BASIC PROFESSIONAL TRAINING COURSE

Module XVIII

Decommissioning

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Background

In 1991, the General Conference (GC) in its resolution RES/552 requested the Director General to prepare 'a comprehensive proposal for education and training in both radiation protection and in nuclear safety' for consideration by the following GC in 1992. In 1992, the proposal was made by the Secretariat and after considering this proposal the General Conference requested the Director General to prepare a report on a possible programme of activities on education and training in radiological protection and nuclear safety in its resolution RES1584.

In response to this request and as a first step, the Secretariat prepared a Standard Syllabus for the Post-graduate Educational Course in Radiation Protection. Subsequently, planning of specialised training courses and workshops in different areas of Standard Syllabus were also made. A similar approach was taken to develop basic professional training in nuclear safety. In January 1997, Programme Performance Assessment System (PPAS) recommended the preparation of a standard syllabus for nuclear safety based on Agency Safely Standard Series Documents and any other internationally accepted practices. A draft Standard Syllabus for Basic Professional Training Course in Nuclear Safety (BPTC) was prepared by a group of consultants in November 1997 and the syllabus was finalised in July 1998 in the second consultants meeting.

The Basic Professional Training Course on Nuclear Safety was offered for the first time at the end of 1999, in English, in Saclay, France, in cooperation with Institut National des Sciences et Techniques Nucleaires/Commissariat a l'Energie Atomique (INSTN/CEA). In 2000, the course was offered in Spanish, in Brazil to Latin American countries and, in English, as a national training course in Romania, with six and four weeks duration, respectively. In 2001, the course was offered at Argonne National Laboratory in the USA for participants from Asian countries. In 2001 and 2002, the course was offered in Saclay, France for participants from Europe. Since then the BPTC has been used all over the world and part of it has been translated into various languages. In particular, it is held on a regular basis in Korea for the Asian region and in Argentina for the Latin American region.

In 2015 the Basic Professional Training Course was updated to the current IAEA nuclear safety standards. The update includes a BPTC text book, BPTC e-book and 2 "train the trainers" packages, one package for a three month course and one package is for a one month course. The" train the trainers" packages include transparencies, questions and case studies to complement the BPTC.

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Editorial Note

The update and the review of the BPTC was completed with the collaboration of the ICJT Nuclear Training Centre, Jožef Stefan Institute, Slovenia and IAEA technical experts.

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1 INTRODUCTION

Learning objectives

After completing this chapter, the trainee will be able to:

1. *Define decommissioning.*
2. *List the aspects of decommissioning.*
3. *List the strategies for decommissioning.*
4. *List the main IAEA Standards relating to decommissioning.*

The terms siting, design, construction, commissioning, operation and decommissioning are normally used to describe the six major stages of the lifetime of an authorized facility and of the associated licensing process. 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 facility (except for a disposal facility for radioactive waste, for which the term 'closure' instead of 'decommissioning' is used). Aspects of decommissioning have to be considered throughout the other five major stages of the facility.

Decommissioning: administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility.

Aspects of decommissioning typically include **planning for decommissioning, conducting decommissioning actions and terminating the authorization**. There may be a period of transition between permanent shutdown and the time when authorization of decommissioning actions is granted.

Decommissioning is performed using a graded approach to achieve a progressive and systematic reduction of radiological hazards. Decommissioning is undertaken on the basis of planning and assessment to ensure the safety, and the protection of workers and the public, and protection of the environment.

Decommissioning actions are the procedures, processes and work activities that are described in the approved final decommissioning plan. Decommissioning actions are considered completed when the approved end state of the facility has been reached. Subject to national legal and regulatory requirements, this end state is a result of conducting decontamination and/or dismantlement, waste management and clean-up, leading to the release of the facility from regulatory control with or without restrictions on future use.

Planning for decommissioning begins at the design stage of the facility and includes the collection of information and data relevant for decommissioning to facilitate it, selection of a decommissioning strategy, performance of a radiological characterization of the facility, preparation of a final decommissioning plan, submission of the plan to the regulatory body for review and approval, and any activities regarding public communication and consultation required by national requirements.

Conducting decommissioning actions includes managing the project, implementing the approved final decommissioning plan, managing radioactive waste and non-radioactive waste, and demonstrating that the facility meets the end state criteria specified in the final decommissioning plan. These activities are performed by the licensee. In parallel, supervisory activities are conducted by the regulatory body.

Termination of the authorization involves demonstration of compliance with the conditions of the authorization for decommissioning of the facility (i.e. meeting the end state criteria), withdrawal of this authorization for the facility, and release of the facility for restricted or unrestricted use.

Strategies for decommissioning that have been adopted or are being considered by member states include **immediate dismantling** and **deferred dismantling**. In principle, these two possible decommissioning strategies are applicable to all facilities.

A combination of these two strategies may be considered practicable on the basis of safety requirements or environmental requirements, technical considerations and local conditions such as the intended future use of the site, or financial considerations. Entombment, in which all or part of the facility is encased in a structurally long lived material, is not considered a decommissioning strategy and is not an option in the case of a planned permanent shutdown. It may be considered a solution only under exceptional circumstances, (e.g. following a severe accident).

1.1 IAEA standards

The fundamental safety objective and the safety principles and objectives that provide the bases for the IAEA's safety standards and its safety related programme are established in Fundamental Safety Principles [1].

The general safety requirements regarding decommissioning are covered in Decommissioning of Facilities, IAEA General Safety Requirements No. GSR Part 6 [2]. In this document requirements are given regarding protection of people and of the environment, responsibilities associated with decommissioning, management of decommissioning, decommissioning strategy and financing. GSR Part 6 also contains requirements for planning of decommissioning during the lifetime of the facility, the conduct of decommissioning actions and their completion, and the termination of authorization for decommissioning. This document applies to nuclear power plants, research reactors, other nuclear fuel cycle facilities including predisposal waste management facilities, facilities for processing naturally occurring radioactive material (NORM), former military sites and relevant medical facilities, and industrial facilities and research facilities. GSR Part 6 supersedes the Safety Standard Decommissioning of Facilities Using Radioactive Materials [3].

There are currently three Safety Guides regarding the decommissioning of specific types of facilities [4, 5, 6]. Three other Safety Guides address important aspects of decommissioning that are of interest for the decommissioning of all types of facilities [7, 8, 9].

The Safety Guide Decommissioning of Nuclear Power Plants and Research Reactors [4] deals with key issues specific to decommissioning of nuclear reactors, selection of a decommissioning option (decommissioning strategy), issues that facilitate decommissioning, the process of planning and safety assessment for decommissioning, critical tasks and management of decommissioning, and finally completion of decommissioning. Other Safety Guides cover similar topics for nuclear fuel cycle facilities [5] and medical, industrial and research facilities [6].

The Safety Guide Safety Assessment for the Decommissioning of Facilities Using Radioactive Material [7] provides recommendations for the development and review of the safety assessment for decommissioning activities and guidance on the review of the safety assessment. It also provides guidance for the regulatory framework within which a safety assessment is prepared.

One of the most demanding subjects during decommissioning is clearance of different materials. Since the regulatory body may use different clearance criteria for bulk amounts of materials from decommissioning, in the Safety Guide Application of the Concepts of Exclusion, Exemption and Clearance [9] guidance to national authorities and operating organisations on the application of the concepts of clearance and exclusion are given.

Relevant standards relating to the fulfilment of fundamental safety principles also apply during decommissioning; for example, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [10] (usually referred to as Basic Safety Standards, BSS) and others listed as references [11] and [12].

1.2 Questions

1. Why is a graded approach used in the performance of decommissioning?
2. What set of actions comprise decommissioning?

3. What are the stages of decommissioning planning?
4. What actions are taken in conducting decommissioning?
5. When is the authorization terminated?

2 DECOMMISSIONING PROCESS

Learning objectives

After completing this chapter, the trainee will be able to:

1. *Describe the protection of people and the environment.*
2. *List the responsibilities of the government.*
3. *List the responsibilities of the regulatory body.*
4. *List the responsibilities of the licensee.*
5. *Define immediate and deferred dismantling.*
6. *Describe the process of selecting a decommissioning strategy and relevant issues.*
7. *Describe what factors facilitate decommissioning.*

The time period to complete decommissioning activities for facilities, e.g. nuclear power plants and research reactors, may typically range from a few years to a decades. As a consequence, decommissioning may be carried out in one continuous operation following shutdown or in a series of discrete operations over time.

Decommissioning may include the phased release of parts of the nuclear installation or of the site from regulatory control, before the decommissioning process for the entire installation or site is complete. However, the potential safety implications with respect to the interaction between any decommissioning work and any continuing nuclear operations need to be addressed on a case by case basis.

Subject to national legal and regulatory requirements, a nuclear installation or its remaining parts may also be considered decommissioned if incorporated into a new or existing facility, even if the site at which it is located is still under regulatory or other institutional control. This could apply, for example, to the decommissioning of a nuclear installation located on a multifacility site.

There are many factors that have to be addressed to ensure the safety of nuclear reactors and other facilities using radioactive materials during their operational phase. Some of these factors continue to apply during decommissioning, but decommissioning gives rise to issues that are in some respects different from those prevailing during the operation of the installation. These issues need to be considered in an appropriate way to ensure overall safety during decommissioning.

2.1 Protection of people and the environment

Consideration must be given to the radiation protection of workers, members of the public and the environment, not only during the course of decommissioning but also as a result of any subsequent occupancy of the decommissioned site. National radiation protection requirements need to be established in line with the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [10].

Optimization of protection and safety

Exposure during decommissioning is considered to be planned exposure situation and the relevant requirements of the Basic Safety Standards are applied accordingly during decommissioning.

The relevant dose limits for the exposure of workers and members of the public are applied during decommissioning. Radiation protection of persons who are exposed as a result of decommissioning actions are optimized with due regard to the relevant dose constraints. In addition the provision for protection from exposure due to an incident is also provided.

Compliance with national environmental protection regulations and the requirements of the Basic Safety Standards addressing protection of the environment is maintained during decommissioning and beyond if the facility is released with restrictions on future use.

Graded approach

A graded approach is used for all aspects of decommissioning in determining the scope and level of detail for any particular facility, consistent with the magnitude of the possible radiation risks arising from the decommissioning.

The type of information and the level of detail in the decommissioning plans and supporting planning documents, including the safety assessment[1], are commensurate with the type, scale, complexity, status and stage in the lifetime of the facility and with the hazards associated with its decommissioning.

Conducting decommissioning by the licensee and its regulatory oversight is commensurate with the magnitude of the hazards and risks (e.g. Safety Assessment, Emergency Response Arrangements). For all facilities planning to and undergoing decommissioning a safety assessment is made.

The final decommissioning plan is supported by a safety assessment addressing the planned decommissioning actions and incidents that may occur or situations that may arise during decommissioning.

2.2 Responsibilities

When a nuclear facility is taken out of service, responsibility for the

[1] Safety assessment of decommissioning is described in detail in Chapter 4.

installation may be transferred to a different organization, which becomes the operating organization of the installation for the decommissioning phase. The **operating organization of the installation undergoing decommissioning is ultimately responsible for the safety of the installation during the decommissioning operations**. For such transference to be effective, a complete set of records and drawings are maintained and passed on to the new operating organization. Decommissioning activities may involve many different organizations, including contractors and subcontractors who may not be familiar with nuclear installations, and it is of prime importance to define clearly the responsibilities between the different organizations.

Responsibilities of the government

The government needs to establish and maintain a governmental, legal and regulatory framework within which all aspects of decommissioning, including management of the resulting radioactive waste, can be planned and carried out safely. This framework includes a clear allocation of responsibilities, provision of independent regulatory functions and requirements for financial mechanisms for decommissioning.

The responsibilities of the government include:

- establishing a national policy for decommissioning and for the management of the resulting radioactive waste;
- establishing and maintaining the legal, technical and financial responsibilities for organizations involved in decommissioning, including decommissioning authorization and for the management of the resulting radioactive waste;
- ensuring that the necessary scientific and technical expertise remains available for both the licensee and for the support of regulatory review and other independent national review functions;
- establishing a mechanism to ensure adequate financial resources are available when needed for safe decommissioning and for the management of the resulting radioactive waste.

Responsibilities of the regulatory body

The regulatory body regulates all aspects of decommissioning, from the siting and design of the facility to the completion of decommissioning actions and the termination of authorization. The regulatory body must establish the safety requirements for decommissioning and adopt regulations and guides, including management of the resulting radioactive waste, and takes actions to ensure that the regulatory requirements are met.

The responsibilities of the regulatory body include:

- establishing criteria and the timeframe for authorization of decommissioning;
- establishing criteria for safety, radiation protection and

environmental protection for the decommissioning of facilities;
- establishing requirements for financial assurance for decommissioning and for a mechanism to ensure that adequate resources are available when necessary for safe decommissioning in the case where the government has delegated this to the regulatory body;
- establishing requirements for the planning of decommissioning;
- giving interested parties an opportunity to provide comments on the final decommissioning plan and supporting documents before approval based on national requirements;
- inspecting and reviewing decommissioning actions and taking enforcement actions in case of non-compliance with the national legal and regulatory framework and the authorization or licence conditions and safety requirements established by the regulatory body;
- promoting a safety culture in order to encourage a questioning and learning attitude towards safety and to discourage complacency;
- establishing requirements for the collection and retention of records and reports relevant to decommissioning;
- evaluating the end state of a decommissioned facility and deciding whether the conditions have been met to allow the termination of authorization;
- establishing requirements and criteria for the termination of authorization and especially when facilities are released with restrictions on future use;
- terminating the authorization when the licensee has demonstrated that the approved end state has been met.

Responsibilities of the licensee

The licensee implements planning for decommissioning and carries out the decommissioning actions in compliance with the authorization and with requirements derived from the national legal and regulatory framework. The licensee is responsible for all aspects of safety, radiation and environmental protection during decommissioning.

The responsibilities of the licensee include:
- selecting a decommissioning strategy as the basis for preparing and maintaining decommissioning plans (initial and final) throughout the lifetime of the facility;
- preparing and submitting an initial decommissioning plan and its updates for review by the regulatory body;
- establishing and implementing an integrated management system;
- fostering a safety culture in order to encourage a questioning and learning attitude towards safety and to discourage complacency;
- estimating the cost of decommissioning actions and providing financial assurances and resources to cover the costs associated with safe decommissioning, including management of resulting

radioactive waste;
- notifying the regulatory body prior to permanent shutdown of the facility;
- submitting a final decommissioning plan and supporting documents for review and approval by the regulatory body, in accordance with national regulations, in order to obtain authorization for decommissioning;
- managing the decommissioning project and performing decommissioning actions;
- managing remaining operational waste and all waste from decommissioning;
- ensuring that the facility is maintained in a safe configuration during the transition and until approval of the final decommissioning plan;
- performing safety assessments and environmental impact assessments in relation to decommissioning actions;
- preparing and implementing appropriate safety procedures, including emergency plans;
- ensuring that properly trained, qualified and competent staff are available for the decommissioning project;
- performing radiological surveys in support of decommissioning;
- ensuring that end state criteria have been met by performing a final survey;
- keeping and retaining records and submitting reports as required by the regulatory body.

