice of strategy.

In the past radiological aspects, in particular the decay of radionuclides during the period of safe enclosure, were a determining factor in the selection of a decommissioning strategy. In the meantime, techniques are available and have been successfully applied for immediate dismantling of nuclear facilities without compromising radiological safety. In most instances, e.g. in the case of light water reactors, radiation levels would remain too high to allow manual dismantling, even after 100 years of safe enclosure.

The volume of radioactive waste is primarily influenced by the implementation of a clearance policy. It will also depend on the decay period. Calculations show that a decay period of about 100 years would result in a 30% decrease of the mass of radioactive waste.

Good information on radionuclide inventories of materials and waste is necessary for clearance, handling, storage, processing and disposal. The practical approach consists of (a) establishing a correlation between gamma emitters (e.g. Co-60, Cs-137) and the other radionuclides and (b) of measuring the respective gamma emitters and (c) calculating the full radionuclide inventory with the established correlations. This task becomes more difficult as Co-60 and Cs-137 decay with time.

Uncertainties increase with time.

Long term uncertainties are of particular importance when a decommissioning strategy is selected. Although the radiological hazards decrease, the uncertainties increase with time. Policies and legal / regulatory frameworks are subject to change. The direction of change is uncertain although regulatory standards have tended to become more stringent with time.

The funds for decommissioning must be available when needed. Due to uncertainties in cost development and fund management over time, immediate dismantling may be the preferred strategy, if funds are available. Calculating the decommissioning costs is associated with uncertainties that will be exacerbated over longer periods of time. The risk for potential loss of funds will increase with time. Experience from the last 100 years illustrates that funds were badly affected, e.g. by inflation and warfare.

The availability of an operator and of qualified staff is also depending on the decommissioning strategy. Over long periods of time operators may change or even disappear and qualified staff may not be available, in particular in the case of phasing out nuclear power.

It is an implication of the complex decision making process that national decommissioning strategies are different and that they change with time.
Several distinct and decisive factors can be identified from the assessment of situations in selected countries. Countries continuously using nuclear power generation tend to dismantle obsolete plants immediately in order to use the sites for the construction of new facilities. The local public opinion became a decisive factor for changing national strategies from deferred to immediate dismantling.

Decommissioning costs are very important for strategy selection as preference will be given to the cheaper option. Cost calculations are neither trivial nor straight forward and cost calculations for similar plants in different countries came to different results. The often substantial differences in labour costs, disposal costs and decommissioning end points may explain the diverging findings and thereby the choice of decommissioning strategy.

Different approaches have been taken to funding decommissioning activities. Some countries require operators to set aside funds in a national funding system based on the estimated present-day costs for carrying out the decommissioning activities. This approach assumes that inflation and interest rates are at a comparable level. Other countries allow operators to set aside funds based on a net present value approach, which takes into account the growth of current day investments, through the accrual of interest, up to the planned time for decommissioning. The fraction of the total cost that needs to be invested today is dependent on a number of factors, including the number of years of safe enclosure until decommissioning occurs and the assumed interest rate over that time period. Uncertainties in such an approach will ultimately rest with the national government. Regardless, it is not good practice to use the lower current-day funding requirements associated with a net present value calculation as justification for taking a deferred dismantling approach.

In a phase out situation immediate dismantling would help to maintain nuclear technology and qualified staff.

2. INTRODUCTION

2.1 Background

Nuclear power technology has been in use since more than 50 years and thus there are many items of plant and equipment, mostly research and development facilities, that have served their purpose and need to be decommissioned. As current nuclear programmes mature and large commercial nuclear power plants approach the end of their useful life, they will also need to be decommissioned. International experience demonstrates that successful decommissioning of the full range of nuclear facilities can and has been done. The technology and practice is well developed and has resulted in end-states that include return to green field status or industrial reuse of nuclear sites and buildings.

These decommissioning projects have been subject, individually, to the careful planning that is a standard safety requirement of nuclear regulatory arrangements worldwide. It is not so apparent, however, that the planning has always been done within a strategic framework. That is to say, a broad framework of objectives and timescales, accepted by all interested parties, within which detailed planning and implementation may be carried out. It is clear from a review of past projects that strategic decisions have varied from country to country and from operator to operator. With over 400 nuclear power plants worldwide, and with their rate of withdrawal from service peaking around 2015-2025, it is timely now to review the existing experience with strategy selection and analyse future trends.

2.2 Decommissioning Strategy

The term "decommissioning" refers to the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a nuclear facility after shutdown and the return of its site to an acceptable end-state. These actions involve decontamination, dismantling and removal of radioactive materials, waste, components and structures. They are carried out to achieve a progressive and systematic reduction in radiological hazards and are undertaken on the basis of pre-planning and assessment, in order to ensure public and occupational safety during and after decommissioning operations, and protection of the environment.

For the purpose of this review it is also necessary to distinguish between the overall decommissioning "strategy" for a nuclear facility and the detailed technical decommissioning plans prepared within the framework of a selected strategy. The latter are not the subject of this paper.

The three main strategies for decommissioning are characterised by timing of final dismantling. They are commonly described as follows.

"Immediate Dismantling" normally starts within a few years from shutdown of the facility, giving time for transition from operating status to decommissioning status and allowing for removal of spent fuel, in the case of a reactor, and residual radioactive waste from the operating phase.

"Deferred Dismantling" or "Safe Enclosure", after removal of spent fuel and some peripheral items of equipment, the facility is then kept in a state of safe enclosure, for a period of 30 to 100 years before dismantling. This involves the need for a control of the facility throughout the "safe enclosure" period to ensure the necessary level of safety. Nevertheless, the part of the plant which will be maintained under control (for decay of radionuclides) can vary greatly, e.g. from only the reactor pressure vessel and primary loop (for Light Water Reactors,) up to the entire area described as "controlled" for radiological protection purposes.

"Entombment" is a strategy for encapsulating the facility on site and keeping it isolated until the radionuclides have decayed to levels that allow the site to be released from nuclear regulatory control. It is similar in principle to near-surface disposal and requires a similar level of control for a similar period of time.

2.3 Scope of Review

This review analyses the factors that influence decommissioning strategy and addresses the challenge associated with balancing them in the process of strategy selection. In addition to technical characteristics, there are many other factors that influence the selection of a decommissioning strategy.

