IAEA Nuclear Energy Series

No. NW-G-2.1

Policies and Strategies for the Decommissioning of Nuclear and Radiological Facilities

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FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property." The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

The IAEA assists its Member States in managing radioactive waste in a safe, efficient and responsible manner by developing international standards and disseminating information on proven technical approaches. As part of these efforts, the IAEA provides guidance to its Member States on establishing national decommissioning policies and relevant strategies.

In order to demonstrate that the entire life cycle of nuclear facilities is being properly and safely managed, countries should have a national policy and a technical strategy, or strategies, for decommissioning their nuclear facilities. The two components are linked — the policy establishes the principles for decommissioning, and the strategy contains the approaches for the implementation of the policy. It is recognized that national, site and facility specific factors may play an important role in the decision making process to determine the decommissioning strategy.

The features of the decommissioning policy and strategy, and their development, are the main subjects of this publication. It is intended to help in facilitating proper and systematic planning, and safe, timely and cost effective implementation of all decommissioning activities. This guide is aimed at strategic planners, operators of facilities under decommissioning, waste managers, regulators and a variety of stakeholders.

The IAEA officer responsible for this publication was M. Laraia of the Division of Nuclear Fuel Cycle and Waste Technology.

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SUMMARY

The main objectives of decommissioning are to place nuclear facilities[1] that have reached the end of their useful lives in such a condition that they pose no unacceptable risks to the public, to workers or to the environment, and to reuse facilities and sites for new purposes. Simply abandoning or leaving a facility after cessation of operations is not considered an acceptable alternative to decommissioning because, if not decommissioned, they could degrade and potentially present an environmental hazard in the future.

Since decommissioning can be a complex activity, its implementation can take place either soon after final shutdown or in a series of stages lasting a number of years. The formulation of strategic options and the selection of the optimum strategy must be done in accordance with national policies and reflect other technical and non-technical needs, priorities, constraints and infrastructure specific to the facility, owner or country. Thus, some form of national policy and strategy for decommissioning nuclear facilities usually exists, and it is important that it is clearly set out as visible evidence of the concern and intent of the government and the relevant national organizations to ensure that disused nuclear facilities are properly taken care of.

A typical policy should include the following elements: Defined safety and security objectives; allocation of national responsibilities for decommissioning arrangements for providing resources for decommissioning; identification of the main approaches for the decommissioning of nuclear facilities; provisions for managing the radioactive waste generated; and provisions for public information and participation.

The strategy reflects and elaborates the goals and requirements set out in the policy statement. For its formulation, information is needed on the current situation in the country on the arrangements for funding and for managing the radioactive and other waste. The technical options proposed should reflect national needs and imperatives, and take into account the potential impact of decommissioning on the local economy and on the local workforce as well as the views of all relevant stakeholders. The evidence shows that many decommissioning decisions have been based mainly on non-technological factors.

[1] For the sake of brevity, in this publication ‘nuclear facilities’ are taken to mean all facilities at which radioactive material is handled or generated.

This publication seeks to contribute to the development and improvement of the contents of national policies and strategies for the decommissioning of nuclear facilities.

1. INTRODUCTION

1.1. BACKGROUND

All industrial facilities, whether or not they contain radioactive materials, will eventually need to be decommissioned. All countries have had experience in removing from service and in dismantling and demolishing disused industrial and other types of facilities. However, for nuclear and other facilities containing radioactive materials, there is particular concern with the safe, timely and cost effective removal and disposal of radioactive materials, and the reuse/redevelopment of the facilities and their sites for new purposes. In addition to this requirement, there is the need to meet normal engineering, economic and industrial safety goals, and to respond to requirements of regulators and other stakeholders concerning the impact of decommissioning on the economy, health, safety and environment of the local area. The achievement of such a range of goals requires a systematic approach to nuclear decommissioning, covering, inter alia, policy and strategy. This publication provides guidance in the area of policy and strategy.

This report forms part of the IAEA Nuclear Energy Series, in which the apex publication is the Nuclear Energy Basic Principles [1]. Guidance on the implementation of the Basic Principles is contained in the second tier Objectives and Guides. To date, Objectives have been published for radioactive waste management [2], which includes decommissioning. A guide has been published in the series on Policies and Strategies for Radioactive Waste Management [3]. This guide is a sister publication to that on radioactive waste management and there is a close linkage between the two.

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Joint Convention) is the safety driven, international legal instrument in the present context [4]. In its General Safety Provisions, it specifies the legislative and regulatory system needed in a country to facilitate the safe management of spent fuel[2] and radioactive waste. Since decommissioning[2,3] is one of the main generators of radioactive waste, these provisions are considered to apply equally to the activities involved in

[2] This holds true insofar as spent fuel is radioactive waste, which is not applicable to certain nuclear fuel cycles. Any reference to spent fuel in this report should be viewed with this point in mind.

[3] 'Decommissioning' is defined in Ref. [4] as all steps leading to the release from regulatory control of a nuclear facility other than a disposal facility.

decommissioning nuclear facilities. The Joint Convention provides specific requirements for decommissioning in its Article 26. The words 'policy' and 'strategy' are often used interchangeably. In this report, a distinction is made between them: 'policy' is taken to mean the particular goals or requirements for the decommissioning of facilities, while 'strategy' is taken to mean the ways and methods used to implement the policy. These definitions (Section 2) are consistent with the equivalent definitions in the closely related area of radioactive waste management [2, 3].