2.3 Decommissioning strategy

A specific decommissioning strategy, among other things, defines the timing and the sequencing of decommissioning activities. Options can range from immediate dismantling and removal of all radioactive materials from the site, allowing unrestricted release, to an option of deferred dismantling when, for various reasons, dismantling is postponed.

In the case of **immediate dismantling**, decommissioning actions begin shortly after permanent shutdown of the facility. Equipment, structures, systems and components of a facility containing radioactive material are removed and/or decontaminated to a level that permits the facility to be released from regulatory control for unrestricted use, or released with restrictions on its future use.

Immediate dismantling - decommissioning actions begin shortly after permanent shutdown.

In the case of **deferred dismantling**, after removal of the nuclear fuel from the facility (for nuclear installations), all or part of a facility containing radioactive material is either processed or placed in such a condition that it can be put in safe storage and the facility maintained until it is subsequently decontaminated and/or dismantled. Deferred dismantling may involve early dismantling of some parts of the facility and early processing of some radioactive material and its removal from the facility, as preparatory steps for safe storage of the remaining parts of the facility.

Deferred dismantling - all or part of a facility containing radioactive material is either processed or placed in such a condition that it can be put in safe storage and the facility maintained until it is subsequently decontaminated and/or dismantled.

Other approaches, like entombment, in which all or part of the facility is encased in a structurally long lived material, or in situ disposal involving encapsulation of the reactor and subsequent restriction of access, are not as a considered decommisioning strategy and these approaches are not an option in the case of planned permanent shutdown. Only under exceptional circumstances, (e.g. following a severe accident), could entombment be considered as a solution.

Selecting a decommissioning strategy

The licensee selects a decommissioning strategy, which forms the basis for the planning for decommissioning. The strategy needs to be consistent with national policy on decommissioning and radioactive waste management. The IAEA Safety Report Decommissioning Strategies for Facilities Using Radioactive Material [12] provides information that can be used by decision makers to decide on which decommissioning strategy is best for a particular facility.

The **preferred decommissioning strategy is immediate dismantling**. However, there may be situations in which immediate dismantling is not a practicable strategy when all relevant factors are considered.

The selection of a decommissioning strategy is justified by the licensee. The licensee demonstrates that, for the strategy selected, the facility will be maintained in a safe configuration at all times and will be decommissioned, and that no undue burdens will be imposed on future generations.

If the shutdown of a facility is sudden, the decommissioning strategy is reviewed on the basis of the situation that initiated the sudden shutdown to determine whether revision of the strategy is required. If shutdown is caused by an accident, the facility needs to be brought to a safe configuration before an approved final decommissioning plan is implemented.

For sites with more than one facility, a site strategy for decommissioning is developed to ensure that the interdependences of the facilities are taken into account in the planning for individual facilities, leading to final decommissioning plans for each facility (e.g. by means of partial site release).

Issues to be considered during the selection process

An evaluation of the various decommissioning options is performed by considering a wide range of issues, with special emphasis on the balance between the safety requirements and the resources available at the time of implementing decommissioning. Cost–benefit or multi attribute type analyses provide systematic means for such an evaluation. These analyses utilize realistic estimates of both costs and radiation doses. It must to be ensured that the selected option meets all the applicable safety requirements. The selection of a preferred decommissioning strategy is made by analysing components such as:

- compliance with the laws, regulations and standards which apply during decommissioning;
- characterization of the installation, including its design and operational history, as well as the radiological inventory after final shutdown and how this changes with time;
- safety assessment of the radiological and non-radiological hazards;
- the physical status of the nuclear installation and its evolution with time, including, if applicable, an assessment of the integrity of buildings, structures and systems for the anticipated duration of the deferred dismantling;
- adequate arrangements for waste management, such as storage and disposal;
- adequacy and availability of financial resources required for the safe implementation of the decommissioning option;
- availability of experienced personnel, especially staff of the former operating organization, and proven techniques, including decontamination, dismemberment and dismantling, as well as of remote operating capabilities;
- lessons learned from previous, similar decommissioning projects;
- the environmental and socioeconomic impact, including public concerns about the proposed decommissioning activities; and
- the anticipated development and use of the installation and the area adjacent to the site.

2.4 Safety

Radiological and non-radiological hazards are identified in a formal safety assessment (including accident analysis, where necessary), leading to the provision of appropriate protective measures. These ensure the safety of workers and the public, protection of the environment and that the relevant criteria are met.

Decommissioning may involve operations that may not be normal during the operation of the installation, and the significance of non-radiological hazards may be increased after the fuel and the operational waste are removed. The problem of ageing of the reactor's components becomes important when deferred decommissioning is being considered and needs to be addressed in the safety assessment.

The safety assessment aids in identification of the engineering and administrative arrangements that are in place to ensure the safety of the decommissioning process, and in the choice of a particular decommissioning option. The protective measures may require changes in the established systems for operational installations, but the acceptability of such changes must be clearly justified in the safety assessment.

2.5 Financing

Responsibilities in respect of financial provisions for decommissioning are set out in national legislation. These provisions include establishing a mechanism to provide and ensure that adequate financial resources are available when needed to ensure safe decommissioning.

All activities described in the decommissioning plan are included in the estimation of the cost of decommissioning. These activities include planning and engineering during the post-operation phases, development of a specific technology, decontamination and dismantling, conducting a final survey and management of radioactive waste, including its disposal. The cost of maintenance, surveillance and physical protection of the nuclear installation is also taken into account, especially if any phase of decommissioning is deferred for an extended period.

The cost estimate is updated on the basis of the periodic update of the initial or final decommissioning plan. The financial assurance instrument is maintained consistent with the facility's specific cost estimate and is changed if appropriate.

If financial assurance for the decommissioning of an existing facility has not yet been obtained, adequate financial resources are put in place as soon as possible. Approval of a renewal or extension of the authorization includes provisions for financial assurance.

If the decommissioned facility is released with restrictions on its future use, the financial assurance ensures financial resources are available for monitoring, surveillance and control of the facility throughout the necessary time period.

2.6 Availability of existing expertise

The availability and utilization of facility-specific expertise is highly important for efficient and safe operations during decommissioning.

This also includes also retention and utilization of key personnel familiar with site-specific conditions. This expertise could decrease the potential for events such as industrial accidents or overexposures, and may help to reduce problems associated with loss of corporate memory, and retraining or recruiting of new personnel. A good system of record keeping during operation of the facility is important for this purpose.

2.7 Considerations relating to the public

The issue of public concerns surrounding decommissioning is largely centred on the problem of waste disposal. However, public opinion is also influenced by other factors like:

- local factors, including the anticipated development and use of land after decommissioning;
- local employment considerations after cessation of facility operation and during decommissioning; and
- visual impact and the public attitude.

2.8 Facilitating decommissioning

The requirements for decommissioning are considered at the design stage for a new reactor or nuclear installation, or as soon as possible for existing installations. The later in the facility lifetime consideration is given to facilitating decommissioning, the more difficult and costly decommissioning may become. This may be due to a lack of adequate records and information, the need to install or modify equipment, the increased complexity of decommissioning activities, and the incurring of unnecessary radiation doses as a result of aspects of the design interfering with decommissioning.

Considerations at the design and construction phase

A baseline background radiological characterization of the site for the proposed facility and the facility itself (as normally required for operation) must be undertaken. This includes appropriate radiological monitoring of the site for the proposed facility and its surroundings to establish baseline levels of radiation for assessing the future impact of the facility; this may be critical to future decisions on the acceptability of decommissioning proposals. Quantification of the natural activity in the building materials used for construction may prove useful in determining future clearance and target clean-up levels in the installation during decommissioning.

A thorough review of design features, from the viewpoint of facilitating decommissioning, is performed during the design stage of the reactor installation. In general, design features which assist maintenance and inspection during the operational lifetime of the reactor also assist decommissioning. Specific factors include:

- **Careful selection of materials to** reduce activation, minimize the spread of activated corrosion products, ensure that surfaces are easy to decontaminate and minimize the use of potentially hazardous substances (e.g. oils, flammable and chemically hazardous materials and fibrous insulation);
- **Optimization of the facility's design, layout and access routes to facilitate** the removal of large components, easy detachment and remote removal of significantly activated components, future installation of decontamination and waste handling equipment, decontamination or removal of embedded components such as pipes and drains and control of radioactive material within the installation.

The inclusion of design features to assist decommissioning is supported by the use of suitable scale models or computer models.

Full details of the design specification and information relevant to the siting, final design and construction of the facility need to be retained as part of the documentation needed to assist in decommissioning. For example, essential information required for decommissioning purposes at the end of the operational lifetime of the reactor is first identified. This information is collected, maintained and revised throughout the operational lifetime of the reactor. The mechanism for doing this must be clearly stated to be the responsibility of the operating organization and the regulatory body. Such information may include 'as built' drawings, models and photographs, the construction sequence, piping, details of construction, cable penetrations, repairs or accepted deviations in components and structures, and location of reinforcement.

Considerations during facility operation

Accurate and relevant records are kept of the operating phase of the facility in order to facilitate successful decommissioning. If these records have not been or are not being maintained, such record keeping is initiated as soon as possible. These records are arranged so that those relevant to decommissioning may be readily identified (e.g. estimates of the radioactive inventory should be easy to locate and update). In addition to drawings and diagrams, photographic records of the construction and operational phases of the reactor lifetime are kept.

For example, for a power plant these records include **details of the operating history of the reactor, including records of**:

- fuel failures and fuel accounting;

- incidents leading to spillage or inadvertent release of radioactive material;
- radiation and contamination survey data, particularly for plant areas that are rarely accessed or especially difficult to access;
- releases that could potentially affect groundwater;
- radioactive inventory; and
- wastes and their location.

In addition, records must include **details of modifications to the plant and maintenance experience including records of**:

- updated 'as built' drawings and photographs, including details of the materials used;
- special repair or maintenance activities and techniques (e.g. effective temporary shielding arrangements or techniques for the removal of large components); and
- details of the design, material composition, and the history and location of all temporary experiments and devices.

During operations, consideration is given to **minimizing the extent of contamination of structures and surfaces, segregation of different categories of wastes, and avoidance and prompt clean-up of spillages and leaks**. This also includes maintenance of protective coatings and containment of contaminated materials.

Experimental irradiation of specimens of selected materials used in the construction of the installation may assist in comparing the measured with the calculated activation levels for estimating the final radioactive inventory.

2.9 Questions

1. What measures ensure the protection of people and the environment?
2. What aspects are covered in the safety assessment of the final decommissioning plan?
3. What are the responsibilities of the government, the regulatory body and the licensee in regard to decommissioning?
4. Compare immediate and deferred dismantling.
5. What is analysed when selecting the preferred decommissioning strategy?
6. How is selection of a decommissioning strategy justified?
7. What costs are considered in the financial plan for decommissioning?
8. Which considerations relating to the public are taken into account when choosing among different decommissioning strategies?
9. Why is careful selection of materials of a nuclear facility important?
10. What is the importance of optimization of the plant's design, layout and access routes in facilitating decommissioning?

11. What information is recorded during plant operation regarding decommissioning?

3 PLANNING OF DECOMMISSIONING

Learning objectives

After completing this chapter, the trainee will be able to:

1. *Describe the planning of decommissioning.*
2. *Describe the initial planning of decommissioning.*
3. *Describe preparation of the final decommissioning plan.*
4. *List the objectives of a safety assessment of decommissioning.*
5. *List the general considerations covered in a safety assessment.*
6. *List the hazards during decommissioning.*
7. *Describe what is covered by hazard identification and screening.*
8. *List the objectives of a hazard analysis.*
9. *Describe the safety functions during decommissioning.*
10. *Describe the identification of safety measures and evaluation of their results.*
11. *List the results of the regulatory review of a safety assessment.*

Successful decommissioning depends on careful and organized planning. **A decommissioning plan is prepared for each nuclear facility.** The extent of such plans, their content and degree of detail required may differ, depending on the complexity and hazard potential of the nuclear installation, and need to be consistent with national regulations.

The operating organization must plan for adequate financial resources to ensure the decommissioning of a nuclear facility. Especially in the case of deferred decommissioning, where there may be long safe enclosure periods, these financial provisions are reviewed periodically and adjusted as necessary to allow for inflation and other factors such as technological advances, waste costs and regulatory changes. Responsibility for this review may reside with the operating organization, the regulatory body or other parties, depending on the national legal framework.

Three stages of planning are envisaged: initial, ongoing and final. For a given facility, the degree of detail increases from the initial to the final decommissioning plan. This planning process results in the production of a decommissioning plan, as described below.

IAEA Safety Report Standard Format and Content for Safety-Related Decommissioning Documents [13] provides practical information to the regulatory body and the operating organisation on the type of safety-related documents that need to be prepared to support the decommissioning process and to elaborate on the contents of these documents. According to this Safety Report, the decommissioning plan should address the following main topics:

1. Description of the facility,
2. Decommissioning strategy,

3. Project management,
4. Decommissioning activities,
5. Surveillance and maintenance,
6. Waste management,
7. Cost estimate and funding mechanisms,
8. Safety assessment,
9. Environmental assessment,
10. Health and safety,
11. Quality assurance,
12. Emergency planning,
13. Physical security and safeguards,
14. Final radiation survey.

Records from the siting, design, construction, operation and shutdown phases are essential to the planning of decommissioning. Although such records need not be explicitly included in the decommissioning plan itself, the process of initial, ongoing and final planning utilize pertinent records to achieve safety and optimal efficiency in decommissioning.

3.1 Planning of decommissioning

The licensee prepares a decommissioning plan and maintains it throughout the lifetime of the facility, according to the requirements of the regulatory body, in order to show that decommissioning can be accomplished safely to meet the defined end state.

The regulatory body ensures that licensees take decommissioning into account in the siting, design, construction, commissioning and operation of the facility, including the use of features to facilitate decommissioning, maintenance of records of the facility, and consideration of physical and procedural methods to limit contamination and/or activation.

At the siting stage, a background survey of the site, including information on radiological conditions, is performed prior to the construction of a new facility and the baseline data are updated prior to its commissioning. This information is used to determine background radiological conditions. For those sites for which no such background survey has been made in the past, data from analogous and undisturbed areas with similar characteristics are used instead of pre-operational baseline data.

For new facilities the planning of decommissioning begins early in the design stage and continues through to termination of the authorization.