These include, for example:

- Policy, regulatory and socio-economic factors concerning regulatory arrangements, end-states, funding arrangements, availability of waste disposal facilities, and community-related aspects.
- Technological and operational factors concerning radiological aspects, the availability of relevant technology and the state of a facility at shutdown.
- Long-term uncertainties concerning evolution of regulatory standards, availability of adequate funds, future ownership of facilities, availability of trained and qualified staff, waste disposal arrangements and future policy on the use of nuclear power.

3. FACTORS THAT INFLUENCE STRATEGY SELECTION

The three main strategies for decommissioning nuclear facilities are characterised by reference to the timing of their dismantling. At a more detailed level, however, the end-state and other objectives need to be defined. Hence, the selection of a strategy involves the following key questions:

- What end-state do we want to achieve?
- What actions are required to achieve this?
- When are these actions best undertaken?

At a level of greater detail, further practical questions arise, such as:

- Are these actions technically feasible?
- Do we have the qualified people to undertake them?
- Are public and occupational safety and the protection of the environment provided?
- How much will it cost?
- How do we ensure availability of the necessary funds?
- What will be the impact on society and local communities in particular?
- How do we secure the support of affected stakeholders?

The answers to these questions involve factors that are interrelated and that will need to be balanced in the final judgements about strategy selection, with individual weights that may be country, site or stakeholder dependent. For example, local communities will have a strong interest in the end-state. The availability of funds and qualified staff may influence the choice of timing of the decommissioning project. End-state and timing may also be influenced by environmental, regulatory and waste management aspects, by specific technical or safety-related factors and, perhaps, by matters of national policy, for example, on the continued use of nuclear power. The overall costs are likely to be influenced by all of these factors.

The discussion below is grouped under the headings of “Policy and Socio-Economic Factors”, “Technological and Operational Factors” and “Long-Term Uncertainties”.

3.1 Policy and Socio-Economic Factors

3.1.1 National Policy

National policy may influence decommissioning strategy directly or indirectly. Insofar as national policy is reflected in legislation, direct influence is exerted by way of the legal framework, and the extent of this influence depends on the extent to which laws are either prescriptive or enabling. Policy and regulation varies from country to country and affect some or all of the issues associated with public and occupational health and safety, environmental protection, definition of end-state, waste management, reuse and recycling of materials, arrangements for release of materials from regulatory control, and matters concerning regional development.

Indirect influence may be by way of national policies that are not concerned specifically with the process of decommissioning but may be linked to it by way of wider issues. These may include matters such as the future use of nuclear power, economic and societal issues associated with the effects of shutting down major industrial facilities, safety issues and broad financial issues concerned with costs, the use of available funds and the timing of their deployment. Although perhaps not associated with national policy, as such, the prospects for continued availability of qualified and trained staff may also have such an influence.

In addition, countries that are Contracting Parties to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management have specific national obligations in regard to decommissioning nuclear facilities and it is possible, under certain circumstances, that any such Party (i.e. Member State) might have to assume direct responsibility for the decommissioning. National policy will usually have regard to this possible eventuality.

Hence it may be seen that national policy, in one form or another, can impinge on many of the key factors in decommissioning strategy described below.

3.1.2 Regulatory Arrangements

All NEA Member Countries with nuclear power programmes, nuclear research facilities or facilities that use radioactive materials, have national regulatory arrangements for securing public and occupational health and safety, environmental protection and safe waste management. Such arrangements are traceable to current international standards and have been developed and proven in application to operational facilities. Much of this is directly transferable to regulation of facilities undergoing decommissioning although it is recognised that some adaptation is inevitable in order to recognise the changing nature of hazards in the course of decommissioning and the progressive reduction of the radioactive inventory. On the other hand the potential for conventional hazards is increasing by way of activities such as dismantling and demolition, and exposure to conventionally hazardous materials such as asbestos, acids, toxic gas, etc. Securing the continuing safety of decommissioning operations, together with environmental protection and safe waste management should be the principle focus and major feature of any strategy. The current, proven regulatory arrangements, subject to adaptation as appropriate, are likely to continue during decommissioning and any period of safe enclosure with a deferred dismantling strategy.

National regulations that may influence the end-state of decommissioning and the management of waste, however, vary from country to country and in many cases are still subject to further development. These concern the radiological standards associated with the release from regulatory control of buildings, materials and land. They influence the practicality and costs associated with waste management and with achieving desirable end-states such as green field status or industrial use of a site. The current standards adopted in various countries are reported in the NEA document, “Removal of Regulatory Control for Materials and Sites – National Regulatory Practices”, (see “Further Reading” list), but it should be noted that these might change with time as national policies develop.

3.1.3 End-States for Decommissioned Facilities

The desired end-state for decommissioning of a nuclear facility may range from site reuse for a new nuclear facility, redevelopment with restrictions on future site use or site release without restrictions (the so-called green field state). The choice is likely to depend on national and local circumstances and policy. It is almost certain to have an influence on the extent and timing of dismantling operations.

Reuse of the site for a new nuclear facility means that sufficient decontamination and dismantling of the old facility must be carried out to allow new construction, although certain buildings may remain for continued use. In this case the levels to which decontamination must be carried out will be consistent with the requirements for a licensed nuclear site, which are not as stringent as for a site released for conventional industrial or unrestricted use. The decision to reuse a site for a new nuclear facility may be attractive to countries committed to future use of nuclear power and with a scarcity of available land, or to those with more than one facility on a nuclear site and committed to a programme of replacement in rotation. In such circumstances, the programme for new construction is likely to dictate the timing of dismantling.

Reuse of a site with restrictions on future site use involves reducing contamination to a level that is acceptable given the proscribed use of the site after completion of decommissioning. Restricted reuse should consider not only the potential doses to workers at the site if the restrictions remain in place, but also consider the doses to workers and the public if the restrictions fail.

The green field end-state involves complete removal of all equipment and structures and remediation of any contaminated land to a level that allows unrestricted use of the site for any purpose. In this case, timing of dismantling and remediation are more likely to be dictated by national policy, consideration of benefits from radioactive decay, availability of funds, the need to release land in a premium location, etc.