The main aim of decommissioning is to place facilities in such a condition that they pose no unacceptable risks to the public, to workers or to the environment, and to ultimately release the facilities and sites for new uses. To achieve this, some action is normally required. If facilities were not decommissioned, they could degrade and potentially present an environmental hazard in the future. The cost of not taking prompt action is normally also high. Simply abandoning or leaving a facility after cessation of operations is not considered an acceptable alternative to decommissioning.

The approach to decommissioning is not always the same. Some countries have chosen to decommission their nuclear facilities as soon as they cease to generate nuclear energy (immediate dismantling), others delay the process for a number of years (deferred dismantling), while still others convert their facilities into a form of waste disposal, after ensuring that they are safe (entombment). (These general decommissioning strategies are described in more detail in Section 4.1.3). The choice of approach depends on many factors, some of which are related to national circumstances, although immediate decommissioning is normally regarded as the preferred strategy [5]. Thus, there is usually some form of national policy and strategy for decommissioning nuclear facilities, and it is important that it is clearly set out as visible evidence of the concern and intent of the government and the relevant national organizations to ensure that disused nuclear facilities are properly taken care of.

There is diversity in the types and sizes of the facilities that need to be decommissioned, ranging from small research laboratories, where radioisotopes have been used, to large nuclear fuel reprocessing plants. As a result, the strategies for implementing the policies are sometimes different, although the main elements of policy are likely to be similar from country to country.

As a result of lessons learned, planners and operators of nuclear facilities are being required to consider decommissioning at the earliest possible stage. Operating organizations are required to prepare and maintain a decommissioning plan throughout the lifetime of the facility.

In some countries, national policies and strategies are well established and documented, while in others, they are only inferred from the contents of laws, regulations and guidelines. This is usually because the policy and strategy have

been developed gradually over time and incorporated into legislation. The absence of clearly defined policies and strategies can, however, result in a lack of transparency on particular aspects. Another reason for wishing to have clearly defined policies and strategies is related to the comparative speed with which political changes can occur in a country, thereby affecting policy and strategy. The content of laws and regulations cannot usually be changed quickly, while the revision of national policy and strategy statements is usually less difficult.

This publication has been prepared to help in developing or improving the contents of national policies and strategies for the decommissioning of nuclear facilities. It is intended for the use of persons engaged in preparing, drafting or updating national policies and strategies, and should also be useful to all countries that have yet to establish their national policies and strategies.

This report draws on a number of IAEA publications that address various aspects of decommissioning and refers the reader to particular reports where more detail can be obtained.

1.2. OBJECTIVE

The objective of this publication is to provide guidance on the development of policy and strategies for the decommissioning of nuclear facilities. It is intended as an aid, resource and reference for those engaged in the development or updating of national policies and strategies for the decommissioning of nuclear facilities.

1.3. SCOPE

This publication addresses policies and strategies for the decommissioning of nuclear facilities in a general way that is applicable to all types of nuclear facility, that is, nuclear power plants, research reactors, nuclear fuel cycle facilities, and laboratories using radioactive material. It does not apply to mill tailings or waste disposal sites, but it does apply to surface buildings found at mining and milling sites or at waste disposal sites. It is concerned with the contents of policies and strategies and does not address the development of national laws, regulations and guidelines. It provides an indication of what might be contained in national policies and strategies, but it does not prescribe what the contents should be, since national policy and strategy must be decided at the national level taking into account national priorities and circumstances.

1.4. STRUCTURE

Section 2 provides some basic definitions relevant to this publication. Section 3 sets out the principles underlying the policies and strategies for decommissioning, while Section 4 contains the typical elements of a decommissioning policy and the process for its implementation. In Section 5, the factors influencing the choice of decommissioning strategy are discussed, and the process for strategy selection is set out in Section 6. Annex I contains summaries of the IAEA's Nuclear Energy Basic Principles and Fundamental Safety Principles.

2. DEFINITIONS

The following definitions are used in this publication.

Policy is a set of established goals or requirements for the safe, effective and efficient decommissioning of nuclear facilities. The national policy usually includes a specification of national roles and responsibilities, and is mainly established by the national government.

Strategy is the means for achieving the goals and requirements set out in the national policy for the decommissioning of nuclear facilities. It is normally established by the relevant facility owner or operator.

The line separating policy from strategy is not always clearly defined, and sometimes it is not clear whether an issue should be taken up as policy or strategy. For example, some policy makers might put into policy only the requirement for the decommissioning of nuclear facilities, and then rely on strategy makers to decide on the method for achieving this. Other policy makers might include a requirement for a particular decommissioning approach directly in national policy. Some countries may not distinguish between the two concepts and instead have a national plan that is in fact a combined policy and strategy.

3. PRINCIPLES FOR ESTABLISHING DECOMMISSIONING POLICY AND STRATEGY

The IAEA has established principles that govern the safety and implementation of nuclear energy: the Nuclear Energy Basic Principles [1] and the Fundamental Safety Principles [6]. Both sets of principles are reproduced in the Annex. Many of these principles are relevant to the decommissioning of nuclear facilities. In particular, the decommissioning of a nuclear facility should:

— Provide protection of people and the environment both now and in the future;
— Include a long term commitment to ensuring that sites and waste from them are properly managed;
— Provide efficiency in the use of resources;
— Provide open and transparent interactions with stakeholders.