Initial planning

The licensee prepares and submits an initial decommissioning plan with the application for authorization to operate the facility. This initial decommissioning plan is required in order to demonstrate the feasibility of decommissioning, to ensure that sufficient financial resources will be available for decommissioning, to identify the categories and estimate the quantities of waste that will be generated during decommissioning.

The initial decommissioning plan is updated by the licensee and reviewed by the regulatory body periodically, at least every five years, unless otherwise prescribed by the regulatory body, or when specific circumstances warrant, such as if changes in an operational process lead to significant changes to the plan. The initial plan is updated as necessary in the light of operational experience gained, lessons learned from the decommissioning of similar facilities, new or revised safety requirements, or technological developments relevant to the selected decommissioning strategy. If an incident occurs or a situation arises with consequences relevant for decommissioning, the initial decommissioning plan is updated by the licensee as soon as possible and reviewed by the regulatory body.

For existing facilities where there is no initial decommissioning plan, a suitable plan for decommissioning is prepared by the licensee as soon as possible and then periodically reviewed and updated.

Appropriate records and reports that are relevant to decommissioning (e.g. records and reports of events) are retained by the licensee during the lifetime of the facility. The design and modifications to the facility and its operating history are identified and considered in preparing/updating the decommissioning plans. If permanent shutdown occurs before a final decommissioning plan is prepared, such a plan is prepared as soon as possible and adequate arrangements are made to ensure the safety of the facility until the final decommissioning plan can be implemented.

Between the permanent shutdown of operations at the facility and approval of the final decommissioning plan, there may be a period of transition. During the transition to decommissioning, the operational authorization remains in place unless the regulatory body has approved modifications of the authorization on the basis of a reduction in the hazards associated with the facility. During this period, some preparatory actions for decommissioning can be performed based on the operational or modified authorization.

Final planning

When the **date of the permanent shutdown of a facility is known, the licensee informs the regulatory body about the planned shutdown.** If a facility is permanently shut down and/or no longer used for its intended purpose, the licensee submits the final decommissioning plan to the regulatory body for approval within a period agreed with the regulatory body (typically within 2-5 years of permanent shutdown).

In the case of installation shutdown without a decommissioning plan, such a plan must be promptly prepared.

Prior to the conduct of decommissioning actions, a final decommissioning plan must be prepared and submitted to the regulatory body for approval.

The final decommissioning plan and supporting documents include the decommissioning strategy, the schedule and sequence of decommissioning actions, the proposed end state and how the licensee will demonstrate that the end state has been achieved, the storage or disposal of the decommissioning waste, the timeframe for decommissioning, and details of the financing for the completion of decommissioning.

If the final decommissioning plan or updates include new technologies and concepts for decommissioning actions, the licensee must demonstrate prior to their use that the use of such methods is safe and can effectively achieve the desired result.

During the preparation and update of the final decommissioning plan, the extent and types of radioactive materials (e.g. activated and contaminated structures and components) at the facility are determined by means of a detailed characterization survey and on the basis of records collected during the operational period. If contamination or radioactive waste from operations remains at the facility (including in subsurface soils and groundwater), this radioactive material is included in the characterization survey. Additional characterization of the site for the purpose of evaluating and preventing potential migration is considered.

If decommissioning is divided into several phases (this could be beneficiary for large and complex decommissioning projects) then all phases necessary to reach the end state must be described in the final decommissioning plan and supporting documents. Updates of the final decommissioning plan must include additional information for subsequent phases.

If the deferred dismantling strategy has been selected, the licensee demonstrates in the final decommissioning plan and/or supporting documents that such an option can be implemented safely. The availability of adequate financial resources to ensure the facility is maintained in a safe condition during the deferral period and for subsequent decontamination and/or dismantlement is demonstrated.

Updates of the final decommissioning plan are made as necessary in the light of experience gained in decommissioning, new or revised safety requirements, or new or revised national regulations. Updates of the final decommissioning plan by the licensee are subject to review and if warranted, approval by the regulatory body.

Power plant example

For a power plant, the following list of items should to be considered in the final decommissioning plan and updated whenever previous decommissioning experience warrants:

- a description of the nuclear reactor, the site and the surrounding area that could affect, and be affected by, decommissioning;
- the life history of the nuclear reactor, reasons for taking it out of service, and the planned use of the nuclear installation and the site during and after decommissioning;
- a description of the legal and regulatory framework within which decommissioning will be carried out;
- decommissioning strategy with a description of the proposed decommissioning activities, including a time schedule;
- explicit requirements for appropriate radiological criteria for guiding decommissioning;
- safety assessments and environmental impact assessments, including the radiological and non-radiological hazards to workers, the public and the environment; this includes a description of the proposed radiation protection procedures to be used during decommissioning;
- a description of the proposed environmental monitoring programme to be implemented during decommissioning;
- a description of the experience, resources, responsibilities and structure of the decommissioning organization, including the technical qualification/skills of the staff;
- an assessment of the availability of special services, the engineering and decommissioning techniques required, including any decontamination, dismantling and cutting technology as well as remotely operated equipment needed to complete decommissioning safely;
- a description of the quality assurance programme;
- an assessment of the amount, type and location of residual radioactive and hazardous non-radioactive materials in the nuclear reactor installation, including calculational methods and measurements used to determine the inventory of each;
- a description of the waste management practices,
- a description of other applicable important technical and administrative considerations such as safeguards, physical security arrangements and details of emergency preparedness;
- a description of the monitoring programme, equipment and methods to be used to verify that the site will comply with the release criteria;

- details of the estimated cost of decommissioning, including waste management, and the source of funds required to carry out the work; and
- a provision for performing a final confirmatory radiological survey at the end of decommissioning.

3.2 Safety assessment

As part of the operator's responsibility for all aspects of safety and environmental protection during all phases of decommissioning, an appropriate safety assessment needs to be performed. The objectives of the safety assessment are:

- **To support the selection of the decommissioning strategy, the development of a decommissioning plan and associated specific decommissioning activities;**
- **To demonstrate that exposures of workers and of the public are as low as reasonably achievable (ALARA) and do not exceed the relevant limits or constraints.**

A safety assessment forms an integral part of the decommissioning plan. The licensee is responsible for preparing the safety assessment and submitting it for review by the regulatory body. The safety assessment must be commensurate with the complexity and potential hazard of the installation and, in the case of deferred decommissioning, must take into account the safety of the installation during the period leading up to final dismantling.

The safety assessment for decommissioning needs to be consistent with the decommissioning plan and with other relevant national and site-specific strategies and requirements, for example, with requirements for radioactive waste management and for the release of material and sites from regulatory control.

The safety assessment for decommissioning must:

- Document how regulatory requirements and criteria are met to support the authorization of the proposed decommissioning activities;
- Include a systematic evaluation of the nature, magnitude and likelihood of hazards and their radiological consequences for workers, the public and the environment for planned activities and for accident conditions;
- Quantify the systematic and progressive reduction in radiological hazards to be achieved through the conduct of the decommissioning activities;
- Identify the safety measures, controls, limits and conditions that need to be applied to the decommissioning activities to ensure that the relevant safety requirements and criteria are met and maintained throughout decommissioning;
- Where relevant, demonstrate that the institutional controls

applied after decommissioning will not impose an undue burden on future generations;

- Provide input to on-site and off-site emergency planning and to safety management arrangements;
- Provide an input to the identification of training needs for decommissioning and of competences for staff performing decommissioning activities.

The safety assessment for decommissioning must be reviewed and updated, as appropriate, to ensure that it remains an accurate representation of the physical, chemical and radiological state of the facility as the decommissioning activities proceed.

General considerations in safety assessment

The range of decommissioning activities for which a safety assessment is required is broad, and the scope, extent and level of detail of safety assessments must be commensurate with the types of hazards and their potential consequences. A graded approach is therefore applied to the development and review of safety assessments. **A graded approach is a process by which the level of analysis, the documentation and the actions necessary to comply with the safety requirements and criteria are commensurate with the following factors**:

- The purpose of the safety assessment;
- The scope of the assessment;
- The size and type of the installations/facilities;
- The physical and radiological state of the installations/facilities at the commencement of decommissioning activities and in particular the extent to which ageing may have compromised building structures or engineered safety measures;
- The complexity of the decommissioning activities;
- Uncertainty issues, such as the quality of the characterization of the installations/facilities, and the reliability and availability of relevant supporting information to be used as input data for the safety assessment;
- The radiological hazard (source term), such as the activity inventory of the installations/facilities, its radiological characteristics, and the chemical and physical state of the radioactive material;
- The likelihood of hazards and their potential unmitigated consequences, with account taken of site characteristics and the presence and type of potential initiating events of incident/accident sequences;
- The nature and reliability of safety measures that could be put in place, or that are in place, to protect against or to mitigate the consequences of accidents;
- The safety requirements and criteria against which the results are assessed;
- The end state of the decommissioning of the installations/facilities;

- The availability of applicable safety assessments for this or other similar installations/facilities and the novelty of the proposed decommissioning activities; and
- The extent to which decommissioning could adversely affect ongoing operations with safety significance elsewhere at the installations/facilities or at others nearby.

This graded approach is applied in such a way that it does not compromise safety but ensures compliance with all relevant safety requirements and criteria.

At installations/facilities for which a phased approach to decommissioning has been selected, account is taken in the safety assessment of the phases, the nature of the decommissioning activities and the hazards they entail, which may differ for each phase. A graded approach is applied to each decommissioning phase.

The graded approach addresses the radiological aspects. However, the operator also takes into account relevant non-radiological hazards that may lead to the higher grading of the safety assessment.

Description of the installations/facilities and of the decommissioning activities

The safety assessment uses the following information from the decommissioning plan in relation to the installations/facilities and their associated land, buildings and SSCs and their decommissioning:

- The existing hazards associated with the installations/facilities;
- The decommissioning activities to be performed;
- The end points and the final state of the installations/facilities after decommissioning (e.g., land and buildings remaining on the site for unrestricted or restricted use);
- Existing and planned safety measures; and
- Common systems with other operating installations/facilities or under decommissioning.

This information is provided to a level of detail commensurate with the requirements of the safety assessment.

The description of the installations/facilities as presented in the decommissioning plan includes all relevant details on the site and local infrastructure, the installations/facilities, an inventory of radioactive material and the operational history. The description of the site and local infrastructure includes sufficient information to enable dose and/or risk calculations to be performed (e.g., information on population distribution, present and future land use, meteorology, geology and seismology, surface water and groundwater hydrology and natural resources). The description of the installations/facilities includes all existing safety functions and their associated SSCs, and documents their previous and present use, their physical and radiological state, any hazards they may present, and other items relevant for a safety assessment (the description of the installation/facilities includes all relevant information on the systems, large components and buildings). In addition the inventory of radioactive material, includes relevant radionuclides and calculated and measured activity, the radionuclide distribution in contaminated and (if applicable) activated components and building structures, and the dose rate distribution (the description is based on radiological surveys, calculations and records with an adequate level of detail) and the operational history including in all cases operational records, post-operational on-site and off-site surveys and information from ongoing decommissioning activities. This is particularly important for the specification of any modifications to the installations/facilities design, and for the identification of additional contamination of buildings, structures and systems above or below the ground, as well as contamination of land, including surface or groundwater, as a result of incidents, accidents or due to structures buried on the site.

The end state of the installations/facilities after decommissioning is defined. In some cases, this will be the unrestricted release of the site from regulatory control, or its restricted release administered through some form of institutional control.

The existing safety measures at the installations/facilities (e.g., work control procedures, use of personal protective equipment, training and testing programmes, radiation protection programmes) are also described and considered in the hazard analysis.

Hazards during decommissioning

All relevant hazards (i.e. sources of harm) to workers, the public and the environment must be considered in the decommissioning safety assessment, including:

- **Radiation exposures,** comprising external exposure from direct radiation and other radiation sources (including criticality), internal exposure due to inhalation, ingestion or cuts and abrasions, and loss of containment leading to the uncontrolled release of radionuclides;
- **Toxic and other dangerous materials,** such as asbestos, flammable materials, carcinogens, chemicals used for decontamination purposes, asphyxiates (meaning gases which, when present in an atmosphere in high concentrations, lead to a reduction of the oxygen concentration by displacement or dilution); and
- **Industrial hazards,** for example, dropped loads, work at heights, fires, high temperatures, high pressures, noise, dust, etc.

These hazards are considered regarding their combined and additive effects and for the extent to which they could give rise to radiological consequences (e.g., fire leading to a loss of containment) for workers, the public and the environment.

The initiating events (meaning an identified event that leads to anticipated operational occurrences or accident conditions and that challenges safety functions) **considered includes both those arising internally from the decommissioning activities** or other activities within the operator's overall control, and those **arising externally, such as extreme weather** (e.g., flooding, tornadoes), **off-site industrial accidents** (e.g., flammable vapour clouds leading to fires and explosions, or releases of toxic chemicals from nearby installations/facilities) **and seismic events**.

The safety assessment considers the potential consequences arising from foreseeable initiating events during decommissioning and, where necessary, recommends appropriate safety measures to minimize risks and consequences.

Hazard identification and screening

A systematic approach is taken to the identification of hazards on the basis of the description of the installations/facilities and of the decommissioning activities. The following steps are applied in an iterative manner to identify normal and accident scenarios that could lead to the exposure of workers and members of the public or could have adverse consequences for the environment:

- Identification of hazards and initiating events;
- Hazard screening and
- Identification of scenarios.

The hazard identification process identifies all locations in the installations/facilities where radioactive material is present (e.g., intentional and inadvertent accumulations of radioactive material and radioactive waste, surface contamination, contaminated ground, radioactive sources, activated components and ventilation system filters). Particular attention is paid to radioactive materials which, due to the planned decommissioning activities, constitute new sources for the exposure of workers, for example, as a result of a change to a ventilation system due to loss of containment integrity during dismantling of the installations/facilities, or the removal of a shielding wall.

Future accumulation of material at the site is taken into account, such as that in a storage area for radioactive waste which is gradually filled up and for which an assessment would need to be made on the basis of the maximum radioactivity envisaged to be present at any time. Consideration is also given to the avoidance of inadvertent criticality in the waste storage area, in particular during the decommissioning of a reprocessing facility.

All potential **initiating events** through which harm could be caused are considered in the process, in particular:

- **External initiating events**: natural events such as adverse meteorological conditions (e.g., wind, snow, rain, ice, temperature, flooding, lightning), earthquakes or biological intrusion; and human-made events such as aircraft accidents (with or without subsequent fires), explosions, fires, loss of electric power or other services, and human intrusion (mainly in cases where the installations/facilities are in a state of deferred dismantling).

- **Internal initiating events** at the installations/facilities or on the site, such as fire, explosion, structural collapse, leakage or spillage, failure of ventilation, dropping of heavy loads and failure of protective measures (e.g. failure of shielding or of personal protective equipment); and
- **Human induced initiating events**, such as operator errors and violations, and misidentifications leading to the performance of incompatible activities.