The strategic option of facility entombment does not involve actual dismantling and it results in an end-state that is essentially equivalent to a near surface disposal facility. This situation would therefore require continuing supervision and regulation until either the radionuclides have decayed to background levels or the facility is decommissioned in the future. It has been found, however, that most sites for nuclear facilities would not meet the relevant regulatory requirements for implementation of this option, although it may be a possible option for countries with small nuclear programmes that involve only a research reactor, for example. In the US, clarification of the rules that might permit use of this option has been deferred pending completion of studies on its viability. (See “Further Reading” list)

3.1.4 Costs and Funding Arrangements

The main direct contributors to the decommissioning costs are dismantling and decontamination operations and waste management. The costs of safe enclosure, in the context of deferred dismantling, are also significant to the extent of being a driver towards immediate dismantling. It is apparent, therefore, that the overall costs of decommissioning are dependent not only upon technical matters such as the type, size and condition of the relevant facility but also upon decisions about the timing and end-state. They are also dependent upon national policies and standards for release of materials and sites from regulatory control as this has a direct influence on the amount of radioactive waste for disposal. In addition, labour costs, the costs of waste disposal and financial accounting protocols vary from country to country.

After cost estimation, one of the most important factors in selecting a decommissioning strategy is the availability of adequate funds. In general, the responsibility for providing the funds rests with the relevant operator. This applies also to state-owned operations.

Ideally, funds for decommissioning and waste management will have been built up, from revenues for example, during the operational life of the relevant facilities and should be available whenever it is judged best to carry out decommissioning activities. This is not always possible, however, as in the case of premature closure of a facility. The consequent non-availability of sufficient funds may constrain strategic options to variations involving deferred dismantling / safe enclosure. This does not generally apply to research facilities, whose decommissioning costs are funded by the research organisation or the Government, at the end of their operating life.

For strategic purposes, the systems for securing funds for decommissioning may be described as ranging from having some accounting commitment that the costs will be met out of revenue or assets when necessary, to having a secure, segregated fund of money in independent, trustworthy hands. The choice between these two extremes depends largely upon the level of trust in national or commercial institutions and varies from country to country. Regardless of country or fund management arrangements, however, accumulated reserves held for long periods of time are exposed to considerable risk from inflation, money market losses, economic crises and conflicts involving major changes of state institutions. This leads to the clear international view that, as regards the security of funding, decommissioning should be carried out as soon after closure as the necessary funds are available.

In addition, funding arrangements for decommissioning must be structured to ensure that they remain adequate to complete decommissioning. Therefore they should not rely solely on mechanisms that can depreciate, and the estimate for decommissioning as well as the funds available for decommissioning should be periodically reviewed to ensure that they remain adequate to complete decommissioning.

3.1.5 Availability of Spent Fuel and Radioactive Waste Management Systems

3.1.5.1 Storage and Disposal Facilities

The first technical step in decommissioning a nuclear power plant, specifically, is the removal of all spent fuel from its core. Provisions must be in place, therefore, for its safe removal to a store, repository or to a reprocessing facility, in accordance with national policy on spent fuel management. In general, the provisions for storage of spent fuel during the operational phase of the reactor will suffice, unless of course they have insufficient capacity or if they are unavailable for any other reason. If no such provisions are available, decommissioning and dismantling may be precluded until they are available. This qualification does not generally apply to other types of facilities, where the priority is treatment and conditioning of pre-existing waste.

The availability, or non-availability, of a waste disposal facility is a significant factor in strategy selection. This is often a matter for national policy or government, and beyond the control of operators. If no repository is available, radioactive waste must be processed and stored until the appropriate repository is available. Ideally, the specifications for treatment and packaging of waste will be consistent with the regulatory requirements for transport, storage and eventual disposal. These specifications define the radiological, mechanical, physical, chemical and biological properties of the waste and of any package. Where arrangements for disposal are not yet fixed however, (preliminary) waste package specifications based on a disposal concept should be developed and applied in such a way as to provide sufficient flexibility to allow disposal of waste by a number of possible routes or, at least, allow for the possibility of reworking it when final specifications for waste disposal are eventually defined.

The construction and operation of a storage facility will involve costs that cannot be neglected. These costs are likely to be highly dependent on the type of facility, by way of the type and quantity of waste arising from decommissioning, as typified by the difference in the characteristics and quantities of waste arising from light water and gas-cooled reactors. Furthermore, if such stores are located and remain on the site of the facility being decommissioned, they will prevent the full release of the site from nuclear regulatory control and block its availability for unrestricted use. In particular cases where the volume of decommissioning waste is large, as in the case of graphite-moderated reactors for example, this situation may discourage immediate dismantling and encourage instead the option of safe enclosure until a waste disposal facility is available. In some cases national or centralised storage facilities are built which allow the operator to carry out the decommissioning up to the release of the site for unrestricted reuse.

3.1.5.2 Release of Materials and Sites from Regulatory Control

Another factor relevant to the costs of waste management is the availability of effective provisions for the release of materials and sites from regulatory control. Much of the waste arising from decommissioning comprises materials containing radionuclides at levels below those that constitute radioactive material for the purposes of regulatory control. Establishment of those radionuclide concentration or contamination levels below which these materials may be released without further radiological control, (so-called “clearance levels”), allows much of such material to be reused, recycled or disposed of as conventional waste. In addition, the decommissioning criteria for radioactively contaminated land, which are not necessarily the same as those for waste or other materials, allow removal of regulatory restrictions after remediation to below the prescribed levels. The setting of these levels by national governments has a significant effect on the quantity of materials that remain for disposal as radioactive waste and hence on the overall costs of waste management. However, any advantage arising by way of this provision for clearance is reduced by the cost of activities associated with administering and monitoring it. If, in addition, there are difficulties in finding routes for reuse or recycling of cleared materials, it might be judged that the exercise is not worthwhile and that all such materials should be simply disposed of as radioactive waste or follow a different route, e.g. melting for recycling within the nuclear industry, but such a judgement may be questionable in regard to the principle of sustainable development.

As noted in Section *3.1.2,* the levels adopted by various countries for clearance of materials and sites have been reviewed in an NEA document. Related international recommendations have also been published by the IAEA in a document entitled, “Application of the Concepts of Exclusion, Exemption, and Clearance”. (See “Further Reading” list)

3.1.6 Knowledge Management and Availability of Qualified Staff

Relevant knowledge and technical information about installations as complex as nuclear facilities is of prime importance for their safe decontamination and dismantling. Conservation of such knowledge is a key consideration in decommissioning strategy.