Other relevant principles include:

— The public should be able to participate in decision making, where relevant (the Aarhus Convention [7][4]);
— The needs of the present must be met without compromising those of future generations (sustainable development [8]).

The above listed principles and considerations may not be explicitly present in the national policy, but they will usually have influenced it as well as the relevant national laws, regulations and guidance that flow from it.

[4] The Aarhus Convention grants the public rights regarding access to information, public participation and access to justice, in governmental decision making processes on matters concerning the local, national and transboundary environment. As of July 2009, it had been signed by 40 (primarily European and Central Asian) countries and the European Union.

4. DECOMMISSIONING POLICY

4.1. TYPICAL ELEMENTS OF A DECOMMISSIONING POLICY

A national policy should reflect national priorities, circumstances, structures, and human and financial resources. It should also be compatible with relevant international instruments and be consistent and coherent with other non-nuclear policies, in particular, those dealing with other hazardous materials.

Some of the elements of national policy may be based on the general principles summarized in Section 3. Others may be specific to the circumstances of the country; for example, the choice of a policy on immediate or deferred decommissioning is likely to be influenced by the availability of a suitable waste repository.

In some countries, the policy on decommissioning may be a separate entity, while in others it may be included as one part of the national policy on radioactive waste management.

The policy should enable a graded approach to be taken to decommissioning, reflecting the level of the hazard posed by the facility to be decommissioned and its complexity.

The following are some of the main elements to be considered in establishing a national policy for decommissioning. Not all of these may be relevant to all countries and therefore some selection may be necessary in developing a policy for a particular country. Equally, other items, not included here, may be important for the policy of a particular country.

4.1.1. Allocation of responsibilities

In most countries, it is accepted that the person or organization that creates waste is responsible for it and for its safe management according to the 'polluter pays principle' (see also Article 21.1 of the Joint Convention [4, 9]); however, national governments also have responsibilities (Preamble to the Joint Convention [4]). Thus, in decommissioning, the operator or licence holder is responsible for the conduct of decommissioning activities. Although in Ref. [4] this is drawn from concerns related to spent fuel and radioactive waste, it is normal to apply this philosophy to the other hazards encountered in decommissioning, such as asbestos, chemicals and general industrial hazards.

If an operator should fail to undertake decommissioning, possibly due to insolvency following an early end to facility operations, the government should take responsibility for the completion of decommissioning and the safe management of waste (Article 21.2 of the Joint Convention [4]).

Governments should establish a legislative and regulatory framework, including the designation of an independent regulatory body, to enforce, inter alia, the regulations for the safe decommissioning of nuclear facilities (Articles 19 and 20 of the Joint Convention [4]). Governments should also ensure that arrangements are implemented for the safe, long term management of any resulting radioactive waste.

Governments must define the role of the regulatory body or bodies (e.g. there may be separate nuclear, environmental, industrial safety and security regulators) with respect to decommissioning policy and strategies. It may be anticipated that the regulators will be involved in the preparation and review of decommissioning policy, ensuring that the policy includes adequate coverage of relevant regulatory requirements.

The national arrangements for managing the radioactive waste from decommissioning should be specified in the national policy, and the interface with national policy on radioactive waste management should be clarified.

To summarize, the decommissioning policy should identify:

— The government departments or other organizations responsible for establishing the legislative and regulatory framework;
— The relevant regulatory bodies and their roles;
— The organization responsible for ensuring that the facility is decommissioned safely, effectively and in a timely manner, and that the materials generated are properly managed (normally the operator/licensee); it should also indicate the national arrangements if the operator/owner is unable to carry out these duties;
— The organization responsible for ensuring that radioactive waste is safely and effectively managed in the long term.

In addition to numerous other requirements, Ref. [5] sets out the specific administrative, legislative and regulatory framework necessary for decommissioning.

4.1.2. Provision of resources

The national policy should set out the arrangements for:

— Establishing the mechanisms for providing the resources or funds for the decommissioning of nuclear facilities;
— Ensuring that there are adequate human resources available to provide for the decommissioning of nuclear facilities, including, as necessary, resources for training, and research and development;

— Providing institutional controls and monitoring arrangements during the various stages of decommissioning.

With regard to the provision of resources, see Article 26 of the Joint Convention [4].

4.1.3. Decommissioning approaches

As discussed in Section 1, there are various generally adopted approaches for decommissioning. Approaches typically being implemented or considered by Member States include *immediate dismantling, deferred dismantling and entombment*. These strategies are, in principle, applicable to all facilities; however, their application to some facilities may not be appropriate owing to political concerns, safety or environmental requirements, technical considerations, local conditions or financial considerations. The following is a short description of each of these decommissioning strategies:

— ***Immediate dismantling*** is the strategy by which the equipment, structures and parts of a facility containing radioactive contaminants are removed or decontaminated to a level that permits the facility to be released for unrestricted use, or with restrictions imposed by the regulatory body. In this case, decommissioning implementation activities begin shortly after the permanent cessation of operations. This strategy implies prompt completion of the decommissioning project and involves the removal of all radioactive material from the facility to another new or existing licensed facility and its processing for either long term storage or disposal.
— ***Deferred dismantling*** (also called safe storage, safe store or safe enclosure) is the strategy in which parts of a facility containing radioactive contaminants are either processed or placed in such a condition that they can be safely stored and maintained until they can subsequently be decontaminated and/or dismantled to levels that permit the facility to be released for unrestricted use or with restrictions imposed by the regulatory body.
— ***Entombment*** is the strategy by which radioactive contaminants are encased in a structurally long lived material until radioactivity decays to a level permitting the unrestricted release of the facility, or release with restrictions imposed by the regulatory body.