Experience has shown that internal and human induced initiating events are often the most important considerations in safety assessments for decommissioning. Initiating events with low probabilities are considered, where appropriate, with account taken of the existing and potential hazards and the complexity of the decommissioning activities.

The hazards identified need to be quantified and screened to direct safety efforts towards all significant and relevant hazards for the installations/facilities. Hazards lacking the potential to cause harmful consequences for workers, the public or the environment that exceed the relevant safety requirements or criteria, or hazards that could not be realized in view of the scope of the decommissioning activities being assessed, can be screened out from the subsequent hazard analysis.

Although the focus of this chapter is on radiological hazards and the associated radiation safety measures, non-radiological hazards are also addressed as specified in national regulatory requirements. It is noted that non-radiological hazards for which criteria exist may be assessed in similar ways and may be modelled along with the analysis of radiological hazards.

The screening process for hazards involves consideration of **all exposure pathways** within the installations/facilities relevant to the workers and to potentially affected members of the public. This aspect of the process takes into account radioactive releases and exposures from planned decommissioning activities (as such releases and/or exposures occur continuously over a relatively long time interval) and from accidents, which are, typically, single events. Justification is provided for excluded hazards.

All potential exposure pathways through which the identified hazards could cause harmful consequences **for workers are considered** in the screening process, for example:

- **External exposure** due to contamination, activation of structures (components, buildings, surfaces, etc.) or other radioactive material (e.g., sealed sources, radioactive waste packages), such as by direct radiation from gamma emitting radionuclides;
- **Internal exposure** due to inhalation or ingestion from airborne releases (i.e., particularly gases, aerosols and particulates) during the application of cutting techniques (e.g., thermal and mechanical cutting) or decontamination techniques, or in fires; from aerosols originating from chemical decontamination baths or the application of mechanical techniques for decontamination, and from other sources; and
- **A combination of radiological contamination and physical injuries** (e.g., the contamination of wounds).

Exposure pathways to members of the public and releases to the environment are considered wherever applicable (e.g., lack of containment or fires could lead to the inadvertent spread of radioactive substances beyond the site). In addition to the three pathways listed above for workers, the potential for off-site exposure pathways to the public through water, airborne routes and/or the food chain are considered.

The above considerations of initiating events, hazards and exposure pathways lead to the **identification of a list of scenarios**. The scenarios describe how the hazards identified could be realized, either as anticipated operational occurrences in normal operation or as accidents. Those hazards that cannot cause significant harmful consequences (as assessed against the relevant safety criteria) because no realistic and relevant scenarios can be identified, are not considered further.

Hazard analysis

The hazard analysis is performed with the following objectives:

- To quantify the radiological consequences for workers and the public resulting from normal scenarios;
- To quantify the radiological consequences for workers and the public resulting from accident scenarios;
- To identify the limits, controls and conditions necessary to reduce exposures to acceptable levels during planned decommissioning operations; and
- To identify further measures necessary to prevent and protect workers and the public against accident scenarios and/or to mitigate their consequences.

These objectives are achieved by using deterministic and probabilistic analysis as appropriate, applied in a complementary manner. Deterministic methods are applied in cases where it is difficult to assign realistic probabilities to selected relevant scenarios. Probabilistic methods are applied in cases of complexity or where there is a requirement for compliance with risk criteria. For accident scenarios, or where national regulations require the comparison of certain scenarios against dose criteria for workers or the public, a deterministic approach is used. Where risk criteria are applicable, probabilistic methods taking into account the likelihood of incidents and accidents should be used.

The hazard analysis identifies, addresses and documents the following aspects:

- The sources and magnitude of radiological hazards (e.g., inventory characteristics and source terms: namely locations, dimensions, spatial distribution, constituents and quantities);
- Scenarios that could lead to these hazards being realized (e.g., frequency of occurrence, exposure pathways, assumptions necessary to support the calculation of frequencies, and consequences during normal and accident conditions);
- Consequences (e.g., occupational exposures and public exposures) with and without protective/mitigating measures (e.g., shielding against radiation at high dose rates, or the use of respirators, or the use of additional ventilation or other means of controlling contamination);
- Uncertainties and the approach adopted in the hazard analysis (e.g., performance of bounding calculations or use of sensitivity studies); and
- Measures to be put in place to prevent, to protect against or to mitigate the consequences of each scenario.

While insignificant hazards and scenarios are eliminated by the screening process, a graded approach is used and appropriate methods are chosen for analysis of the remaining scenarios and hazards. In cases where the overall exposure is certain to be low, it may be sufficient to use an approach by which the scenarios that are expected to result in the highest exposures of workers or of the public (the bounding approach) are evaluated and other scenarios are excluded from calculation.

A more detailed assessment is applied to those scenarios that have been identified as having the potential to give rise to on-site or off-site releases, consistent with the national legislative and regulatory framework.

Defence in depth

Decommissioning is **conducted using the defence in depth principle for safety** (appropriate to the degree of hazard), which means a hierarchical deployment of different levels of diverse equipment and procedures to prevent the escalation of anticipated operational occurrences and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, in accident conditions. This includes:

- The definition of appropriate **operational limits, controls and conditions to prevent adverse consequences** occurring during planned activities or arising as a result of accidents;
- The provision of **protective measures which ensure that any accidents will not result in significant harm to workers, the public or the environment**; and
- The use of additional measures to **mitigate the consequences of accidents that could occur** during decommissioning.

The safety assessment identifies the necessary preventive, protective and mitigating measures and justifies that these are suitable and sufficient to ensure safety during decommissioning, in compliance with the relevant safety requirements and criteria.

Safety functions

The term “safety function” means a specific purpose that must be accomplished for safety. Its use here is more general than the three main safety functions for a nuclear power plant (control of reactivity, cooling of radioactive material and confinement of radioactive material), to reflect the wider range of hazards and scenarios that are relevant to decommissioning activities. Examples of safety functions during decommissioning include, **in addition to these three main safety functions, shielding, radiation detection and actuation of alarms, fire suppression and ventilation**.

As part of the safety assessment, safety functions and their associated structures, system and components (SSCs) need to be identified, both for planned decommissioning activities and for accident conditions, and their suitability and sufficiency demonstrated. The safety functions required to be fulfilled during decommissioning comprise a combination of safety functions that were needed during operation of the installations/facilities and additional functions that will be needed as a result of the specific decommissioning activities proposed (e.g., fire detection and suppression during cutting and grinding activities). The effects of decommissioning on the safety functions at adjacent installations/facilities also need to be evaluated. In addition, dismantling of major structures during decommissioning may involve the deliberate destruction and removal of engineered SSCs that had fulfilled specified safety functions during operation of the installations/facilities (e.g., containment, shielding, ventilation, cooling). If these safety functions are still required, the associated SSCs are maintained in an appropriate state during decommissioning. If this is not practicable, these functions are provided by suitable alternative means (e.g. tents, temporary facilities, fire systems, electrical systems, administrative procedures) for as long as is required on the basis of the safety assessment. The appropriateness of alternative means of fulfilling these functions must be demonstrated. Any changes in safety functions during decommissioning must be justified in advance before their implementation.

If a deferred dismantling strategy is adopted, preference is given to safety functions that are fulfilled by means of passive systems, devices and approaches, with minimal reliance on active SSCs, human intervention or the need for monitoring. The safety assessment evaluates the suitability, sufficiency and reliability of these safety functions (e.g., the containment function) for the entire duration of the decommissioning (e.g., including deferral periods).

Optimization of protection

The safety assessment determines whether the decommissioning strategy, plans and activities minimize exposures of workers and the public to levels as low as reasonably achievable and reduce the risks due to normal and/or accident conditions during decommissioning. The optimization of protection considers both the magnitude of individual doses and the collective dose, taking into account the number of persons that could be exposed. To achieve these objectives, the **safety assessment should determine whether the proposed preventive, protective and mitigating measures for radiological hazards provide the maximum safety benefit to workers, the public and the environment**. However, since risks from non-radiological hazards can make a significant contribution to overall risks during decommissioning, these risks are also taken into account in the overall optimization process.

The optimization of protection results in predicted doses and risks that, in addition to being as low as reasonably achievable, comply with the relevant limits and constraints. However, where it is permitted by national legislation, allowing higher risk activities for short periods during decommissioning may be appropriate in cases where these activities result directly in significant and long term reductions in effective doses, risks and/or hazards. In such cases, the safety assessment for decommissioning provides a justification for the elevated risks and the period over which they will be present.

The optimization of protection also considers the minimization of radioactive waste generated during decommissioning and the activities for waste management that are necessary to ensure compliance with waste acceptance criteria for processing, storage, transport and disposal.

Long term safety

The safety assessment demonstrates that the decommissioning of the installations/facilities does not impose unacceptable hazards (e.g., hazards leading to effective doses in excess of relevant limits and constraints) or undue burdens on future generations over the entire decommissioning period. In particular, the safety assessment demonstrates that, where deferred dismantling is proposed, the installations/facilities will meet the relevant safety requirements and criteria in the deferred dismantling period and can be safely decommissioned in the future. If deferred dismantling is the option adopted, a periodic review of the safety assessment is performed during the decommissioning period to account for various factors, such as ageing and monitoring results. The periodic review is performed in accordance with national regulatory requirements.

Engineering analysis

To identify relevant existing and potential hazards, and to ensure appropriate levels of protection and accident mitigation during decommissioning, the safety assessment considers:

- The physical, chemical and radiological state of the installations/facilities after shutdown, and the extent of ageing and their safety systems;
- The reliability of any existing engineered SSCs still necessary for fulfilling safety functions during decommissioning, and their compliance with appropriate current engineering codes and standards; and
- The need for additional engineered SSCs to deliver safety functions that cannot be provided to an appropriate standard by existing SSCs, or that are needed as a result of the specific decommissioning activities being proposed.

The safety assessment demonstrates that all SSCs that are necessary during decommissioning are engineered on the basis of appropriate engineering codes and standards. It also demonstrates **that the SSCs will be tested, inspected and maintained to a level commensurate with their associated safety functions, account being taken of the unmitigated consequences of their possible failure**. In the case of pre-existing SSCs, this aspect of the safety assessment draws upon experience and information (e.g., maintenance records) from the safety assessment that was used to justify these SSCs during operation of the installations/facilities.

The safety assessment demonstrates that the installations/facilities and its SSCs are of suitable continuing integrity to withstand any demands (e.g., additional loads due to decommissioning equipment and personnel) placed on them during decommissioning, while continuing to fulfil all necessary safety functions for the duration of the proposed decommissioning.

Material management

Material management constitutes a major part of the decommissioning activities and includes the segregation, categorization, quantification, processing, storage, handling and record keeping associated with radioactive and non-radioactive material on the site. To ensure the radiological protection of workers, the public and the environment during the performance of these and other related tasks, material management is considered in the safety assessment.

The safety assessment assesses the radiological consequences from:

- The management of material arising from decommissioning, including metals, building rubble, liquids and other material destined for release from regulatory control; and
- The management of radioactive waste on the site, including any processing, handling and storage of such waste.

It is noted that the management of materials from decommissioning is addressed in the safety assessment, since separate assessments are prepared for clearance, transport, predisposal and disposal of radioactive waste. Material management aspects (waste management and release of material) of the safety assessment can be documented in the safety assessment for decommissioning or can be addressed in other documentation, provided that this is consistent with, and linked to, the safety assessment for decommissioning.

The safety assessment for decommissioning need to be consistent with relevant site and national strategies and regulatory requirements for the management of material and radioactive waste, and the following, in particular, is taken into account:

- Clearance criteria and procedures;
- Criteria for the classification of material and radioactive waste;
- Acceptance criteria for the processing, storage, transport or disposal of radioactive waste;
- The flow and quantity of material and of radioactive waste at the site during decommissioning;
- The availability and capacity of processing and/or storage facilities (on and off the site), account being taken of material arising from other decommissioning activities (e.g., activities at other installations/facilities or sites); and
- The availability and capacity of disposal facilities.

Uncertainties

In the safety assessment for decommissioning, due account is taken of all known uncertainties. For example, the quality, reliability and availability of information from the characterization of the installations/facilities may be limited; clean-up activities may not be well defined (as the operator may need to revise the approach on the basis of changing conditions at the site); and scenarios and the stages in the decommissioning plan may need to be revised on the basis of knowledge gained from previous stages in the process or from other similar activities at other facilities or sites (including international experience).

In cases where such uncertainties are significant, the safety assessment considers applying a phased approach to the safety assessment for decommissioning, addressing individual phases and/or stages of the decommissioning plan so as to reduce the uncertainties as decommissioning progresses.

Safety assessment technical team

The safety assessment for decommissioning is carried out by an experienced multidisciplinary team with expertise in all the relevant technical areas. The composition of the team may vary, depending on the safety assessment to be performed, but the team normally includes personnel with expertise in safety assessment (e.g., hazard analysis, probabilistic analysis, deterministic analysis), relevant engineering aspects (e.g., civil, process, control and instrumentation, electrical, chemical and mechanical), radiation protection, and industrial safety and management of radioactive waste and other material generated during decommissioning. The team should also include members with knowledge of the design, operation and history of the installations/facilities, and specialist assessors as appropriate and necessary (e.g., in the areas of criticality safety, hydrogeology, human factors and computer modelling).

Evaluation of results and identification of safety measures

The results of the safety assessment serves to demonstrate compliance with regulatory requirements and criteria expressed in terms of effective dose (e.g., individual annual effective doses due to normal decommissioning operations, individual effective doses for single incidents or accidents) or in terms of risk. To achieve this, the results are expressed in the same units as the associated safety criteria.

Sensitivity analyses are performed to identify and assess those parameters and values with the highest impacts on the assessment results. If the outcome is particularly sensitive to an input parameter or assumption, the operator directs efforts towards reducing the uncertainties and repeating that part of the safety assessment.

The safety assessment demonstrates that there are adequate safety measures in place that are commensurate with the likelihood of the occurrence of accidents and their possible radiological consequences, in order to demonstrate compliance with safety criteria. These safety measures can be:

- **Engineered measures:** this means that technical or physical measures are in place during decommissioning work, such as the provision of additional shielding or the installation of new filters, a new ventilation system or a water treatment plant, the erection of temporary tents, the use of cutting tools with low aerosol generation, the installation of an alarm system set at a fraction of the level for compliance with the safety criteria, the use of protective equipment such as respirators, or the provision of other mitigating systems; and
- **Procedural measures:** this means that administrative measures are available for a certain decommissioning task, such as the prescription of certain work procedures for specific tasks, the use of activity reduction by radioactive decay, the restriction of access to radiation areas, or the positioning of fire watches during cutting operations.