The relevant knowledge and information about a facility resides mainly in archived documents and in the minds of staff involved with construction, operation and any modification of the facility. Documents may comprise original and modified engineering drawings of the plant, paper records, microfilm, magnetic tape, compact discs, etc. Their availability, or not, is likely to influence the timing of decommissioning. For example, if the relevant drawings are not available the plant will have to be carefully examined. Dismantling can only be carried out with extra caution, thereby slowing down operations, and increasing costs in the process. This is commonplace in the case of early experimental and development facilities. Any strategy needs to ensure that, for currently operating facilities, relevant documents are identified and safely retained. The point is particularly important for single unit sites or for small facilities.

Likewise, the knowledge of staff that has been involved with the facility over a long period of time will be invaluable during its characterisation prior to decontamination and dismantling as well as during dismantling. This is particularly true of staff involved in its construction and in any subsequent modification. At least, their information needs to be recorded, by way of interview for example, before access to them is lost through retirement. Ideally, the same staff would be employed so far as possible in decommissioning of the facility, which is an obvious argument for immediate dismantling.

When choosing the option of deferred dismantling, particularly in countries committed to phasing out nuclear power or, indeed, where the phase-out has already occurred, the availability of adequately trained and qualified staff also needs to be addressed. Where there is no longer a ready source of trained staff from operational facilities, there needs to be consideration of whether a country can depend on importation of the necessary skills when required, or whether a system of ongoing nuclear education and training needs to be maintained. This requirement is likely to be paralleled by a similar requirement for waste management staff, particularly where radioactive waste is being held in indefinite storage. These high-level strategic considerations also raise questions about where the relevant responsibilities will lie in the long term.

3.1.7 Social and Community Aspects

Meaningful stakeholder engagement is now recognised as essential to progress on many issues of nuclear power, and not least in regard to decommissioning and dealing with the waste and materials arising from it. At one level, local communities that host a nuclear facility may suspect that any deferral of dismantling might result in its abandonment, and failure to ensure its continuing safety. Such deferral also encourages a wider societal perception that decommissioning is too difficult or too costly to undertake and that, nuclear power is not consistent with sustainable development. At another level, the same local communities may fear that immediate dismantling, and return to green field conditions of a facility that is a major contributor to the local economy will have an adverse affect on local employment, business, education, infrastructure, etc.

In most NEA Member Countries there are formal requirements for involving stakeholders and local communities in the planning of activities that affect such social and environmental issues. For example, countries in the European Union are bound by directives that require detailed assessment of a wide range of factors including impact on amenities, landscape, noise, transport provisions, general nuisance, effects of accidents and contribution to sustainable development as well as the more specific issues of waste management and impact on the environment. Most importantly, they make specific provision for informing and involving the public and neighbouring Member States. Nevertheless, accumulating experience shows that dialogue with those stakeholders most affected is the best way to achieve consensus and ensure that both broad strategy and detailed plans recognise and result in a transparent balance between the interests of all concerned.

Many nuclear facilities are located in remote areas and are the main source of employment in their area. Hence, their shutdown without creation of alternative employment has a dramatic effect on the local community. In some cases, the decommissioning strategy and end-state has been designed in part to smooth the loss of local employment and to create new jobs by attracting other industry. This approach is employed in Greifswald, Germany.

Such dialogue should be designed to create the so-called “three pillars of trust” that relate to ensuring continuing safety of the facility, effective participation in decision-making and protection of socio-economic interests, although it must be recognised that the last point may not be, solely, the responsibility of the plant operator.

3.2 Technological and Operational Factors

3.2.1 Radiological Aspects

The continuation of effective public and occupational radiological protection is a primary consideration in the process of strategy selection. In this regard, there is potential for taking advantage of the natural decay of radionuclides over time, and the consequent reduction of radionuclide inventory and dose-rate. By waiting for sufficient radioactive decay, decommissioning operations may be carried out safely without resort to remote handling equipment, robotic devices, etc, and volumes of radioactive waste may be reduced. However, this advantage applies only to situations where the main radionuclides are short-lived, such as ^{60}Co, which has a half-life of about 5 years. On the other hand, in the case of actinides, it has to be taken into account that deferral may be detrimental from a radiological point of view because of an in-growth of Am-241 from the decay of Pu-241.

In the case of a gas-cooled reactor, for example, it is probably necessary to wait for about 80 - 120 years before manual dismantling operations are permissible. In the case of light water reactors, the radiation levels remain too high to allow manual dismantling, even after 100 years. From the strategic point of view, the benefits from delay for radioactive decay, in terms of reduced worker doses and reduced costs of dismantling operations must be offset by the worker doses and costs accruing during the safe enclosure period, and by any technical issues associated with deterioration of the facility. Such deterioration might result in leakages that may lead to increased dose uptake during dismantling, for example the activated parts of light water reactors. In such cases, the benefits from radioactive decay may even be cancelled out completely.

As regards reduction in waste volumes, the benefit of radioactive decay lies primarily in the possibility of reducing the radionuclide inventory of large volumes of material to levels that will allow it to be cleared for reuse, recycle or disposal as conventional waste. Clearly, the extent of this benefit depends on national clearance levels, as mentioned in Section 3.1.5, and on the availability of routes for reuse or recycling. For a pressurised water reactor with a 40-year operating life, it is calculated that the effect of radioactive decay for 100 years would be a reduction of about 30% in the mass of waste defined as radioactive.

In the case of facilities contaminated with long-lived radionuclides such as actinides, there is clearly no benefit of any kind in waiting for radioactive decay.

3.2.2 Availability of Technology for Decommissioning

The techniques required for decommissioning nuclear facilities include:

- Decontamination techniques for removing contamination from metal, concrete or other surfaces.
- Cutting techniques for dismantling the facility, including metal or concrete structures, and plant and equipment of all kinds.
- Measuring techniques used for drawing up the radionuclide inventory of the installation and for planning and monitoring decommissioning operations, including waste management.
- Remote control techniques used for working at a distance, or behind radiation shielding, and involving use of manipulators, semi-automatic tools and lifting and moving equipment.
- Techniques for the protection of humans and the environment involving use of moveable shields, airlocks and temporary cells, mobile ventilation and filtration systems, and special clothing.