These distinctions are not very clear in practice, and often the final approach taken by a country lies somewhere between these categories (e.g. partial dismantling followed by a period of safe enclosure for the remaining parts).

National policy on decommissioning may define the approach to be adopted for decommissioning or it may be left to those responsible for strategy design to determine it. It may specify the time within which spent fuel must be moved from the nuclear reactor to a storage facility away from the reactor, either on- or off-site. It may specify the maximum time that a facility can be left in the state of safe enclosure before decommissioning has to begin.

The factors that may influence the approach adopted are discussed more fully in Section 5.

4.1.4. Safety and security objectives

A common overarching element in national policy for decommissioning is the safety objective. This can be stated as protecting individuals, society and the environment from the harmful effects of ionizing radiation due to the decommissioning of nuclear facilities both now and in the future [4, 6]. In addition, the policy should require, where appropriate, physical protection and security of facilities in order to prevent the unauthorized access of individuals and the unauthorized removal of radioactive material [10].

4.1.5. Radioactive waste management

The national policy should recognize that the decommissioning of nuclear facilities gives rise to radioactive waste. In addition, it should:

— Identify the intended national arrangements for the management of the main types of radioactive waste;
— Identify the end points of the management process (i.e. the final destination of the waste);
— Recognize that some radioactive waste may be potentially hazardous for long periods of time and therefore require long term safety measures.

If this policy is separate from the national policy on spent fuel and radioactive waste management, the links between the two policies should be recognized so that a consistent national approach is presented.

4.1.6. Waste minimization

The national policy may address the need to minimize the generation of radioactive waste at the decommissioning stage of facilities (Articles 4(ii) and 11(ii) of the Joint Convention [4]). In this regard, it may identify some of the

main means for achieving waste minimization in the decommissioning stage of facilities including:

— The recycling and reuse of materials which are free of contamination or only slightly contaminated; and
— The use of the clearance concept for determining the materials that can be released from regulatory control [10, 11].

4.1.7. End points for decommissioning

The national policy may address the final target of the decommissioning work. For example, it may envisage that sites would be released for unrestricted use or that there would be some restrictions on the use of sites after decommissioning. This would have implications for the allowable residual levels of radioactive materials at the sites [12]. Documentation and record keeping are also essential elements of the end-state (see Section 5.8).

4.1.8. Public information and participation

The national policy may indicate the State's intention to inform the public about proposed plans for decommissioning and to consult concerned parties and members of the public to aid in making related decisions [4, 13]. Currently, governments tend to emphasize their commitments to policies of openness and transparency with respect to their intentions and plans on nuclear projects.

4.2. ESTABLISHING AND IMPLEMENTING A DECOMMISSIONING POLICY

A national policy statement must represent the views of all of the organizations concerned in the decommissioning of nuclear facilities. Therefore, an appropriately representative committee should be established to develop the policy or to update an existing policy. It should contain representatives of the regulatory body(ies), the facility owners or operators, the radioactive waste management organization and other organizations with responsibilities in the area of decommissioning. The process for developing policy should take account of all of the topics listed in Section 4.1 and of any others that are specific to the country. If a policy is being updated, account should be taken of all relevant national and international changes and events that have occurred since the previous policy was developed. The draft policy document should be reviewed by all relevant national organizations and then approval of the policy statement by

the government should be sought through appropriate channels; it is generally recognized that these will differ from country to country. The aim is to produce a policy statement that reflects the official position of the government on the decommissioning of nuclear facilities.

The incorporation of national policy into the relevant legislation adds formalization and is a desirable outcome of the policy updating process. However, this may not be necessary if it is clearly understood that the policy statement represents the government position on the subject and provided that it does not cause any conflicts with existing legislation.

Implementation of the policy requires that there is an adequate and appropriate institutional framework for decommissioning in the country. If this does not exist, the initial implementation step should be to establish it. This framework should include an independent regulatory body established to enforce the implementation of the regulations on decommissioning as well as organizations responsible for implementing the decommissioning and managing the radioactive waste. Other governmental bodies may be stakeholders in the process, for example, government organizations concerned with environmental protection or the transport of radioactive materials, funding bodies and local governmental organizations. Responsibilities for implementing the various aspects of national policy should be allocated within the relevant organizations.

5. FACTORS INFLUENCING THE CHOICE OF DECOMMISSIONING STRATEGY

The operating organization is normally responsible for defining the decommissioning strategy on which the planning for decommissioning will be based. The strategy should be consistent with national decommissioning and waste management policies.

The three main strategy options for decommissioning are set out in Section 4.1.3. However, it is recognized that the actual decommissioning strategies in each country are likely to be less distinct than indicated in Section 4.1.3 because they are influenced by local and national circumstances.