If the results of the safety assessment do not demonstrate compliance with safety requirements or criteria, the assessment is revised in accordance with the safety assessment framework. The results are used to identify potential amendments to the existing decommissioning strategy, plan or activities, as well as engineering measures and protective safety measures, and where appropriate, to identify additional safety measures to ensure compliance with the safety requirements and criteria. If the decommissioning plan is revised, the safety assessment is also reviewed or revised as necessary to evaluate the revisions to the decommissioning plan.

3.3 Regulatory review of the safety assessment

The regulatory review of the safety assessment is coordinated with the review of the decommissioning plan to ensure consistency, and is carried out in accordance with national legislation. The parts of the decommissioning plan that are particularly relevant to the safety assessment include the description of the installations/facilities, the decommissioning strategy, the relevant safety requirements and criteria, the proposed decommissioning activities, the management system, the decommissioning techniques, the availability of supporting services, and the plan for the management of radioactive waste.

In cases where decommissioning is conducted in phases, regulatory reviews are performed for each phase, for the entire decommissioning and for the interrelation of the phases.

The principal **objectives of regulatory reviews** of the safety assessment are:

- To consider whether the safety assessment provides an appropriate basis to support the proposed decommissioning strategy, plan and activities;
- To support the authorization process for the decommissioning strategy, plan and activities by confirming that all relevant safety requirements and criteria have been met;
- To identify any regulatory limits and conditions that will need to be applied during decommissioning or before decommissioning activities may be commenced; and
- To provide an input into the process of releasing the site (together with any remaining buildings and/or structures) from regulatory control.

The **results of the review** of the safety assessment demonstrate to the regulatory body that:

- The safety assessment is consistent with the decommissioning plan and other related safety assessments;

- Decommissioning activities are optimized with due regard to dose and risk constraints for planned activities;
- Suitable and sufficient safety measures (procedural measures and engineered safety features) will be in place so that the decommissioning activities can be carried out safely and in accordance with all relevant safety requirements and criteria, and in an optimized manner;
- Surveillance measures and maintenance measures are adequate to ensure safety;
- Emergency planning and preparedness during decommissioning are adequate; and
- Good engineering practice has been used in developing the proposals for decommissioning.

3.4 Questions

1. Who prepares and maintains the decommissioning plan?
2. What does the regulatory body ensure regarding the decommissioning plan?
3. When is an initial decommissioning plan submitted?
4. Does the initial decommissioning plan need any updates and reviews? If so, when?
5. When is the decommissioning plan finalized?
6. List the items to be considered in the final decommissioning plan.
7. What is included in the final decommissioning plan and support documents?
8. What is included in the safety assessment?
9. Which factors are taken into account in the graded approach of safety assessment?
10. What are the hazards considered in the decommissioning safety assessment?
11. What does the description of the installations/facilities include?
12. Why is the hazard identification process needed?
13. How are initiating events classified in the decommissioning safety assessment?
14. List all types of initiating events.
15. What is meant by defence in depth regarding the safety assessment?
16. List the safety functions necessary during decommissioning.
17. How is the optimization of protection considered in the safety assessment?
18. What requirements for the management of materials and radioactive waste are taken into account in the safety assessment?
19. What are the characteristics of the safety assessment considering significant uncertainties?
20. What are the potential pathways by which identified hazards cause harmful consequences?
21. What should be done if the safety assessment does not demonstrate compliance with the safety requirements?

22. List the principal objectives of the regulatory review of the safety assessment.

4 CONDUCT OF DECOMMISSIONING ACTIONS

Learning objectives

After completing this chapter, the trainee will be able to:

1. *Describe the critical tasks of decommissioning.*
2. *State the concerns regarding fuel removal.*
3. *Describe the importance of containment regarding decommissioning.*
4. *Describe the decontamination process.*
5. *Describe the dismantling procedure.*
6. *Describe the importance of the final radiological survey.*
7. *List the considerations regarding radiological protection during decommissioning.*
8. *Describe waste management during decommissioning.*
9. *Describe emergency planning and physical protection regarding decommissioning.*

The licensee must implement the final decommissioning plan once the regulatory body has approved it.

The licensee must implement the final decommissioning plan, including management of radioactive waste, in compliance with national regulations.

In the case of deferred dismantling, the licensee must ensure that the facility is maintained in a safe configuration so that subsequent decontamination and/or dismantling can be performed. An adequate programme for maintenance, monitoring and surveillance, which shall be subject to approval by the regulatory body, must be developed to ensure safety throughout the period of deferral.

In accordance with the final decommissioning plan, **decommissioning techniques must be selected such that the protection of workers, the public and the environment are optimized, the generation of waste is minimized, and the potential negative impact on storage and disposal of waste is minimized** (e.g. by avoiding the use of decontamination techniques that may result in increased mobility of the radionuclides in the waste). As decommissioning actions progress, such as decontamination, cutting and handling of large components, new hazards may arise. The impact of these actions on safety must be assessed and managed so that the potential consequences of such new hazards are prevented and/or detected and mitigated.

During decommissioning, the licensee must keep the list of structures, systems and components important for safety updated. Such structures, systems and components can progressively be declassified and dismantled as the decommissioning progresses, provided that the facility's inspection and maintenance programme is updated accordingly.

The regulatory body must make arrangements for and implement the inspection and review of the decommissioning actions to ensure that they are being carried out in accordance with the final decommissioning plan and the authorization to conduct decommissioning and with other requirements which the regulatory body has the responsibility to oversee. If safety requirements and the conditions for authorization to conduct decommissioning are not met, the regulatory body must take appropriate enforcement actions.

4.1 Critical tasks of decommissioning

Initial characterization of the installation

A survey of radiological and non-radiological hazards is an important input to the safety assessment and for implementing a safe approach during the work, and is conducted to identify the inventory and location of radioactive and other hazardous materials. In planning and implementing surveys, use is made of existing records and operating experience. A characterization report is prepared which documents the information and data obtained during the characterization process. The report is retained as part of the official records of the installation.

An adequate number of radiation and contamination surveys should be conducted to determine the radionuclides, maximum and average dose rates, and contamination levels of inner and outer surfaces of structures or components throughout the reactor installation. For completeness, contamination in shielded or self-shielded components, such as inside pipes and pumps, should be characterized. The results of such surveys aid in the preparation of radiation and contamination maps. Furthermore, special surveys to determine the penetration depth and the extent of contamination may be required to assist in the selection of appropriate procedures for decontamination or dismantling. For activated components, calculations are used together with selective verification sampling.

An extensive review of radiological characterisation methods and techniques, together with a description of detection methods, assessment and validation tools can be found in Ref. [14]. In this document, although major emphasis has been placed on characterizing neutron activated materials in a nuclear reactor, as this represents the major source when estimating the total inventory during decommissioning of a reactor site, methods for the detection and assessment of radioactive contamination which are of general interest for all nuclear facilities are also discussed in depth. The report also summarizes practical experience from radiological characterisation of shut down reactors in different IAEA member states, including radionuclide inventories, characterisation methods and techniques.

An inventory of all hazardous chemicals present in the installation should also be conducted. Hazardous materials such as asbestos require special consideration to prevent harm to human health. Substances such as oils found in nuclear reactors in general, or sodium residues found in fast breeder reactors, may present significant risk of fire or explosion, and have to be dealt with in an appropriate manner.

Fuel removal from reactors

The removal of spent fuel (and other operational waste) from the reactor installation at the end of its operational lifetime is considered to be a part of its operation and fuel should be removed prior to the conduct of decommissioning actions. In case where removal is not possible during the period between permanent shutdown and the beginning of decommissioning, the approved final decommissioning plan should address the removal of the fuel and other operational waste (during the initial phases of immediate dismantling or during the preparatory phase for safe storage). In all cases the management of fuel and other operational waste should be carried out in accordance with the relevant requirements [15].

The procedures used for the removal, storage and shipment of fuel would be expected to be the same as those used during normal operation. While the fuel remains at the reactor installation, it is stored in such a way as to control any risk to the public and to the site personnel.

Where on-site interim storage facilities for spent fuel are utilized, due regard is given with respect to possible interference with future decommissioning activities at the reactor installation.

Containment maintenance and modification

Containment is an important element of defence in depth to prevent the movement of residual radionuclides. Care should be taken to retain containment systems as long as necessary and feasible. However, the containment may require changes before or at the beginning of decommissioning as radioactive materials (spent fuel and operational waste) are removed from the installations or as the installation is modified, for example, in order to increase accessibility. When containment related barriers or devices are removed or altered in the course of dismantling, acceptable confinement of the residual radioactive material is planned and demonstrated by the operating organization. Similarly, adequate containment is planned and demonstrated when cutting and dismantling operations are carried out which may give rise to airborne contamination.

In the case of deferred dismantling, structures and systems may have to perform for longer periods than their accepted design life. This is important for active containment devices. Care is taken to ensure that proper maintenance is performed and to assess their integrity and efficiency regularly. Similar considerations may also apply to non-radiological hazards that may arise in the installation, including those due to toxic materials, flammable liquids or vapours, heavy metals or asbestos.

Decontamination

The term decontamination covers the broad range of activities directed to the removal or reduction of radioactive contamination in or on materials, structures and equipment at a nuclear installation. The decommissioning of a nuclear installation may be aided at certain stages by partial or total decontamination. Decontamination may be applied to internal or external surfaces of components and systems, structural surfaces and the tools employed in decommissioning. The process of decontamination associated with decommissioning can be conducted before, during or after dismantling.

The objectives of decontamination include:

- a reduction of exposures during decommissioning activities;
- a minimization of the volume of the categories of material to be classified or disposed of as solid radioactive waste; and
- to increase of the possibility of recycling and reuse of equipment, materials or premises.

A number of decontamination techniques have been developed which may be applicable to decommissioning. Exchanges of information in this regard are encouraged. The IAEA has published several documents related to the technology and implementation of decommissioning, among them the Technical Report State-of-the-art Technology for Decontamination and Dismantling of Nuclear Facilities [16], where decontamination and dismantling technologies, including waste management and remote systems, are reviewed. Although the document covers the technologies available at the end of nineties, it is far from being outdated. More recent information may be acquired from IAEA-TECDOC-1602 Innovative and Adaptive Technologies in Decommissioning of Nuclear Facilities [17], or Proceedings of an International Conference on Lessons Learned from the Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities [18], where practical experience from different decommissioning projects is presented.

Exchange of information and experience is especially important in the decommissioning of smaller facilities where development of new specific and optimised techniques is less feasible. New and innovative techniques should be first demonstrated in mock-up trials and other simulations.

Before any decontamination strategy is undertaken or a decontamination technique is selected, an evaluation of its effectiveness should be performed. In order to ensure that exposures are kept as low as reasonably achievable, this evaluation should include:

- the target decontamination level;
- the estimated doses to workers;
- consideration of the possible generation of aerosols;
- consideration of the likelihood that the available techniques will achieve the target level on particular components;
- an ability to demonstrate by measurement that the target level has been reached;
- the availability of facilities required for decontamination and their eventual decommissioning;
- the cost of the application compared with the expected benefit (e.g. cost of decontamination versus the cost of disposal of the original material);
- an estimate of the volume, nature, category and activity of any primary and secondary wastes;
- consideration of the compatibility of these wastes with existing treatment, conditioning, storage and disposal systems;
- any possible deleterious effect of decontamination on equipment and system integrity;
- any possible on-site and off-site consequences as a result of decommissioning activities; and
- the non-radiological hazards (e.g. the toxicity of solvents used).

Dismantling

There are many available dismantling techniques applicable to equipment decommissioning. Each technique carries some advantages as well as some disadvantages in comparison with others. For example, where **remote dismantling** is necessary owing to high fields of radiation, thermal cutting methods allow the use of relatively simple holding mechanisms. However, these methods generate large quantities of radioactive aerosols requiring local ventilation with filtration systems; this results in the generation of secondary wastes.

In contrast, **mechanical cutting** methods need robust and elaborate holding mechanisms, but these methods usually result in smaller quantities of secondary wastes. **Underwater cutting** methods (e.g. as used for reactor pressure vessels) have the advantage of enhanced radiation protection, because of reduced generation of aerosols and the shielding effect of water. These methods require, however, special tools and control mechanisms which can operate safely underwater, but usually generate secondary wastes in the form of liquid slurry.

Basic cutting, dismantling and remote operating capabilities have been developed and used in different dismantling projects. International information exchanges are encouraged to improve the knowledge of practices. A review of available methods is given alongside the decontamination methods in the Technical Report State-of-the-art Technology for Decontamination and Dismantling of Nuclear Facilities [16]. An extensive amount of practical information regarding the implementation of methods in decommissioning projects could also be acquired from IAEA-TECDOC-1602 [17] and Proceedings of an International Conference on Lessons Learned from the Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities [18].

Special tools and devices may be needed during dismantling. In such cases, these tools and devices should be tested in mock-up trials before their use. The applicability of these techniques to the particular decommissioning project needs to be thoroughly assessed before selection. Where necessary, maintenance and periodic testing of these tools and devices form part of their deployment strategy.

The selection of methods and techniques to be used in safe dismantling should take into account such aspects as:

- the types and characteristics (e.g. size, shape and accessibility) of the materials, equipment and systems to be dismantled;
- the availability of proven equipment;
- the radiation hazards to the worker and the general public, e.g. level of activation and surface contamination, production of aerosols and dose rates;
- the environmental conditions of the workplace, e.g. temperature, humidity and atmosphere;
- the radioactive waste produced;
- the non-radioactive waste produced; and
- the requirement for development work.

Each dismantling task is analysed to determine the most effective and safe method for its performance. Some considerations are as follows:

- equipment is simple to operate, decontaminate and maintain;
- effective methods for controlling airborne radionuclides are implemented;
- there is effective control of discharges to the environment;
- when underwater dismantling and cutting is used, provision is made for water treatment to ensure good visibility and assist in effluent treatment;
- the effect of each task on adjacent systems and structures and on other work in progress is evaluated; and
- waste containers, handling systems and routes are defined before the start of dismantling work.

Maintenance

Maintenance may be important during deferred decommissioning since part of the safety of the installation may rely on systems that have to retain their capability to perform for extended periods of time. Periodical monitoring of all the safety-related components of the installation must be incorporated into the decommissioning plan.

Final radiological survey

At the completion of decontamination or dismantling activities, a survey of the residual radionuclides at the facility site must be performed to demonstrate that the residual activity complies with the criteria set by the national regulatory authority and that the decommissioning objectives have been fulfilled. This survey may be carried out in phases, as decommissioning work is completed, to enable parts of the site to be released from regulatory control.

The survey data should be documented in a final survey report and submitted to the regulatory body. This report forms one of the bases for reuse of the site or for its release from regulatory control. The report includes:

- the criteria used;
- the methods and procedures to ensure that the criteria were met; and
- measurement data, including appropriate statistical analysis and systematic approaches used.