- Techniques for waste processing, including processing of liquids and filtration of gaseous effluents, in order to comply with transport regulations and storage and disposal requirements.
- Dealing with non-radiological hazards (chemically toxic materials, etc.).

These techniques are already well developed and proven in practice. Indeed many of the dismantling techniques are based on conventional equipment adapted as necessary for nuclear application. Most operations can now be carried out remotely and safely, without excessive cost. In this context, the main strategic question is about the extent of further research and development that may be helpful in further reducing costs and dose commitment and enhancing efficiency and safety of the operation. It would also be helpful to develop or seek approval for techniques of transporting and disposing of large items of plant and equipment, as this would reduce the requirement for cutting, at least. Also in this strategic context, countries with small nuclear programmes or with only a research reactor, perhaps, will need to consider how far to go in developing a local capability in applying these techniques, as opposed to depending upon contracted effort from elsewhere.

Some of the systems and components already installed on a nuclear facility, such as ventilation systems, lifting and moving equipment, could be used for decommissioning operations provided it has been maintained in good order, with current safety certification. This qualification may be difficult to satisfy if dismantling is deferred for a lengthy period of time, during which such systems and components are likely to deteriorate and their safety certification to expire. In such an event, their re-commissioning might be impracticable and they might have to be replaced at significant cost. The same point applies to structures; both in the case of simply assuring continued safety of the facility as well as in the case of any temporary reuse.

3.2.3 Physical and Radiological State of Facilities

One of the first steps after shut down of any nuclear facility is the so-called "post operational clean out". Amongst other things, this involves flushing of pipe work and vessels to remove as much contamination as possible. The residual physical and radiological state of a facility will then influence the strategy for decommissioning it, particularly if it remains highly contaminated or if its physical structure is in a poor state and likely to deteriorate. In such a situation early action might be necessary for securing its safety. Hence both physical and radiological characterisations are essential inputs.

Physical characterisation normally involves inspection of the facility in order to detect hazards and identify the arrangements required for protection against any abnormal conditions. It involves documenting the current state of the facility through photographs, videos, maps and diagrams that may help determine what hazards are present, and to analyse in particular:

- The state of structures (foundations, roofs, walls, floors, pillars, etc.).
- Control systems (security entrances, fencing, etc.).
- Fire protection (detectors, alarms, fire-fighting systems, etc.).
- Issues for staff safety (physical hazards, hazardous materials, etc.).
- Functionality of systems (heating, ventilation, air and electricity supply, internal and external lighting, etc.).
- Process materials (in containers or tanks, uncontrolled landfills, etc.).

Radiological characterisation has two main purposes. The first involves identification of the radiological hazards to workers who will have to enter the facility in order to carry out decommissioning tasks. This identification of hazards helps to determine whether or not it is necessary to decontaminate any areas of the plant for direct worker access, and it facilitates the design of radiological protection measures for later activities. This work includes the sampling of unknown materials, the updating of radiological maps and the estimating of physical parameters and quantities of waste arising from later decontamination and dismantling tasks.

The second purpose is to establish, at a more detailed level, the inventory of radionuclides in materials that will require storage, disposal as radioactive waste or release from regulatory control by way of clearance arrangements. This work also continues as decommissioning progresses and as access becomes available. For technical reasons associated with ease of detection and measurement, the work is most conveniently done by detecting and measuring γ-emitting radionuclides such as ^{60}Co and ^{137}Cs and calculating the quantities of other radionuclides by way of known correlations with the measured species. However, the easy-to-measure radionuclides have relatively short half-lives, (5 years for ^{60}Co and 30 years for ^{137}Cs) so this element of the task becomes more difficult and complex the longer dismantling is deferred.

3.3 Long-term Uncertainties

Balancing the above factors in the process of selecting the decommissioning strategy must have regard to the long-term uncertainties attached to them. The more significant uncertainties are explained in the following text.

3.3.1 Evolution of Regulatory Standards

As explained in Section 3.1.2 the regulatory arrangements for securing occupational health and safety, environmental protection and safe waste management are traceable to current international standards. History shows that, over the years, these standards have been substantially tightened. In some cases this has been because of greater public sensitivity and a general improvement of safety standards. In others, particularly in relation to waste management issues, it has been because of the negative perception of "radioactive waste". There is currently no indication that these standards will be relaxed over time, and it is more likely that any change will involve further tightening.

This is likely to affect activity levels for release of materials from regulatory control, (i.e. "clearance levels"). These have a strong influence on the amount of waste remaining for disposal as radioactive waste, and in turn, would have an impact on both waste management costs and the need for radioactive waste disposal capacity.

3.3.2 Costs and Fund Management

The effects of tightening standards, and of public opinion, have been to increase the cost of waste management and disposal over the years. It is unlikely that this upward trend will change in the near future, but its extent is uncertain. Similarly, the costs of labour and materials are likely to increase by amounts that are increasingly uncertain with increasing timescales. In calculating the lifetime costs of a decommissioning project, these uncertainties will be exacerbated by further uncertainties associated with the evolution of interest rates and discount rates for calculating Net Present Values over long periods of time. The assumption of continuing economic growth and achieving a net interest rate of, for example, 4-5% per year over a period of up to 100 years is a real challenge. Uncertainties associated with such an approach can be easily illustrated by looking back for the last 100 years with its drastic monetary losses due to inflation and warfare. Some countries require financial provisions to be made on a more conservative basis of undiscounted costs because ultimate decommissioning would become a State responsibility should all provisions being made fail. Another way of mitigating funding uncertainty would be immediate dismantling and its early completion because uncertainties would increase with decommissioning timescales. Funding uncertainties are mitigated, in some countries, by financial guarantees required of operators under regulatory arrangements in addition to segregated decommissioning funds.

These issues create an obvious need to evaluate the funding arrangements very thoroughly in order to minimise uncertainties, including the uncertainties associated with the performance of investments, rates of inflation, and possible economic or political crises.

3.3.3 Evolution of Facility Ownership and Availability of Qualified Staff

These two issues are linked, particularly in situations where there is a commitment to phase out nuclear power or where the phase-out has already occurred.

Major nuclear facilities are usually operated by commercial utilities whose continuing existence depends on operational revenues. If nuclear power is phased out for whatever reason, it is not obvious that such utilities will still be in business to fund and carry out the required decommissioning activities when required. Countries that are Contracting Parties to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management are required to assume responsibility if no owner is identifiable. In any country, however, strategy development must accommodate the uncertainties associated with this eventuality, the probability of which is likely to increase with time from facility shutdown.