This section describes the factors to be considered in determining decommissioning strategies, that is, how the choice between the options of Section 4.1.3 is likely to be influenced by the national situation. Many of the topics discussed in this section are the subject of specific IAEA reports, which are referenced to allow a more detailed study if required.

5.1. MEETING POLICY REQUIREMENTS

It is clear that the key policy requirements regarding national administrative, legislative and regulatory infrastructure must be in place before proceeding with decommissioning. Similarly, there must be a recognized competent organization capable of performing the decommissioning work in a safe and efficient manner. In countries where decommissioning has not been undertaken, it is likely that regulations relating to decommissioning will have to be developed and that regulators will have to be appropriately trained in the special requirements for decommissioning [14].

The established national policy on decommissioning may have the effect of limiting the choice of possible strategies, for example, if one or more of the general strategies listed in Section 4.1.3 is excluded for political or other non-technical reasons. Reference [15] provides guidance in cases when the selection of a decommissioning strategy is forced and constrained by prevailing factors and conditions.

A decision on the decommissioning strategy may be influenced by the intentions of the site owner or the government with respect to the future of the site. If the site is urgently required for locating new facilities, then immediate dismantling would be appropriate. There may be other reasons, for example, related to public opinion for wishing to urgently remove the facility and to release the land.

5.2. AVAILABILITY OF RESOURCES

Ideally, funding arrangements for decommissioning should be established early in the life of a nuclear facility to enable decommissioning to be carried out in a safe, timely and efficient manner. These arrangements can vary from an independent decommissioning fund to the provision of funds directly from the government.

Certainly, the availability of funds is a key issue for the development of a strategy, and can determine whether or not immediate decommissioning can go ahead, the rate at which it can be implemented, or whether deferral will be necessary. (If full funding is not available, then early spending could focus on ensuring nuclear security and reducing occupational hazards to allow a period of deferral while adequate funds are accumulated.)

Over the last few decades, many IAEA Member States have established legal provisions for the collection and accumulation of decommissioning funds. Most decommissioning funds for nuclear power plants are accumulated based on electricity surcharges. However, there is still little experience on how these funds

will be used in the long term. In earlier times, decommissioning was not considered during the design, construction and operation of nuclear facilities. For many nuclear facilities, therefore, there are no decommissioning funds available when the facilities reach the end of their operating life. If no funds are available from the operating organization or from the government, the facility must be placed in deferred dismantling mode until they become available. The financial aspects of decommissioning are discussed in more detail in Ref. [16].

5.3. COSTS

For the purposes of planning, it is necessary to have some estimate of the likely cost of decommissioning options as this may be an important factor in determining strategy. Cost estimates for future activities are necessarily uncertain, but several international working groups, sponsored by the European Union, the IAEA and the OECD Nuclear Energy Agency, are currently developing standardized definitions and structures for decommissioning cost estimates [17].

5.4. SPENT FUEL AND RADIOACTIVE WASTE MANAGEMENT

Immediate decommissioning is normally the preferred strategy [5]; however, it is associated with the greatest amounts of radioactive waste since there is no time for radioactive decay to occur. This is more important for some types of facilities than for others; for nuclear power plants there are usually significant benefits, in terms of reduction of waste amounts due to radioactive decay, to be obtained from deferral, while for facilities in which long lived radionuclides are used, such as reprocessing plants, the waste reduction is much less.

If there is no available repository for the waste from decommissioning, one option is to proceed with immediate decommissioning and to temporarily store the spent fuel and radioactive waste from decommissioning at the facility itself or at an intermediate store, pending the availability of disposal facilities. Another option is to defer the decommissioning, thereby not creating waste, until a waste management solution is available.

The management of radioactive waste from decommissioning is discussed in two IAEA reports [18, 19].

5.5. SAFETY AND SECURITY

Irrespective of the decommissioning strategy chosen, it is necessary to ensure the protection of workers and the public. However, the potential radiation doses to workers can vary depending on the option chosen.

In the case of nuclear power plants, the removal of the fuel, process fluids, and operational waste from a reactor and, if practicable, from the site removes the main radiological and security risks presented by the facility. The remaining residual radioactive material presents a smaller, but still significant risk to workers, the public and the environment during decommissioning. One argument for delayed dismantling in the past has been that a prolonged period of safe enclosure between the initial and final phases of decommissioning allowed radioactive decay, which both reduced local dose rates to workers and allowed the re-categorization of some radioactive waste. Technological progress over the last 10 to 15 years in electronics, robotics and remote handling has considerably reduced the need for manned access to the more highly contaminated areas and for large scale commercial operations, which has reduced the importance of radiological factors in choosing a decommissioning strategy. Radiation protection aspects of decommissioning are discussed more fully in Refs [20, 21].

Should off-site facilities for spent fuel or the higher radioactivity categories of waste be unavailable at the time of decommissioning, then the need for suitable interim storage will have to be recognized in producing the decommissioning strategy. The early removal of fuel from the site (or, for example, into casks on-site) greatly eases the dismantling of reactor systems and components because the associated instrumentation and biological shielding are no longer required. Ideally, therefore, the early removal and/or storage of fuel are to be preferred in nuclear reactor decommissioning strategies, which could commence in advance of the cessation of plant operations. If fuel remains in storage on site, then appropriate security and safeguards controls will be necessary, even if the facility itself is completely dismantled.