4.2 Additional aspects of decommissioning actions

Radiation protection

The radiation protection programme ensures that **radiation protection is optimized and that doses are kept within appropriate limits**. Although the principles and aims of radiation protection during operations and during decommissioning are fundamentally the same, the methods and procedures of implementation of radiation protection may be different. During decommissioning special situations may need to be considered, which may require the use of specialized equipment and the implementation of certain non-routine procedures.

With respect to the need for radiation protection during decommissioning, certain points are considered, such as:

- use of protective equipment for shielding, to limit internal and external exposure, and to minimize doses, e.g. leaded blankets, tents, local ventilation and filtering systems;
- having the appropriate number of skilled radiation protection personnel to assist in ensuring the safe conduct of the decommissioning tasks;
- ensuring that the decommissioning personnel have the appropriate skills, qualifications and training with respect to radiation protection techniques and requirements;
- good housekeeping practices to reduce doses and to prevent the spread of contamination;
- zoning of the nuclear installation as a function of the levels of radiation and contamination, as well as appropriate rezoning as decommissioning work proceeds, according to the radiological hazards involved;
- ensuring an adequate system in which doses to workers and the public are kept as low as reasonably achievable; and
- documentation of all radiation protection measures and survey results.

The radiation protection programme should be clearly set out in the decommissioning plan and implemented during decommissioning. Those involved in its execution should be properly trained and have access to appropriate equipment for carrying out radiation surveys, including equipment for measuring external dose rates and surface contamination levels and for sampling air concentrations.

All **decommissioning work should be planned and carried out using work order procedures and radiation work permits, with adequate involvement of radiation protection expertise** to determine the required radiation protection measures. Moreover, the promotion of awareness of safety issues should be accorded high emphasis in planning and implementation. Those charged with the day to day responsibility for radiation protection need to have the resources, access to decommissioning management and independence necessary to effect an adequate radiation protection programme.

Materials management

Materials management constitutes a major part of decommissioning activities and includes the segregation, categorization, quantification, processing, storage, handling and record keeping associated with radioactive and non-radioactive materials on the site.

To ensure radiological protection of the workers, the public and the environment during the performance of these and other related tasks, materials management must be considered in the decommissioning plan and the safety assessment. The safety assessment assesses the radiological consequences from:

- The management of materials arising from decommissioning, including metals, building rubble, liquids and other materials destined for release from regulatory control; and
- The management of radioactive waste on the site, including any processing, handling and storage of the waste.

Other aspects of materials management (clearance, transport, predisposal and disposal of radioactive waste) should also be addressed in the safety assessment, which could form separate documents. The safety assessment for decommissioning needs to be consistent with the relevant site and national strategies and regulatory requirements for the management of materials and radioactive waste.

Waste management

A waste management plan, part of the decommissioning plan, should consider the different categories of waste produced during decommissioning and aim at the safe management of such wastes.

Consideration should be given to optimizing waste management and minimizing cross-contamination and secondary waste generation. The different categories of waste should be managed through pathways that are proven to be adapted to their characteristics and toxicities (radiological and non-radiological).

Significant reductions in volumes of radioactive waste can be achieved through decontamination programmes, controlled dismantling techniques, contamination control, sorting of waste materials, effective processing and, in some cases, administrative controls or internal audits. Reuse and recycling strategies have the potential to reduce the amounts of wastes to be managed. Similarly, the release of low activity materials from regulatory control (clearance) as ordinary waste or for reuse and recycling can also substantially reduce the amount of material which has to be considered as waste.

The radiation exposure to workers and the public may vary according to the waste minimization strategy. An integrated approach should be used to balance waste minimization goals with the objective of keeping radiation exposures as low as reasonably achievable.

Where disposal is considered and no suitable waste disposal sites are available, the following decommissioning options must be evaluated in the preparation of the decommissioning plan:

- preparing and maintaining the installation in safe enclosure (during deferred dismantling);
- dismantling the installation and storing the generated waste in appropriate temporary waste storage facilities.

In managing the waste from decommissioning, several factors should be considered. These include:

- the amount, category and nature of the waste that will be generated during decommissioning (relatively large quantities of radioactive waste may be generated in a short time);
- the possibilities for removal of waste from the regulatory control regime;
- the possibilities for the reuse and recycling of materials, equipment and premises;
- the generation of secondary waste in the decommissioning process and its minimization to the extent practicable;
- the presence of non-radiological hazardous materials, e.g. asbestos;
- the availability of waste recycling or treatment plants, storage facilities and disposal sites;
- any special requirements for the packaging and transportation of radioactive wastes, e.g. activated materials;
- the traceability of the origin and nature of the wastes arising from the decommissioning process; and
- the potential impact of wastes on the workers, the public and the environment.

A large part of the wastes and other materials arising during the decommissioning process may have sufficiently low activity concentrations for regulatory control to be wholly or partly removed. Some wastes may be suitable for disposal in normal landfill sites, while some materials, such as steel and concrete, may be suitable for recycling or reuse outside the nuclear industry. The removal of regulatory controls should be done in compliance with the criteria established by the national regulatory authority.

The management and staff involved in the decommissioning project must be made aware of and trained, if necessary, in methods of minimizing the waste generated in the tasks assigned. Such methods include installation of contamination control tents, containment of spills, and segregation of radioactively contaminated wastes from those wastes that are not radioactively contaminated.

Emergency planning

During the period of decommissioning, it may be necessary to develop, implement and maintain procedures to cope with abnormal occurrences. Site personnel must be trained in contingency procedures.

Especially in cases where reactor fuel has not been completely removed from the installation, such contingencies must be incorporated into emergency planning in order to deal with accidents and incidents involving fuel, such as the potential loss of coolant for the fuel if it is in a fuel pool.

The decommissioning plan should also specify provisions for minimizing the occurrence and/or for mitigating the consequences of other credible incidents during the decommissioning process, e.g. fire, power failure, equipment failure and spills of radioactive materials.

Physical protection and safeguards

A physical protection system for nuclear facilities against sabotage and human intrusion and for the physical security of nuclear materials should be in place during decommissioning. The level of protection should be commensurate with the nature of the remaining materials, the associated hazards and the value/attractiveness of the materials.

The physical protection system should limit access to radioactive material or facilities to essential individuals only. This can be achieved by designating areas and by providing hardware (e.g. security devices) and procedures (including organization of guards where necessary).

If the site contains materials subject to safeguards, the operating organization must to adhere to the relevant international agreements and comply with IAEA safeguards principles.

4.3 Questions

1. When is the final decommissioning plan implemented?
2. Who makes arrangements for and implements the inspection and review of decommissioning actions?
3. Describe the possibilities for fuel removal from reactors.
4. Why is it important to retain containment integrity as long as possible?
5. What are the objectives of decontamination?
6. What is included in the evaluation of the effectiveness of decontamination techniques?
7. Compare different dismantling techniques.
8. What aspects are considered in selecting methods and techniques of dismantling?
9. Why is the final radiological survey needed?
10. What does the radiation protection programme ensure?
11. How can significant reductions in the volume of radioactive waste be achieved?
12. What factors are considered in decommissioning waste management during decommissioning?

5 MANAGEMENT

Learning objectives

After completing this chapter, the trainee will be able to:

1. *List the areas where staff need competences for performing decommissioning.*
2. *Describe the organization and administrative control of decommissioning.*
3. *Describe the integrated management system for decommissioning.*

An integrated management system provides a single framework for the arrangements and processes necessary to address all the goals of the operating organization. These goals include **safety, health, environmental, quality and economic elements**.

An integrated system for the management and implementation of decommissioning should be established as part of the licensee's organization with the prime goal of ensuring that decommissioning is conducted safely. The reporting hierarchy and lines of authority of the management for decommissioning must not create conflicts between organizations and activities that could compromise safety during decommissioning.

The prime **responsibility for safety remains with the licensee**. The licensee can delegate the performance of defined tasks to contractors and the management for decommissioning ensures that the work of contractors is appropriately controlled and is conducted safely.

Individuals made responsible for performing decommissioning actions need to **have the necessary skills, expertise and training to perform decommissioning safely**. Provisions should be made to ensure that the institutional knowledge about the facility is obtained and accessible and, as far as possible, that key staff are retained.

All individuals performing decommissioning actions have the **responsibility to inform the decommissioning management of any concerns about safety**. The decommissioning management also ensures that processes are in place to grant authority and support such individuals in suspending unsafe decommissioning actions.

Decommissioning must be controlled through the use of written procedures. These procedures should be subject to review and approval by the licensee's departments responsible for ensuring safety and practicability. A methodology for issuing, modifying and terminating work procedures must be established.

There are a number of areas of management which should receive consideration during decommissioning. In particular, they address the potentially extended time-scales which could apply to decommissioning activities.

5.1 Staffing and training

The safety assessment should specify the requirements for personnel competences, the associated training and the minimum number of personnel for maintaining safety. The safety assessment should identify critical areas and tasks during decommissioning where staffing and training play a particularly important role. For these critical areas and tasks, the operator needs to ensure that personnel competences, staffing and training are sufficient to maintain safety under the conditions analysed and in compliance with the relevant safety requirements and criteria. The depth and degree of rigour of training and competence should be commensurate with the complexity of the facility and of the decommissioning activities.

The operating organization should have, or should have access to, **competent staff** to cover the following areas adequately:

- safety requirements of the licence;
- radiation protection;
- familiarity with the facility systems;
- engineering support (e.g. physics, instrumentation, chemical, civil, electrical and mechanical engineering);
- quality assurance and quality control;
- waste management;
- physical protection; and
- project management.

Specialized expertise may be necessary in other areas such as:

- dismantling and demolition;
- decontamination;
- robotics and remote handling; and
- fuel handling.

The safety assessment should consider the consequences of there being insufficient personnel with installation-specific expertise. It would be of benefit to make use of personnel with experience in both operations and decommissioning.

In some cases contractors may be used to carry out all or some aspects of decommissioning. This is likely to occur when decommissioning is deferred or when facility personnel may not have the required expertise. Financial considerations may also require a greater use of contractors. Examples of such activities include the use of specific decontamination processes and dismantling/demolition activities. Appropriate levels of control, supervision and training must be provided to ensure safety.

All persons involved in decommissioning activities must be familiar with the facility and the safety procedures for the safe and effective conduct of their duties. Specialized training may be needed in certain areas of work. For some activities, the use of mock-ups and models in training can improve efficiency and safety.

Basic requirements for a training programme and for refresher training for decommissioning activities are described in the decommissioning plan.

5.2 Organization and administrative control

The organizational structure to be employed during decommissioning should be described in the decommissioning plan. In the description of the organizational structure, there should be a clear delineation of authorities and responsibilities amongst the various units. This is particularly necessary when the operating organization uses outside contractors. The organizational structure should ensure that the quality assurance review function is independent of the unit directly responsible for accomplishing the decommissioning activities.

Administrative measures stemming from the operational phase of the installation may be relevant during decommissioning. These measures should be reviewed and modified to ensure that they are appropriate to the decommissioning. Requirements for additional measures should be addressed. The administrative control measures may be required to be endorsed by the regulatory body.

A team composed of decommissioning specialists and appropriate site personnel should be formed to manage the decommissioning project. Although new competences may be required for the decommissioning phase, attention should be given to the retention of key personnel who are familiar with the installation during its operational phase. Since deferred decommissioning may continue for several decades, it is essential to document the historical knowledge possessed by personnel associated with the reactor installation before final shutdown. This information should be accessible to decommissioning workers for use during active decommissioning phases.

5.3 Integrated management system

The management system should be applied throughout the entire process of decommissioning until the final decision is made on compliance with the release criteria. The aim of the system is to ensure integration of all aspects of managing the facility and decommissioning activities, including safety, health, quality and environmental requirements, in a coherent manner, to describe the planned and systematic actions necessary to provide adequate confidence that all these requirements can be satisfied, and to support the enhancement and improvement of safety culture.

The management system should be designed and implemented so as to ensure that:

a) The objectives and the safety requirements and criteria (radiological and non-radiological) are adequately defined and met;
b) Adequate strategies for decommissioning, radioactive waste management and monitoring for compliance are developed and implemented;
c) Appropriate management arrangements are in place with a clear allocation of responsibilities between the operator and contractors;
d) The required competences of staff and interfaces are in place;
e) Adequate selection, calibration, maintenance and testing of equipment for use in appropriate monitoring techniques are performed;
f) Adequate control over procurement, including control over subcontractors' services, is implemented;
g) Appropriate sampling and measurements (in terms of locations, media, number of samples, frequency, etc.) are performed;
h) Verification and analysis of results are carried out;
i) Record keeping and reporting are undertaken;
j) Appropriate qualifications, experience and training of personnel involved in the decommissioning and the release of sites are ensured;
k) Adequate financial resources are available;
l) Adequate auditing covering internal and external audits and regulatory inspections are performed;
m) Measures for the detection of non-conformance, adequate corrective actions and arrangements for termination of the authorized practice are provided.

A system for archiving, retrieving and amending records should be maintained to document the decommissioning activities and the basis for decisions for authorizations or approvals of any changes in the activities that were made during their implementation. Such records should include:

a) Data characterizing the site prior to decommissioning;
b) The decommissioning plan, including the choice of clean-up options, measures and procedures;
c) Data from monitoring and surveillance;
d) Occupational health and safety records for the decommissioning workers;
e) Identification of radioactive waste and description of its management and disposal on and off the site;
f) Details of abnormal occurrences;
g) Records of equipment used for decommissioning and monitoring;
h) Cost estimates;

i) Control measures adopted by the operators;
j) Involvement of interested parties;
k) Locations of sites released from regulatory control;
l) An inventory of land, buildings and structures with specified restrictions for their release (e.g. restricted use of land or surface water);
m) Final survey reports;
n) Regulatory decisions on and authorizations or approvals for site release;
o) Lessons learned.

This records system should be commensurate with the size, complexity and hazard potential of the site to be released from regulatory control. The management system should be described in a set of documents that establish the overall controls and measures to be developed and applied by the decommissioning organization to achieve its goals.

More on the integrated management system may be found in Module XXI Management system, leadership and safety culture.

5.4 Questions

1. Who is responsible for the safety of decommissioning?
2. In the case of concerns about safety what should individuals performing decommissioning actions do?
3. Which areas may need specialized experts?
4. What should the decommissioning management system ensure?
5. What should be included in the decommissioning records?

6 COMPLETION OF DECOMMISSIONING

Learning objectives

After completing this chapter, the trainee will be able to:

1. *Describe when decommissioning actions are completed.*
2. *State when an authorization is terminated.*

On completion of decommissioning actions, the licensee must demonstrate that the end state criteria as defined in the final decommissioning plan and any additional regulatory requirements have been met. The regulatory body verifies compliance with the end state criteria and decides on termination of the authorization. Guidance to the regulatory body and operators on the release of sites or parts of the sites from regulatory control may be found in the IAEA Safety Guide "Release of Sites from Regulatory Control on Termination of Practices" [8].