Similarly, the demise of a nuclear utility following phase out of nuclear power is likely also to result in the loss of staff qualified to undertake decommissioning activities and related waste management. The uncertainties associated with this will have to be accommodated by strategic decisions about the future acquisition of such staff or about the continued training of nuclear technologists for both decommissioning operations and for its effective regulation. Again, this is an issue that is likely to become more complex with increased time from shutdown.

3.3.4 Availability of Radioactive Waste Disposal Facilities

The ideal situation would be to be able to deliver the radioactive waste arising from decommissioning directly to appropriate disposal facilities. Otherwise, it has to be retained safely in storage facilities for an undefined time and at a cost that will be uncertain but clearly significant.

This situation applies to disposal of all types of waste that will remain for disposal as radioactive waste, in particular if effective clearance arrangements are not in place. Disposal facilities are already available in some countries but, with exceptions, are generally limited to disposal of low and intermediate level short-lived waste. If a disposal route is not available operators may be reluctant to treat and package waste. Some countries when faced with this uncertainty, developed and apply (preliminary) waste acceptance requirements for future repositories, following appropriate scrutiny by regulators, allowing the operators to progress with waste conditioning (see 3.1.5).

In some countries where clearance levels for materials are very low, or where the costs and practicalities associated with administering and monitoring the clearance process make it unattractive, there is likely to be a large volume of very low level radioactive waste for disposal. The disposal of such waste in facilities designed for the more usual types of radioactive waste is unlikely to be either practical or economic, which may create further uncertainty as regards the fate of waste arising from decommissioning.

These uncertainties, taken together, may discourage operators from undertaking the decontamination and dismantling activities that would generate such waste, and cause them to defer such activities until the necessary disposal facilities are available. This means that consideration of decommissioning strategy may be influenced by national policy and strategy for radioactive waste disposal. However, both solid and liquid waste are safer after treatment and packaging, and the overall risk of the installation will be reduced significantly after such processing.

3.3.5 Evolution of Policy on Future of Nuclear Power

Current intentions on the future use of nuclear power seem to be rather uncertain in many countries. Potential global threats include climate change resulting from release of greenhouse gases from fossil fuel burning, and various possible threats to the sources and supply routes of imported fuels such as natural gas. This, together with revised expectations about the capacity, economics and environmental acceptability of renewable energy sources, seems to be causing second thoughts in several countries apparently committed to phasing out nuclear power.

Such uncertainty may affect decisions about the end-state for decommissioning where, for example, it might have been assumed that the preferred end-state was green field status or reuse of sites for conventional industry, but the possibility now emerges of nuclear licensed sites being reused for new nuclear facilities. In this last case there may be economic and practical advantage in preserving parts of shut down facilities including waste stores.

4. SELECTION OF DECOMMISSIONING STRATEGY

4.1 The Strategy Selection Process

The owners or operators of nuclear facilities are normally responsible for selecting the decommissioning strategy, within which detailed planning may be done. In some cases this might become a national responsibility but, in any case, the strategy will need to be designed having regard to national policies and the need to comply with regulatory requirements (Sections 3.1.1 and 3.1.2.).

Also, it is essential to involve stakeholders in the process at the earliest opportunity (Section 3.1.7). The first task is to identify those with a legitimate interest, and then to establish the means of communication, consultation and decision-making. Experience indicates that the key features of any such arrangement are broadly as follows:

- The process must be open, transparent, fair and truly participatory.
- It should involve step-wise decision making, with clear definition of the steps or stages.
- The steps should be reversible in the light of new knowledge, so far as practicable.
- It should be clearly understood what is expected at each step, and how facts, expert opinions and value judgements will interact in decision making.
- The responsibilities of each stakeholder for each step should be defined and accepted.

As regards the actual process of weighing and balancing the different and often conflicting factors that influence strategy selection, there are various approaches and aids to decision-making. It should be noted, however, that such techniques are only guides to the decision-making process and that their real value is in providing a transparent, documented record of how decisions were arrived at and how the relative importance of the various factors was judged.

The precise circumstances and the weights attached to individual factors vary from country to country and even from facility to facility, so the strategies selected differ for justifiable reasons and there is no obviously best option. This is further illustrated by examples from different countries, given below.

4.2 Examples of Strategy Selection

4.2.1 France and Japan

These countries are committed to continued use of nuclear power. They want to be able to reuse existing nuclear sites for new nuclear facilities and, because of the prospect of a substantial ongoing requirement, they need to retain, and build up, the industrial capacity and expertise for decommissioning operations. Also, in addition to various types of power reactors, they both have early experimental and fuel-cycle facilities contaminated with long-lived radionuclides for which there is no benefit in waiting for radioactive decay. There is already provision for disposal of low-level waste and, in the case of France at least, for disposal of large quantities of the very low-level waste arising from dismantling.

Consequently, both countries have selected variations of the option of immediate dismantling to a site end-state compatible with continued nuclear use, but recognise that detailed decommissioning plans need to be prepared by operators on a case-by-case basis. In the case of France, it is foreseen to complete decommissioning of the already shut down nuclear power plants within 25 years. In Japan it is foreseen to dismantle facilities after only 5-10 years of safe enclosure, starting from when spent fuel has been removed and initial decontamination carried out. This decision thus removes any difficulties with the uncertainties described in Section 3.3, except perhaps in regard to availability of disposal facilities for high-level and long-lived waste, and for the large quantities of graphite arising from their gas-cooled reactors. (In practice, availability of a graphite disposal facility is likely to be a controlling factor in the timing of dismantling of the gas-cooled reactors in both countries.)

In the case of France, and for its first generation power reactors at least, this represents a recent change from the earlier policy of deferring dismantling in order to benefit from decay of ^{60}Co. This is apparently driven, at least in part, by a desire to demonstrate that decommissioning is perfectly feasible, that the technology is available and affordable, and that an overall waste management system is in operation. This shows that, at least in regard to the safe and environmentally acceptable decommissioning of shutdown facilities, nuclear power is consistent with sustainable development. It also shows that in choosing between immediate and deferred dismantling, any difference in the costs associated with use of remote dismantling techniques or with waste management, for example, were either not significant or was outweighed by other factors.