5.6. REGULATORY ASPECTS

Immediate dismantling permits the regulatory body to effect a direct transition from regulating facility operations to regulating decommissioning. It provides for continuity in the regulatory process and the possibility of regulatory staff familiar with the operational facility being involved in its decommissioning. Thus, the decommissioning could be overseen by an experienced and knowledgeable regulatory body, which may be considered a positive aspect of immediate dismantling.

5.7. MULTIPLE FACILITIES

Strategies for decommissioning are likely to be influenced when there are several nuclear facilities located on the same site. If more than one facility is located on a site, it may be beneficial to place the oldest facilities in a deferred decommissioning mode until the remaining facilities are closer to permanent shutdown. The ongoing operations at the site will ensure the safety and security of the facility. In addition, the deferral will make it possible for the decommissioning process to be more efficient because it will allow a workforce to freely move between the facilities.

5.8. KNOWLEDGE MANAGEMENT

In planning and implementing decommissioning, arrangements should be put into place to ensure that the necessary information is available and preserved, for example, in the forms of records. When there are significant delays between permanent shutdown and the completion of dismantling, problems can arise due to the loss of knowledge about the facility. This is due to the unavailability of key members of the operational workforce to assist in planning or to supervise the decommissioning work. In this regard, immediate dismantling offers clear advantages. The subject of knowledge management in the context of decommissioning is discussed in two IAEA reports [22, 23].

5.9. SOCIAL AND ECONOMIC IMPACTS

The selection of a particular strategy for the decommissioning of a facility can have some significant social and economic impacts at the local, regional and national levels. The shutdown of a large facility will have a direct impact on local employment. The social and economic impacts of the closure of a facility may be the most important aspects of any decommissioning strategy selection, because they directly influence employment and local revenues. If the duration of the decommissioning is spread over an extended period, the social and economic impacts of facility closure may be less acute. However, a long period of safe enclosure with little involvement of the workforce may be unacceptable to the local communities.

The number of workers needed to implement a decommissioning strategy is dependent on the strategy selected and the type of facility to be decommissioned. For most facilities, the number of employees needed is generally less than the number employed during facility operations. If deferred dismantling is selected

as the option, the workforce will be reduced considerably during the enclosure period and then may increase again during the dismantling phase. For small facilities (e.g. research reactors) undergoing either immediate or deferred dismantling, the number of workers might increase during the decontamination and dismantling activities.

An entombment strategy may be difficult for the local population to accept because a structure containing radioactive waste is normally left after the decommissioning activities are completed. This structure is permanent and may be visible to the local population. Therefore, the adoption of this strategy is likely to require extensive interaction with the concerned public. Regulatory control will remain until a specified end-state is reached.

The potential demand for reuse of the site either for specific restricted or unrestricted purposes is a consideration for decommissioning strategy decision makers. Reuse of the site is generally not compatible with entombment and may be complicated if deferred dismantling is chosen, except in the case where reuse involves the siting of new nuclear facilities on the existing site. The socioeconomic aspects of decommissioning are discussed more fully in an IAEA report [24].

5.10. STAKEHOLDER CONSIDERATIONS

Currently, any waste management or decommissioning decision requires thorough public examination and the involvement of stakeholders. Stakeholders include, but are not limited to, local communities, elected representatives, and technical intermediaries between the general public and decision makers as well as the facility owner and other technically involved organizations.

From studies of stakeholder involvement in past decommissioning decisions, the one generality that can be drawn is that each decision is unique. The diversity of relevant social, political, economic and cultural environments makes it difficult to develop guidance that is universally applicable. Nevertheless, it is clear that decommissioning strategy can be influenced by opinions of stakeholders and thus is an important factor in decision making. Stakeholder involvement in nuclear issues is discussed in Ref. [13].

5.11. FACILITY RELATED STRATEGY ISSUES

Much of the previous discussion has generally concerned nuclear power plants; the issues affecting choice of strategy for other types of facility are not always the same.

5.11.1. Research reactors

The decommissioning of research reactors poses many technical issues similar to those at nuclear power plants; the major differences are likely to be related to:

— *Scale.* Research reactors are much smaller and therefore produce smaller volumes of waste than nuclear power plants.
— *Contamination/activation.* Research reactors may have been used for experiments with fuel (including high enriched uranium) and other materials that may have generated unknown radioactive material. Consequently, a comprehensive characterization of the facility must be performed before a final decommissioning strategy is decided.
— *Location.* Research reactors are often located in urban areas, creating special problems for decommissioning.
— *Funding.* Funds have not been put aside for decommissioning, and usually funds from the government are the only possible source.

The decommissioning of research reactors is not usually a significant issue in countries with a well developed nuclear infrastructure. There is usually sufficient expertise and arrangements in place for the safe storage or disposal of the smaller volumes of radioactive waste. However, since many research reactors are located in countries with few or no other nuclear facilities, skills, knowledge and facilities are limited or absent. The decommissioning of research reactors in these countries will often require expertise from outside the country. Bilateral schemes exist for the removal of spent fuel from research reactors and its return to the manufacturer.