A final decommissioning report should be prepared by the licensee to demonstrate that the end state of the facility as specified in the approved final decommissioning plan has been met. This report should be submitted to the regulatory body for review and approval.

The regulatory body should review the final decommissioning report and evaluate the end state to ensure that the all regulatory requirements and end state criteria, as specified in the final decommissioning plan and in the decommissioning authorization, have been met. Based on this review and evaluation the regulatory body should decide on the termination of the facility's authorization and on its release from regulatory control.

If the approved end state of decommissioning is authorization with restrictions on future use of the remaining structures, appropriate controls and programmes for monitoring and surveillance should be maintained to ensure optimization of protection and safety. These controls should be specified and should be subject to approval by the regulatory body. Clear responsibility should be assigned for implementing and maintaining these controls and programmes. The regulatory body ensures that a mechanism is in place to ensure compliance with the restrictions on the release of the facility.

A system should be established to ensure that all records are maintained in accordance with the records retention requirements of the integrated management system and the regulatory requirements.

If radioactive waste is stored on the site after decommissioning has been completed, a revised or new, separate authorization, including requirements for decommissioning of the storage facility, should be issued.

In the case of the partial release of the site, a revised or new, separate authorization should be issued, as appropriate.

6.1 Questions

1. What are the contents of the final decommissioning report?
2. When does the regulatory body terminate the facility's authorization?

7 APPENDIX: PRACTICAL DECOMMISSIONING EXPERIENCE

In the last two decades a wealth of decommissioning experience has been accumulated and has revealed some best practices, mistakes and associated lessons learned. It can be said that hardly any of the problems were of a serious technical nature. Many of the problems were associated with management and staff relations during the transition to decommissioning. In some cases shortage of funds has been the main factor causing delays in the start of decommissioning. Although there often seem to have been funds available from the operating period, at least to assure continuing surveillance and maintenance, such funds were often insufficient for the implementation of an active decommissioning strategy. In addition, a recurrent challenge is to conserve that funding by adapting the staff resources to the new tasks of shutdown and decommissioning.

The IAEA has published a number of publications related to the problems encountered in decommissioning activities and the solutions implemented in different member states. These publications cover technology, management, implementation, development, and cost estimates of decommissioning. The following, already mentioned, present international experience in decommissioning technologies:

1) Technical Report Radiological characterization of shut down nuclear reactors for decommissioning purposes [14],
2) Technical Report State-of-the-art Technology for Decontamination and Dismantling of Nuclear Facilities [16],
3) IAEA-TECDOC-1602, Innovative and Adaptive Technologies in Decommissioning Of Nuclear Facilities [17],
4) IAEA-TECDOC-1478, Selection of Decommissioning Strategies: Issues and Factors [19].

Below some more general experience in decommissioning activities that took place in some member states in recent decades is given.

7.1 United Kingdom

The United Kingdom, with a large but ageing nuclear programme, encountered a number of problems and the resulting lessons learned associated with decommissioning planning, studies and the early management of decommissioning. Important lessons and experience from this programme in the early 1990s are highlighted as follow:

- Generic studies of decommissioning were started more than 15 years before the first plant was shut down but were mainly for outline costing purposes and to highlight any potential technical problems. In a study on cost estimates it was found that earlier initial estimates tend to be overvalued, especially as large contingencies were added for uncertainties. As cost estimating became more refined and accurate, costs estimates were reduced since smaller contingencies could be applied.

- Very detailed studies were started on two NPPs just before the final shut down of the first plant. They were not completed before shut down in spite of the regulators request to complete and submit plans at least two years before shut down. The other plant that was studied in detail continued to operate for another 10 years. Two additional plants that had not been studied in detail shut down subsequently and there were therefore three plants needing attention. The lack of practical decommissioning experience was very apparent.
- The actual shutdown date of these installations/facilities was never established in advance and came as a surprise because the decision not to restart was made after a maintenance and upgrading outage. It proved in the end that continued operation for their remaining life would be too costly. It was accepted that precise shutdown dates cannot be predicted, but in subsequent years this was changed and a planned closure programme was announced.
- A detailed and comprehensive strategy study was undertaken covering all installations/facilities. This established a strategy of deferred dismantling (deferral for many decades to take account of beneficial radioactive decay, to reduce immediate decommissioning costs and due to the lack of a suitable waste disposal route).
- Detailed specific plans were subsequently made in a short period of about 2 years for all NPPs within the country. This was the responsibility of a central headquarters specialist group. The work proceeded with minimal and only reluctant involvement by operating plant staff whose main objective was to continue operation. The control and planning of decommissioning from a headquarters department caused conflict with the plants in terms of responsibility and proposals. In retrospect, more operating staff involvement should have been integrated into the decommissioning planning.
- The regulatory body was not inclined to approve the decommissioning plans as a whole due to the extended time scales of the decommissioning programme. They preferred to give approval for day-to-day activities, which was their normal regulating practice. This gave the opportunity to make amendments to the plans at later dates, but also made plans susceptible to regulatory changes since they were never officially approved.
- Public relations issues occurred almost immediately after shut down was announced and a great deal of effort was expended in satisfying interested parties and the public (stakeholders). During the operating period, interest in NPPs was not nearly so intense.
- Staff morale problems were significant at all three NPPs, but

especially at two of the plants that were more remote with fewer opportunities for re-employment. Staff relationship problems occupied considerable management time. A particular problem was that the site licence (a single licence which covers operating and decommissioning responsibilities) was held by the operating organization and they proceeded to undertake de-fuelling and spent fuel management under the licence. This caused conflict with early decommissioning activities. Only when the licence responsibility was transferred to the decommissioning team was the conflict allayed. In addition, the regulatory body was not initially prepared for decommissioning and regulated the site as though it was still an operating organization. This caused delays.

- The situation concerning lifetime records for decommissioning was worse than expected and addressed too late (i.e., after most of the experienced staff had left). The lessons from this adverse experience should contribute to better records management for the future.
- The on site management and conditioning of long-term stored operational waste was deferred too long. This should have been attended to during operation and not left until the end of the operating life. This led to significant problems during decommissioning.

7.2 United States of America

In the USA, experience and perspectives in the regulation of decommissioning are also available. The USA relies on multiple regulatory agencies to control nuclear waste. In particular, the Environmental Protection Agency (EPA) develops standards for radiation in the environment and the Nuclear Regulatory Commission (NRC) regulates licensing and decommissioning. The Department of Energy (DOE) manages clean-up of DOE installations/facilities. Some responsibilities for special nuclear materials, sources, by-products etc. are carried by individual States.

The NRC operates a risk informed, performance-based strategy. It does not, however, endorse a probabilistic risk analysis approach. The NRC established decommissioning rules in 1988 with the promulgation of standards, particularly concerning the setting aside of sufficient funds for decommissioning. This requirement was modified between 1993 and 1997 to set up a financial assurance mechanism. Decommissioning procedures were formally issued in 1996 and criteria for licence termination finalized in 1997. An allowance was made to permit sites to be released for restricted use where it could be demonstrated that it was not as low as reasonably achievable to clean them up to meet unrestricted release levels. The delays in the start of decommissioning by utilities was identified as a concern to the NRC and a rule on timing was introduced to allow only 2 years for installations/facilities to remain idle before submission of a decommissioning plan. Another modification of the rules was to set up a system for ensuring retention of the records necessary for decommissioning. This was considered to be a safety-related issue.

Attention also had to be given to the multi-faceted aspects of radioactive waste management, particularly regarding the issues of toxic, non-radioactive materials and mixed wastes.

Decommissioning also raised other aspects involved in licensing:
- Impact of the National Environmental Policy Act of 1969,
- Quality management,
- Recycling and reuse of contaminated materials,
- Cost optimisation,
- Overlapping responsibilities of the NRC and the EPA.

In 1990 a Site Decommissioning Management Plan was established to focus on a series of difficult situations involving contaminated soils, water and other materials associated with site remediation. Experience with Fort St. Vrain and Shoreham revealed that final surveys to demonstrate compliance for site release were very costly. A new final survey guidance manual "Multi-Agency Radiation Survey and Site Investigation Manual" (MARSSIM) was published in 1997 as part of a new site licence termination rule. This new survey protocol uses statistical analysis to demonstrate compliance with decommissioning standards and is expected to reduce final survey costs.

The NRC has adopted a generic approach to the assessment of dose and risk and uses the concept of an average member of the critical group which is defined in terms of residual activity, source location and potential exposure scenarios.

The common problem of naturally occurring radionuclides in the context of site clean-up was addressed by the use of a simple conservative screening approach, rather than sophisticated and complex models which may not be sufficiently robust for use under diverse site and environmental conditions.

It was recognized that there are a number of issues that are especially relevant and significant to decommissioning and site clean-up. These are:
- Uniformity and consistency in site clean-up criteria,
- Validation of dose models and their uncertainties,
- Resolution of key technical shortcomings in determining compliance with criteria,
- Sharing of lessons learned from past experience,
- Developing pragmatic strategies for dealing with site clean-up,
- Public involvement in the decision making process.

The key points on issues associated with the organization and management of decommissioning from a US viewpoint are as follow:

- During operation there should be a small group to study and plan decommissioning,
- Factors to be considered are strategy, staffing, extent of the work,
- The periods of decommissioning depending on the strategy,
- The decision on who will do the decommissioning (in house staff or contractors),
- The extent of guidance given by the regulatory body,
- The national spent fuel policy and the available storage facilities,
- The waste disposal policy and the availability of disposal or storage sites,
- The type and size of the organization depends on the above.

7.3 Italy

The problems related to decommissioning of installations/facilities in Italy arise from the following:

- The significant amount and different types of installations/facilities to be dismantled (e.g., NPPs, reprocessing plants and experimental facilities),
- The absence of any installations/facilities still in operation, and of any new installations/facilities to be commissioned.

The entire nuclear programme in Italy was abandoned after the negative result of a referendum held in 1987. This vote was formally limited to specific aspects of siting under the nuclear legislation in force at that time, but the results represented the negative attitude of the public to nuclear technology. As a consequence, the operation of all NPPs was stopped in the years 1987–1990. At the same time the National Electric Company (ENEL) was instructed by the responsible governmental body to start actions for decommissioning. The "safe storage" option was adopted as a general strategy, in order to benefit from reduction in radioactive levels by decay and allow time to define a strategy for waste and repository management. However, the following difficulties impacted negatively on the start of an effective decommissioning programme:

- The lack of specific acts defining the national policy on decommissioning and allocating specific financial resources for the relevant operations;
- The lack of a national site for the disposal of low and intermediate level waste; and a centralized interim storage facility for spent fuel and high level waste;
- The uncertainty, at national level, of the policy for management of very low level waste (clearance levels);
- The necessity of an independent environmental impact assessment for the decommissioning of nuclear installations by the Ministry of the Environment,
- Some gaps in the nuclear legislation, where commissioning of

installations/facilities is given more emphasis than decommissioning. However, new legislation in force from 1996 (amended in 2000), introduced new regulations in the field of radiological protection, providing for stricter dose limits for workers and the public. The legislation also provided new specific rules on the decommissioning of NPPs.

Subsequently "safe enclosure" of the installations/facilities was adopted as a general strategy, but did not progress smoothly and underwent significant delays.

An additional difficulty resulted from the application of new legislation. As a result of the intention to guarantee the public interest from different points of view, several bodies were involved in similar maters, which resulted in delay in the start of decommissioning, mainly because all authorities concerned had to be involved twice, both at the beginning and at the end of the licensing process.

Previous decommissioning operations, previously subject only to authorization by the Ministry for Productive Activities (MPA), were subject to further authorization of the MPA, but acting in consultation with the Ministries of the Environment, the Interior, Labour and Health, and the Region concerned. In practice, the regulatory body, which is responsible for the technical safety analysis on behalf of the Ministry of Industry, has to receive and take into account observations, conditions and specifications given by the other authorities involved in the licensing process. Having several bodies playing a role in similar matters was intended to guarantee the public interest from different points of view, but, on the other hand, this resulted in delay in the start of decommissioning, mainly because all the authorities involved had to be involved twice, both at the beginning and at the end of the licensing process.

By the end of 1999, the Ministry in charge (Ministry for Productive Activities) issued a document providing strategic guidelines for the management of liabilities resulting from past national nuclear activities. The highlights of this new policy were:

- Treatment and conditioning of all radioactive waste stored on nuclear sites;
- Initiation of a concerted procedure, facilitated by means of a specific agreement between the Government and the Regions, for the selection of a near surface national site for the final disposal of low and intermediate level waste and for the interim storage of the spent fuel and high level waste;
- The adoption of the strategy for prompt decommissioning "DECON" of all shutdown installations/facilities, thus abandoning the previous "SAFE STORAGE" option;
- The establishment of a new national company, SOGIN, responsible for all shutdown NPPs, with a mandate to perform prompt decommissioning;

- The creation of a National Agency for the management and disposal of radioactive waste, with the mandate to realize and operate the national radwaste disposal site; and
- The allocation of special funds for all these activities by means of a specific levy on electricity bills.

According to these directives all the nuclear installations should be completely decommissioned by the year 2020. The new policy was followed by a Ministerial Decree in January 2001, establishing plans and procedures for funding the decommissioning of NPPs and other fuel cycle installations/facilities (i.e., from dismantling to waste conditioning and disposal). The strategy identified in this Decree was further detailed by a Ministerial Decree in May 2001, which provided operational directives to SOGIN to implement prompt decommissioning of the four national power stations up to an unconditional release of the respective sites within twenty years. The Decree also provided directives to SOGIN for the safe management of radioactive waste and spent fuel associated with the NPPs, together with a funding provision by an additional impost on the consumed electrical energy. Comprehensive decommissioning project proposals for Italian NPPs were submitted by SOGIN in 2002.

7.4 France

The nuclear programme in France started in 1945 with the foundation of the French Atomic and Alternative Energy Commission (Commissariat à l'énergie atomique et aux énergies alternatives, CEA). Since then, France has set up and run various types of nuclear installations: research and prototype reactors, process study or examination laboratories, pilot installations, accelerators, nuclear power plants and processing facilities.

CEA's Nuclear Energy Division (Direction de énergie nucléaire, DEN) operates (as of 2012) seventeen reactors and thirty six other facilities, particularly laboratories, fuel processing units and facilities specific to waste management. EDF (Électricité de France), a French electric utility company, started a nuclear programme with Natural Uranium Graphite Gas Reactors (GCR) in 1963, but later moved to PWR technology and now operates 58 PWR units. France has also commissioned two fast breeder reactors, Phénix (a prototype sodium-cooled reactor operated by CEA), and Superphénix (operated by EDF).