In both countries the operators are required to establish and manage funds for eventual decommissioning. In Japan the regulatory authorities ensure the adequacy of such funds by financial audit and review of an accounting report submitted by the operator. In France, the Court of Accounts performs the analogous function. In the latter case, this Court has expressed concern about the adequacy of available funds and about the possibility that the costs of meeting the operator's long-term obligations might fall upon consumers or the state. This might have an influence on the strategy that is actually implemented.

4.2.2 Korea and Finland

These countries are also committed to continued use of nuclear power. The strategy for decommissioning in Korea envisages dismantling after only 5 to 10 years of safe enclosure, so it is not very different from the situation in France and Japan. Where there are two reactors on the same site, however, it envisages waiting until both can be dismantled at the same time. This implies that economies of scale are foreseen and that costs are a significant factor in the decision. There is no apparent distinction between the strategies for decommissioning their heavy water reactors and pressurised water reactors, which indicates that the differences in technical, radiological and waste management characteristics between these facilities, or any differences in the techniques to be used in their decommissioning, are not significant in the balance of factors.

In this last regard, the situation in Finland is somewhat different. The strategy for decommissioning the first pressurised water reactor is immediate dismantling (within 10 years from shutdown), without commitment to return of the site to a green field end-state, i.e. similar to the French situation. The strategy for the first boiling water reactor, however, envisages 30 years of safe enclosure before dismantling.

In the Finnish case, a special feature of the pressurised water reactor decommissioning plan is that large components, (i.e. the pressure vessels and steam generators), would be removed intact without cutting them in pieces. In the case of the boiling water reactor, it had been foreseen that the reactor vessels and internal component would be segmented, but this plan has been re-considered and at present it is intended to use the reactor vessel as a package for reactor internals and dispose it of intact. This indicates that the radiological benefits of a delay of even 30 years for radionuclide decay were judged to be substantial when segmentation is involved. It also indicates, in the case of the pressurised water reactors at least, that the technology for reducing operator radiation doses by handling large components without segmentation, even without delay for radionuclide decay, is available, economic and preferred.

It is also possible that other factors may differ between the two reactor types, for example, differences in the need to clear the related sites for new facilities.

4.2.3 Sweden, Germany and Italy

These countries are committed to phase out of nuclear power and, thus, have no official need to make space for new nuclear facilities on existing nuclear sites. (In Italy, the phase-out occurred in 1987.)

In the case of Sweden, until recently at least, the regulators took the view that decommissioning should normally be finished within a period of 10–15 years after shutdown, but that storage facilities for the resulting waste must be available before dismantling is carried out. The factors influencing this inclination towards immediate dismantling were the uncertainties associated with loss of experienced staff, conservation of records and documents, and the potential safety and cost implications of the inevitable degradation of closed facilities. Social factors have also played a part in regard to the common understanding in Sweden that the generations who have benefited from the nuclear power should finance and take care of the waste arising from operation and_decommissioning. Notwithstanding this regulatory inclination, a strategy of safe enclosure for a period of 15-18 years (up to 2020-2023) has been selected for the first boiling water reactor unit at Barsebäck nuclear power plant.

In Germany, three early reactors were put into safe enclosure, in one case to take the benefit of radioactive decay (Lingen) and, in another case, partly because of non-availability of funds (THTR-300). The current move towards selection of immediate dismantling for power reactors is described as being mainly because of social aspects, the availability of qualified and trained staff, as well as cost considerations. The federal government is very much in favour of immediate dismantling. However, the utilities express a desire also to keep open the option of a deferred dismantling strategy. In either case, the end-state foreseen for dismantling is restoration to a green-field state or for conventional use of the site and the remaining buildings.

In Italy, the original intention was to defer dismantling, primarily because the premature closure of the nuclear power plants resulted in lack of funds, disposal facilities were not available and a national position on clearance of materials from the regulatory system was not yet determined. However, other factors such as the risks associated with potential loss of knowledge and skills have resulted in the making of complementary funding arrangements, definition of clearance levels and adoption of a coordinated national strategy based on completing the dismantling of all facilities within 20 years. Associated with this is a requirement for the early establishment of waste conditioning, storage and disposal facilities, although it is not considered to be a constraint on proceeding with decommissioning.

This example shows both the strategic difficulties associated with insufficient funding and waste management arrangements and also the weight of societal and political factors. The lack of reference to the effect of any technical differences between Italy's boiling water reactors, pressurised water reactors and gas-cooled reactor indicates, as noted in the case of Korea, that the differences in technical, radiological and waste management characteristics between these facilities, or any differences in the techniques to be used in their decommissioning are either insignificant or do not overwhelm other decision factors.

4.2.4 The Netherlands

Although the Netherlands, in principle, is committed to phasing out the use of nuclear power, nuclear power will continue to be used during the next decades. In 2005 it has been decided to expand the operational lifetime of the Borssele nuclear power plant to 60 years. This means that the facility will remain in operation until 2033, economy and safety permitting.

The small Dodewaard nuclear power plant was shut down in 1997 after 28 years of operation. All spent fuel has been removed and since 2005, the plant is in a state of safe enclosure.

The three main decommissioning strategies were considered in the Environmental Impact Assessment for the Dodewaard plant. Since the environmental impact is minute for each of these strategies, the operator, who is responsible for taking that decision, opted in favour of the least expensive strategy, namely deferred dismantling. Calculations of the net present value showed the lowest cost for deferred dismantling. The calculations were done assuming an interest of 4%, corrected for inflation over a period of 40 years. The selected end-state is green field status and unrestricted use of the site. The Borssele nuclear power plant follows the same strategy because of financial arguments.

The Nuclear Research Group NRG, Petten is preparing for licensing of a new research reactor. If the license is granted the old High Flux Reactor will probably be decommissioned and dismantled in 10-15 years.

Urenco Netherlands BV started dismantling the first batch of centrifuges from the closed uranium enrichment plant SP 3.

Although the government had a slight preference for immediate dismantling, no legal means were available to object to the decision of the operator. The slight preference of the government was mainly based on (a) concerns about the availability of dismantling, or in general nuclear, know-how in the Netherlands in the future; (b) concerns about the developments in decommissioning costs; (c) the availability of sufficient funding in the future; and (d) a perceived societal preference for direct dismantling.