Immediate dismantling is normally the favoured option for taking advantage of the experienced workforce and avoiding the loss of corporate memory. However, the lack of funding, national infrastructure and expertise in some countries has led to a deferral of decommissioning. Further guidance on the decommissioning of research reactors is available in Refs [20, 25].

5.11.2. Medical and other small scale facilities

There are medical and other laboratories that routinely utilize radioactive material in almost all countries. Their decommissioning is potentially the least challenging technically since the scale is usually small, there is no activation, and many of the radio-chemicals used are short lived.

There may be a history of experiments and events (e.g. spills), which means that there is uncertainty about the inventory, particularly in drains or other

inaccessible parts of the facility. Characterization of the facility is therefore of great importance in identifying any radiological and non-radiological hazards.

Early dismantling is usually favoured. The advantages include utilization of staff with knowledge of previous activities in the laboratory and the opportunity to reuse the site at an early occasion, especially when it is a hospital or university building in an urban setting.

Further guidance on the decommissioning of small nuclear facilities is given in Refs [26, 27].

5.11.3. Fuel cycle and research facilities

Fuel cycle and research facilities include a wide variety of different types of sites and facilities undertaking various processes, often with extensive use of chemicals and diverse radionuclides. Many are large, particularly military facilities, but some are relatively small.

The decommissioning of these facilities/sites will be influenced by many factors including:

— The extent of activities, i.e. size and complexity of operations: The potential for criticality and the presence of a variety of chemicals.
— The continued use of the site: Only part of it may be decommissioned while the remainder continues to operate normally.
— The radioactive inventory: May include long lived alpha emitting and fissile materials.

Many of the radionuclides involved are long lived and therefore, the technical advantages of deferral will be limited. The reasons for deferral of decommissioning are most likely associated with considerations of radioactive and other waste disposal, funding availability and integration with plans for other facilities on the site. The waste may require substantial processing before it can be released for disposal, and deferral will often be necessary to allow new plants to be built for this purpose. However, there are often political and public pressures in favour of the early decommissioning of such large scale plants.

In smaller research facilities, the issues are likely to be similar to those in research reactors with early dismantling being the favoured option, if resource availability allows. Further guidance on the decommissioning of nuclear fuel cycle facilities is given in Ref. [28].

6. STRATEGY SELECTION

The selection of the preferred decommissioning strategy can be made by evaluating the influencing factors (some of which are listed in Section 5) in terms of their attributes for a specific facility or site. This evaluation can benefit from the use of formal decision aiding techniques [15]. Many aspects must be addressed; the challenge is to achieve the optimal solution in a logical, structured and justifiable manner.

It is important to ensure that all three basic strategies (Section 4.1.3) 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). The process of selecting a decommissioning strategy typically starts by collecting and assessing available data and by considering all potentially influencing factors. A set of possible decommissioning options is then formulation together with a preliminary decommissioning plan for implementing each option. These plans can be relatively brief at this stage, but sufficiently well defined that the associated major hazards and risks can be determined. The next step is to perform strategy selection studies. During this process, formal decision aiding techniques and workshop discussion sessions might be employed. An example of a formal decision aiding technique is multi-attribute utility analysis (MUA), an effective and efficient way of showing the impact of each strategy option and of reaching conclusions based on all of the influencing factors. It should be noted, however, that strategy selection studies (even when using formal methods such as MUA) involve aspects that are judgmental and subjective.

In assembling a team to perform this work, the operating organization should ensure that all relevant stakeholders are represented, or at least consulted, with the aim of reaching a conclusion that all parties are in agreement with.

The appendix to the IAEA's Safety Reports Series No. 50 [14] outlines a process for strategy development. The appendix to IAEA-TECDOC-1478 [15] provides some examples of how strategies for decommissioning were decided upon in different IAEA Member States and show how the intended strategy was modified to take account of national circumstances and constraints.

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Annex

THE IAEA NUCLEAR ENERGY BASIC PRINCIPLES AND THE FUNDAMENTAL SAFETY PRINCIPLES

A–1. IAEA NUCLEAR ENERGY BASIC PRINCIPLES [A–1]

Principle 1: Benefits

The use of nuclear energy should provide benefits that outweigh the associated costs and risks.

Objective: *Manage safely, optimally and cost effectively all types of radioactive waste, contaminated facilities and sites to prevent and reduce risks incurred by their creation.*

Principle 2: Transparency

The use of nuclear energy should be based on open and transparent communication of all its facets.

Objective: *Build long term trust among stakeholders engaged in the management of radioactive waste, decommissioning, and contaminated facilities and sites.*

Principle 3: Protection of people and the environment

The use of nuclear energy should be such that people and the environment are protected in compliance with the IAEA safety standards and other internationally recognized standards.

Objective: *Comply with internationally recognized safety and environmental protection standards in all phases of radioactive waste and liability management.*

Principle 4: Security

The use of nuclear energy should take due account of the risk of the malicious use of nuclear and other radioactive material.

Objective: *Implement physical protection systems of all radioactive materials complying with internationally recognized security standards and codes.*

Principle 5: Non-proliferation

The use of nuclear energy should take due account of the risk of the proliferation of nuclear weapons.

***Objective**: Design and implement proliferation resistant radioactive waste management solutions minimizing the risk of diversion of nuclear materials.*

Principle 6: Long term commitment

The use of nuclear energy should be based on a long term commitment.