CEA started decommissioning nuclear facilities back in the sixties and seventies (the first plutonium plant at Fontenay-aux-Roses and small research reactors and critical models - CESAR and PEGGY at Cadarache and MINERVE at Fontenay-aux-Roses, and others). While these (smaller) facilities were dismantled, the intermediate size reactors, like G1 and Rapsodie were only partially dismantled due to the shortage of graphite and sodium waste processing capabilities. Altogether, about twenty facilities were dismantled up to the year 2001, which is approximately half of all the facilities that were shut down by that time. CEA's goal is to decommission all nuclear facilities that were shut down from 1980 to 2010 by the year 2025. This also includes prototype and experimental reactors and the Phénix reactor, which was shut down in year 2010 after 37 years of successful operation. Two prototype reactors were already shut down in 1968 and 1973. All these reactors were shut down for economic reasons.

CEA has shut down, or is about to shut down all nuclear facilities at the Grenoble Centre (the facilities are in the last stages of decommissioning) and Fontenay-aux-Roses (final decommissioning is targeted for the year 2025). The decision to "denuclearise" these sites was a consequence of the location of these centres in (now) highly populated areas.

EDF has also terminated operation of six facilities from 1973 to 1994. They were all Gas Cooled Reactors located at the sites Chinon, Saint-Lorent and Bugey, and were all shut down for economic reasons after twenty years of operation or more. An exception was the oldest prototype reactor Chinon-1, which was shut down in 1973 after only ten years of operation. The decommissioning strategy adopted for these units was deferred dismantling, where the unit was partially dismantled after shut down in order to reach the stage of a Basic Nuclear Installation for Storage (Installation Nucléaire de Base d'Entreposage - INB-E). The equipment was partially dismantled and stored in the reactor building or heat exchanger buildings, which became the storage facility. Final decommissioning/dismantling has been deferred for 25 to 50 years in order to allow radioactive decay of components (especially the activity of ^{60}Co).

The decommissioning activities of CEA were slowed down through the nineties due to changes in regulations and funding difficulties. The regulations required several successive licences for decommissioning (in contrast to one licence for a new facility), the regulatory framework was designed with power reactors in mind and the regulations were not easily applicable to smaller facilities. At the same time, the regulations did not require from the licensee, nor allowed the regulators to perform an overview of the decommissioning project that could allow them to examine the global optimisation of the project.

In 2001 a special fund for decommissioning facilities was established by CEA in accordance with the regulatory authority requirements. In 2006 and 2007 additional legal tools (Law and Decree) were enacted to enable operation of and provide sufficient income for the fund dedicated to decommissioning nuclear facilities. A separate dedicated fund was also established for decommissioning defence programme facilities, which are also a part of CEA operations. The same approach (i.e. setting of a separate dedicated fund for decommissioning) is also required from EDF.

Deficiencies in the regulatory framework in the nineties (multiple licencing, absence of a graded approach, incomplete overview of projects, and also lack of provisions for termination of a licence) were identified by the French Nuclear Safety Authority (Autorité de sûreté nucléaire, ASN) and the decommissioning approach was changed in the year 2003. ASN decided to promote the immediate decommissioning approach, mainly because of potential knowledge loss and ageing management issues at the facilities. Consequently, EDF was asked to evaluate the feasibility of reducing the time to complete decommissioning and to review its decommissioning strategy.

The new licensing framework for decommissioning is based on the following considerations:

- To provide an overview of the whole decommissioning project, including the intended end state;
- To issue only one licence for the whole project;
- To ensure that regulatory activities are commensurate with the actual hazard posed by the facility and decommissioning project (the graded approach);
- To include a regulatory framework for the licence termination process.

It was concluded that problems associated with the description of the entire decommissioning process at the beginning are outweighed by the possibility to optimise each stage (even the early ones) by taking into account other stages, although some of them (e.g. later stages) could not be well defined at the beginning of decommissioning. According to the new legislation, the licensing process requires the licensee to produce a report on the decommissioning strategy, including a safety assessment of each successive decommissioning phase or main operation. The first phases or operations must be described and assessed in detail, while later phases or operations should be described and assessed in less detail and the main safety aspects assessed. The licence issued will define, if needed, particular phases or operations that will necessitate additional authorisation if they are of particular importance for safety.

Rationale behind the decommissioning approach

After the final shut down of a facility, radioactive clean-up is launched immediately to reduce the risk levels as quickly as possible and to make the most of the experience of operating staff. Immediate dismantling is normally chosen after the clean-up to avoid loss of information on facility construction and operating conditions, as well as to avoid extra expenses from extended monitoring of the facility and its maintenance.

Delayed dismantling can be an option if the gain from decay of short-lived radionuclides is greater than the extra expenses for extended monitoring and maintaining of facility in its current condition. Delayed dismantling is also chosen when it is reasonable to wait for a waste stream to open for operation (e.g. for graphite), thus avoiding the necessity for additional interim storage facilities.

The target final state for a facility must lead to its total decommissioning for potential reuse without restriction or monitoring.

For the site to be released (soils and buildings) after dismantling, the calculated dose from the residual activity, under an envelope (worst case) scenario, must not exceed 300 μSv/year. Further optimisation is based on a number of miscellaneous criteria, including the cost and consequences of work relating to the situation of the facility and its specific features.

Protection of workers is achieved through reduction of integrated doses; for protection of the environment, efforts are made to reduce the volume and level of radioactive waste and effluents generated.

Legal steps in the decommissioning process

The nuclear facility operator intending to shut down and decommission a facility should inform ASN at least three years in advance. This information should be supported by an updated dismantling plan, which must describe and justify the dismantling strategy, the sequence of operations and the required equipment, planned waste management streams and the targeted final state of the facility after dismantling.

At least one year before planned shutdown, the facility operator submits the authorisation request to the authorities. This submission must contain the following main elements:

- Planned stages of dismantling, their sequence, the general operating rules, and a related safety report;
- The state of facility after decommissioning;
- A risk and impact study for the dismantling operations;
- Waste management methods;
- Prediction of the future use of the site;
- An updated internal emergency plan; and
- Any monitoring and maintenance measures required after dismantling.

The final step in decommissioning, removing the facility from legal control, is accomplished after notification from ASN, but it requires also various public consultations and a public enquiry.

Lessons learned

Decommissioning activities are under way in CEA's research centres in Cadarache, Fontenay-aux-Roses, Grenoble and Marcoule and in EDF facilities. These facilities are in different stages of decommissioning, but the CEA's goals (denuclearisation of the Grenoble and Fontenay-aux-Roses sites, and decommissioning of all facilities shut down between 1989 and 2010 by 2025) are achievable.

Feedback experience from decommissioning has confirmed that early dismantling is a better solution than other options. Prompt decommissioning could benefit from the operator's experience (memory not lost), while surveillance and refurbishment costs are lower. Interested parties, particularly the public, are more confident and less concerned. During decommissioning it is important to have an intimate knowledge of the facility's radiological geography, good organisation of the work and tasks, decommissioning techniques should meet ALARA principles and waste production optimised. Education and training of decommissioning workers is essential since decommissioning is a profession, and workers must be experienced.

Feedback experience also relates to the design and operational phases of the facility. It is absolutely necessary to clean-up periodically during the lifetime of the facility, especially when spot contamination occurs. The design of new facilities should minimise decommissioning constraints: equipment and areas should be easily accessible, movable shields and other equipment should be used where possible, materials should be non-porous, lead windows and cameras should be planned and installed, and construction of blind cells without access should be avoided.

7.5 Germany

The first operational nuclear facility in Germany was the Forschungs-reaktor München (FRM) research reactor at the Technische Universität in Munich. This 4 MWth pool type research reactor went critical in 1957 and was in operation until the year 2000. In 1960 VAK Kahl, a prototype BWR reactor of 16 MW electric power was commissioned. It was in operation until 1985 and has already been successfully decommissioned. The first commercial power plant was KRB-A Gundremmingen, a Boiling Water Reactor of 250 MW electric power. KRB-A Gundremmingen was in operation from 1966 to 1977 and is under decommissioning since 1983. Following these pioneers, numerous nuclear facilities were built in the sixties, seventies and eighties, but only a few after 1990. Many of these were shut down and are being decommissioned at present.

At the moment (as of April 2014) there are 9 NPPs in operation (7 PWRs and 2 BWRs), which started routine operation between 1982 and 1989. There are also 7 different research reactors at universities and institutes, with from zero power to 20 MWth and first criticality from 1964 to 2004. Other nuclear facilities in operation (without interim storage and a final depository) are a factory for enrichment of uranium (in operation since 1985), an LWR fuel factory (since 1979) and a utility for waste conditioning (from 2000).

At the beginning of 2011, at the time of the Fukushima accident, 8 additional NPPs (4 PWRs and 4 BWRs) were in operation. Except for one, they all started operation in the seventies. The German Government decided on a moratorium in operation (for 3 months) for these power plants. In August 2011 an amendment to the Atomic Energy Act was confirmed. It was decided that shut down of these 8 power plants will made final, and final phase-out of nuclear power was declared. According to this amendment, the 9 NPPSs that are still in operation will be shut down in the years 2015 (1 NPP), 2017 (1 NPP), 2019 (1 NPP), 2021 (3 NPPs), and 2022 (3 NPPs). As of 2013, the 7 NPPs that were permanently shut down in 2011 have already applied for decommissioning licences.

Before 2011, 12 commercial NPPs were shut down and all except one are in different phases of decommissioning. One NPP (KWL Lingen), which was shut down in 1977, is in safe enclosure. 8 prototype reactors were also shut down, 2 of these are in decommissioning, 2 are in safe enclosure, 3 are cleaned (removed), and one (that has never operated) has been transformed into a leisure park.

10 research reactors were shut down from 1981 to 2010, 5 of these (most of them were shut down before the year 2000) are under decommissioning, while the other five still do not have a decommissioning licence.

11 fuel cycle facilities were shut down from 1987 to 1995, 7 of these have already been decommissioned (or released from regulatory control), while 4 are still under decommissioning.

Approach to decommissioning

The following fundamental decommissioning strategies are applied in Germany:

- Direct dismantling: This strategy involves the dismantling of a nuclear facility and its release from nuclear regulatory control;
- Safe enclosure: This strategy involves transforming the nuclear facility into an almost maintenance-free condition, followed by later dismantling and release from nuclear regulatory control.

Decommissioning strategies may also involve a combination of these fundamental alternatives. The removal of large components without segmentation, the storage of these components and their later segmentation can optimise the whole decommissioning process. The decision on which decommissioning strategy will be implemented is taken by the operator of the facility within the scope of entrepreneurial responsibility.

According to German legislation, after shut down the facility enters the so-called post-operational phase, which is still covered by the operating licence of the facility. In this phase measures can be carried out to prepare decommissioning. These measures are:

- Unloading of fuel elements from the reactor (for reactors),
- Reloading of the fuel elements into storage containers and storage in the on-site interim storage facilities,
- Removal of radioactive materials and the radioactive waste accumulated in the operational phase,
- Decontamination of the facility and systems,
- Taking samples from systems and components required for the application for decommissioning.

Late in the post-operational phase, the operator of the facility applies for licensing of decommissioning. Only after the licence is granted may the actual decommissioning and dismantling activities be started. The costs of the post-operational phase are not included in the decommissioning costs.

In the case of immediate dismantling, the facility will be dismembered immediately; that is, immediately after the post-operational phase, all systems and installations of the controlled area are dismantled. Experience shows that the decommissioning work takes at least a decade.

In the case of the alternative strategy the facility is dismantled after a period of safe enclosure. In this process there are three distinct phases: measures taken in the facility for the purpose of establishing safe enclosure, maintaining the facility in safe enclosure (for example for 30 years), and final dismantling of the facility.

Lessons learned

The preferred decommissioning strategy in Germany is direct dismantling. Experience has shown that the disadvantage of the short decay period can be more than compensated for by means of sensible measures of radiation protection and the use of appropriate technologies.

Large decommissioning projects are typically divided into phases, which correspond to large work packages. These phases can be also reflected in individual licences. In particular phases decommissioning is done from “outside to inside” i.e. from less contaminated to more contaminated components, systems and reactor. The advantage of this approach is that it allows the structuring of large complex technical systems, promotes the gathering of further information needed for later work packages, and allows flexibility in adapting changes in future phases. Decommissioning of large facilities (NPPs) typically consists of four phases.

German companies have acquired extensive experience in large component removal. The options are the following: in-situ dismantling, partial in-situ dismantling (with post-processing on-site or off-site), and removal and ex-situ dismantling (on-site or off-site dismantling). Remote systems for dismantling are widely used during dismantling. These systems must be extensively cold-tested before use.

Material clearance is based on the 10 µSv principle (i.e. radioactive activation and contamination of the material to be cleared, must be such that the exposure of a member of the public is no more than about 10µSv/year). Predefined clearance levels are used, one set for unconditional clearance ("use as you like") and the other conditional clearance ("the use is predicted").

High volumes of material must be handled during decommissioning, therefore the internal logistic capacity within the facility, and the treatment and conditioning capacities must be adequate. This also applies to interim storage facilities for radioactive waste.

7.6 NEA/IAEA/EC joint conclusions

In 1999 a combined NEA/IAEA/EC workshop was held in Rome, focussing on the regulatory aspects of decommissioning. Particular aspects of human relations regarding safety culture and staff morale were emphasized and the threat that these can represent to a project due to change and uncertainty.

A number of approaches have been developed by utilities, including guaranteeing employment for a certain period and emphasising the new and important technical challenges. Presenting decommissioning as an opportunity rather than a threat was an important message, and good and timely communication was seen as a major tool. The sharing of international experience both successful and less successful was also recommended. The key findings from the workshop were the following:

- There are significant variations in the reasons for final shutdown which have a significant impact on work organization and human factors,
- The risk profile of the plant changes during the transition from operation to shut down and eventually to the decommissioning state. This is generally from high risk - low probability to low risk - high probability, and the perception of workers and management of this situation may be under estimated,
- The retention of staff competence for decommissioning work is crucial. Strategies for the retention of skills need to be developed and implemented early in the decommissioning planning process,
- Emphasis on the sharing of experience in organization and human factors is needed since many decommissioning activities are performed only once or at most a few times,

- Oversight of decommissioning by the regulatory body and government needs a clear and consistent strategy, especially if a number of licensing agencies are involved,
- The extensive use of contractors creates a number of issues. The responsibility of the operator is paramount and it is necessary to demonstrate an intelligent customer capability and to maintain sufficient control and supervision of the contractor’s work,
- Degrading the perception of risk must be avoided and the tendency toward lax management and low staff morale guarded against, especially during periods of increased uncertainty,
- No optimum organizational structure emerges, except the need to have a dedicated decommissioning team with sufficient resources.

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