Discussions and negotiations on transfer of the Dodewaard plant in safe enclosure to the national radioactive waste management agency COVRA, failed up to now because of difference in opinions on the liabilities.

4.2.5 United Kingdom and United States of America

These countries are revisiting their policies on the future use of nuclear power. This may impact on the future of existing nuclear sites and their possible reuse for new nuclear facilities in the future. This may also impact on the future availability of qualified staff.

The UK and the USA are both facing liabilities from their historical legacies that are estimated to be in the order of £56 billion for UK and $225 billion for USA. In such legacy situations, strategy decisions are more a matter of prioritisation than decisions on immediate or deferred dismantling.

The UK has had a wide range of experimental and prototype facilities, mostly in state ownership. The strategies for their decommissioning have varied for sound reasons. For example, some facilities have been dismantled immediately in order to gather information and experience and to test new techniques, or because they were in a poor physical or radiological state, or simply because they occupied space that was required for other purposes. Others have been left for about 30 years in safe enclosure in order to benefit from decay of ^{60}Co activity. This illustrates the importance of allowing strategy selection on a case-by-case basis.

For decommissioning of the UK commercial, gas-cooled power reactors however, the strategy preferred by operators is deferral of dismantling for about 100 years, with safe enclosure after removal of fuel and certain peripheral equipment and buildings. This choice is influenced by the absence of a disposal facility for graphite, by the benefits arising from radioactive decay in terms of allowing manual operations and significant reduction of waste volumes, and also by the substantially reduced costs, when expressed as Net Present Values after discounting over the 100 years period (although this aspect is questioned for such long period of time). Furthermore, such deferral would keep open the choice of eventual end-state, giving government time for clarification of future nuclear policy. Government had not rejected this choice but its policy position is that decommissioning be undertaken "as soon as is reasonably practicable, taking account of all the relevant factors". The newly established NDA (Nuclear Decommissioning Authority) quantified the timeframe by expressing its intent to accelerate decommissioning to the lifetime of one generation (about 25 years), including Magnox reactors but with the exception of Sellafield. This is in marked contrast to the previous owner/operator (BNFL) strategy. Hence, this example implies that government may be concerned about societal perception of such long deferral.

The US also has a wide range of experimental and prototype facilities in state ownership, and decommissioning strategies for these state-owned facilities have been selected on a case-by-case basis depending on circumstances. In 2004 the US Department of Energy reported that cleanup had been completed at 76 of its nuclear legacy sites, and that an additional 32 sites will be remediated by 2025, leaving 6 sites to be addressed after 2025.

As regards US commercial power plants, operators are relatively free to select their own decommissioning strategies. This has resulted, to date, in about 9 power plants being immediately dismantled and about 11 in some form of safe enclosure. Plans for the future, however, show about 11 plants destined for immediate dismantling and only 9 for safe enclosure, indicating a change of sentiment towards immediate dismantling. This change of sentiment is apparently driven by uncertainties about future ownership and long-term liabilities, about the security and adequacy of future funding, and about the future costs and availability of waste disposal facilities. Nevertheless, there is still a substantial number in favour of deferred dismantling, apparently because of co-location of shutdown facilities with operating plants and the opportunity for efficient staging of decommissioning of all units, as well as avoiding the need to construct waste stores.

This indicates that, in the US situation, costs and funding are still major factors leading to selection of the deferred dismantling strategy for decommissioning of commercial facilities but that uncertainties about the future are beginning to have an overriding influence in favour of immediate dismantling.

4.2.6 Spain

In Spain, 9 power plants are currently in operation. The assumed lifetime extends to 40 years. New constructions are not foreseen. The Vandéllos I gas-graphite reactor was shut down, the auxiliary buildings were dismantled and the reactor was brought into safe enclosure.

The decommissioning strategy for the operating nuclear power plants is total dismantling to be initiated 3 years after shutdown, following fuel removal from the pools.

The José Cabrera pressurised water reactor is planned to be shut down in May 2006. The above mentioned decommissioning approach will be applied and decommissioning plans are under preparation for this option since 2003. That means that the actual decommissioning work will begin about 3 years after shutdown when the fuel is removed.

In Spain, immediate dismantling is the strategy of choice for all operating nuclear power plants. The sites will be cleared as there is no firm policy on the future use of nuclear power.

5. CONCLUSIONS

Strategy selection is an important element in the safe decommissioning of nuclear facilities. It depends on a large number of factors that have to be taken into account when decisions on immediate dismantling, deferred dismantling/safe enclosure or entombment are to be made.

In general, entombment is not a recommended decommissioning option. It may, for example, be selected in a country with a single nuclear power plant. In general, strategy selection is a choice between immediate and deferred dismantling.

At present, the emerging international trend is more towards immediate dismantling than was previously the case (e.g. France, Italy, UK, Spain, Japan). The societal concerns about the consequences of deferred dismantling seem to be a significant factor, at government level at least. The input of stakeholders/communities into the decision-making process varies among countries.

The uncertainties, particularly about conservation of knowledge and expertise, evolution of costs/funding and liabilities, and about waste management and clearance are also very important.

The influence of radioactive decay seems applicable to only certain types of facilities, and is often outweighed by other factors, e.g. eventual cost savings/worker doses are offset by those accrued during safe enclosure. Remote handling technology is available and has been applied in several instances. The costs of remote handling technology have also not been an issue. These two facts reduce pressure for delay for decay.

Costs and cost minimisation are of very high importance to the operators of nuclear facilities, but also to the regulators because they must ensure that funds will be available when needed. Precise cost calculations, the accumulation of sufficient funds during operation and the security of funds, in particular if dismantling will be deferred, are of vital importance. Underlying all of this, minimisation of costs is still a powerful influence, e.g. in phasing decommissioning of multiple facilities on the same site.

The degree of certainty about the desired end-state may influence the choice of immediate or deferred dismantling. Where future nuclear policy is clear, whether for continued development or phasing out, there would be no risk in selecting immediate dismantling. Where the policy is not clear, and where the desired end-state is unclear, and/or a repository is not available, there may be a tendency to select deferral until the requirements for the site are clear or a repository is available.

This large number of influencing factors and the extremely large variety of these factors makes it easily understandable that decisions regarding strategy selection can be different in different countries for a similar facility or in one country for different sites.

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