***Objective:** Ensure that adequate provision is made for the safe and sustainable management of waste, contaminated facilities and sites over appropriate timescales.*

Principle 7: Resource efficiency

The use of nuclear energy should be efficient in using resources.

***Objective**: Promote the effective use of technologies and systems for waste management, decommissioning and environmental remediation, and minimize the resources required through application of efficient principles and practices.*

Principle 8: Continual improvement

The use of nuclear energy should be such that it pursues advances in technology and engineering to continually improve safety, security, economics, proliferation resistance, and protection of the environment.

***Objective:** Utilize advances in technology and other relevant systems and processes ensuring implementation of the most appropriate practices in radioactive waste management, decommissioning and environmental remediation.*

A–2. IAEA FUNDAMENTAL SAFETY PRINCIPLES [A–2]

Principle 1: Responsibility for safety

The prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks.

Principle 2: Role of government

An effective legal and governmental framework for safety, including an independent regulatory body, must be established and sustained.

Principle 3: Leadership and management for safety

Effective leadership and management for safety must be established and sustained in organizations concerned with, and facilities and activities that give rise to, radiation risks.

Principle 4: Justification of facilities and activities

Facilities and activities that give rise to radiation risks must yield an overall benefit.

Principle 5: Optimization of protection

Protection must be optimized to provide the highest level of safety that can reasonably be achieved.

Principle 6: Limitation of risks to individuals

Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.

Principle 7: Protection of present and future generations

People and the environment, present and future, must be protected against radiation risks.

Principle 8: Prevention of accidents

All practical efforts must be made to prevent and mitigate nuclear or radiation accidents.

Principle 9: Emergency preparedness and response

Arrangements must be made for emergency preparedness and response for nuclear or radiation incidents.

Principle 10: Protective actions to reduce existing or unregulated radiation risks

Protective actions to reduce existing or unregulated radiation risks must be justified and optimized.

REFERENCES TO THE ANNEX

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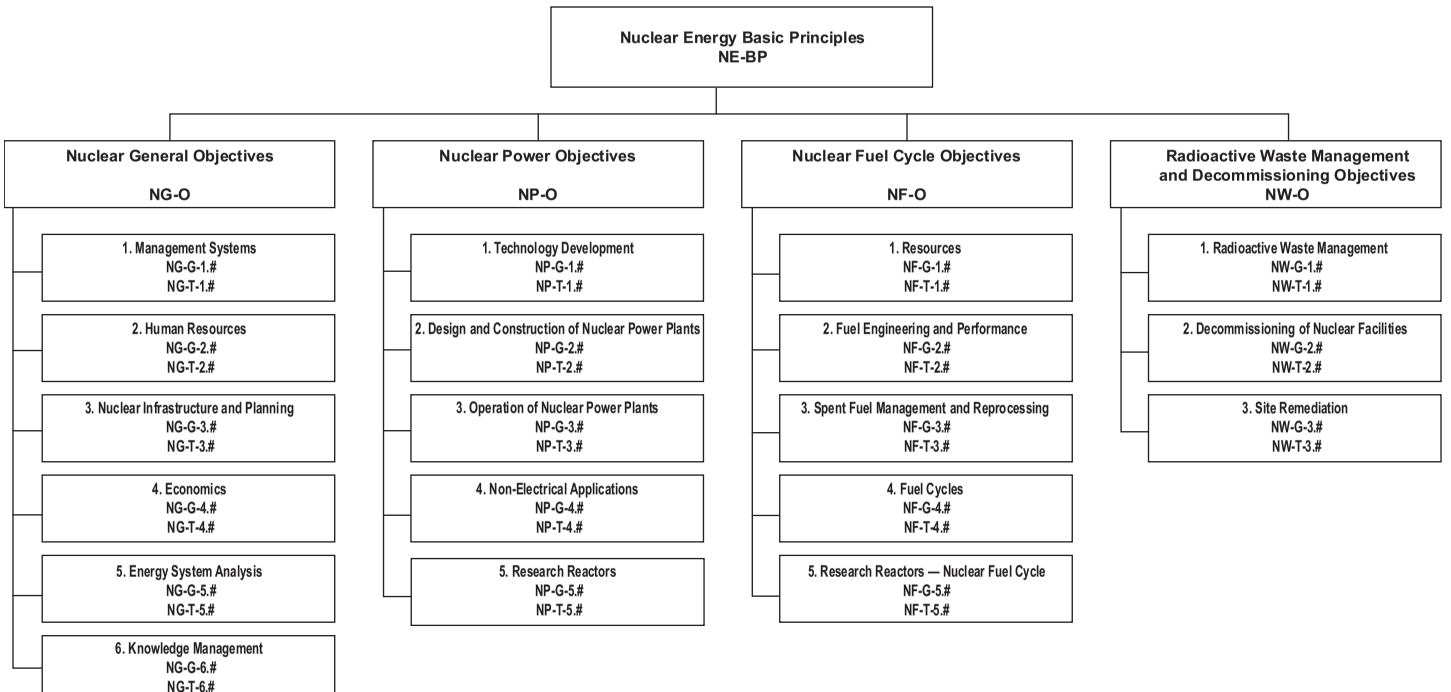

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