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ACHIEVING THE GOALS OF THE DECOMMISSIONING SAFETY CASE

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ACHIEVING THE GOALS OF THE DECOMMISSIONING SAFETY CASE

A status report prepared on behalf of the WPDD
by its Task Group on the Decommissioning Safety Case

This status report reflects the viewpoints and materials of a topical session held in December 2001 plus the sharing of experience within the WPDD, which represent operators, regulators, R&D and policy specialists from countries with advanced nuclear infrastructure that have considerable experience in the field of decommissioning. These materials contribute to the content and substance of a safety case for decommissioning and will be helpful to individuals and organisations involved in the preparation of such a safety case.

FOREWORD

Decommissioning of nuclear facilities in OECD Member Countries is already being carried out and is expected to reach a peak level of activity after about 2015. This increasingly important activity is currently being addressed by the Working Party on Decommissioning and Dismantling (WPDD) set up by the NEA Radioactive Waste Management Committee (RWMC). The WPDD has produced a document entitled ìThe Decommissioning and Dismantling (D&D) of Nuclear Facilities in OECD/NEA Member States - Status, approaches, issuesî in which it recorded general agreement amongst various stakeholders on a number of key points. In particular it noted that:

- Techniques for D&D are already available, and valuable experience is being fed back to plant design and decommissioning plans.
- Many nuclear facilities have already been successfully decommissioned and dismantled.
- There is no unique or preferred approach to D&D of nuclear facilities.
- Current systems for protection of the safety of workers, the public and the environment are satisfactory for implementation and regulation of D&D.

In connection with the last point, the WPDD also noted that it might be advisable to review the protection systems over the entire period of the decommissioning process in order to ensure continuing safety of workers, the public and the environment, and to ensure continuity and transparency of the regulatory process. As a first step, the WPDD held a topical session covering the information and experience on the content of a safety case for decommissioning of nuclear facilities. The scope of the topical session included all types of nuclear facilities and was subject only to the assumption that spent fuel has been removed from the spent fuel pool at reactor facilities.

This status report reflects the viewpoints and materials of the topical session plus the sharing of experience within the WPDD, which represent operators, regulators, R&D and policy specialists from countries with advanced nuclear infrastructure that have considerable experienced in the field of decommissioning. These materials contribute to the content and substance of a safety case for decommissioning and will be helpful to individuals and organisations about to prepare such a safety case.

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INTRODUCTION

The decommissioning of nuclear facilities may be defined as the administrative and technical actions whose purpose, once a facility has been removed from service, is to allow its release from regulatory control and relieve the licensee of the responsibility for its safety, which was necessary when the facility was a operating as a licensed nuclear installation.

A wide range of nuclear facilities has been decommissioned so far, including laboratories, prototype reactors, isotope production plants, accelerators, and commercial nuclear power plants. The scale of national decommissioning programmes will grow significantly as the larger commercial nuclear power plants approach the end of their useful life by reason of age, economics or change of policy on the use of nuclear power. The scale of such challenge may be judged from the fact that over 500 commercial nuclear power plants have been constructed and operated world-wide, but only about 100 have been taken out of service and fewer still have been fully decommissioned. Given an average planned operating life span of 30 to 40 years and given that the average age of nuclear power plants is, at present, about 15-20 years, the rate of withdrawal from service will peak some time after 2015.

Much has been done in the field of decommissioning, especially in terms of techniques and in setting up institutional frameworks, and particularly so in the more mature nuclear programmes. Due to the number of projects to be taken on and the magnitude of those projects in terms of both size and time, there will be national variations in the amount of preparatory work that is still needed to be performed. The work on the safety case for decommissioning projects will be increasingly important to get necessary approval from all stakeholders involved.

This document records the position of the WPDD on the safety of decommissioning and the task for providing a decommissioning safety case. Guidance is already available, both internationally and nationally [**i, ii, iii**] on the detailed technical, management and administrative requirements for the decommissioning of nuclear facilities. Such guidance tends currently to focus on radiological aspects, reflecting its development from the safety case for the operational phase. The decommissioning phase, however, introduces some wider issues, or at least a change of emphasis on existing issues, and it is against this background that the WPDD started to review the key points that need to be addressed specifically for decommissioning safety and to consider whether there is sufficient guidance for the increased level of decommissioning activity expected over the next decade or so.

The present document is written for an audience that may or may not be familiar with the decommissioning process and/or the potential hazards associated with the decommissioning of nuclear facilities. Information is provided that may be used by nuclear facility operators and managers for planning and developing strategies for the shutdown and decommissioning of a facility as it approaches the end of its operational phase. It assumes that the reader has sufficient knowledge about the operation of nuclear installations to apply the general concepts discussed to the site-specific circumstances of his or her facility.

The safety of decommissioning rests on three main items described hereafter:

- the provision of a decommissioning safety case (see Chapter 2), which rests on;
- adequate pre-assessment of the level and location of the hazard (see Chapter 3); and the
- application of relevant technical and management approaches for hazard removal (see Chapter 4)

PROVIDING FOR A DECOMMISSIONING SAFETY CASE

Hazards during decommissioning

It is widely accepted that the radiological hazards associated with a nuclear facility undergoing decommissioning are substantially less than when in normal operation. This is because removal of fuel elements and radioactive materials in systems, and conditioning and removal of operational waste, all has a major, beneficial effect on reducing the amount, composition and distribution of residual radionuclides at the plant. For example, in the case of a modern 1 000 MWe light-water reactor, the quantity of radioactive material present is reduced to 0.1% of the operational level after the fuel has been removed. The quantity of radioactive material removed from the plant at this stage is about 10^{20} Bq compared with the 10^{17} Bq that remains in structures and activated components, and the 10^{14} Bq present as surface contamination. At other types of facilities, too, there is a substantial reduction in the radioactive inventory following the removal of radioactive waste and the radioactive materials involved in activities such as fuel fabrication and spent fuel reprocessing.

The beneficial effect of radioactive inventory reduction is further enhanced during decommissioning by the removal or reduction of some of the more notable hazards such as high pressures and temperatures. Even though these hazards may be reduced, however, other more conventional hazards may be introduced or increased. Also, it is necessary to recognise that the inherent need to remove safety systems from service progressively and to destroy confinement barriers, in order to achieve the long-term reduction in hazard, can temporarily increase the short-term hazards. The various hazards or factors that need to be considered in regard to the main goals of a assuring safety are discussed below.

Underlying Goals of Decommissioning Safety

The underlying goals of decommissioning safety of a nuclear facility are:

- protecting the workers and preventing accidents;
- protecting the public, and
- protecting the environment in which the facility is located.

Worker Protection and Accident Prevention

Workers need to be protected by eliminating or reducing the radiological and non-radiological hazards that may arise during routine decommissioning activities and as well as during accidents. The non-radiological or conventional industrial hazards to which workers are subjected during the decommissioning and dismantling process may be greater than those experienced during the operational lifetime of the facility. The hazards associated with decontamination and dismantling of structures and buildings, or with construction of temporary facilities, are important not only because they may be a direct cause of harm to workers, but also because their occurrence may, indirectly, result in increased radiological hazard. Radiological and non-radiological hazards are summarized below.

Radiological Hazards

As a general requirement, the established dose limits must be fulfilled and applicable dose constraints should restrict the projected individual doses. The magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures should be kept as low as reasonably achievable, economics and social factors being taken into account (ALARA-principle[1]).

Criticality

The occurrence of accidental criticality is not envisaged in shut down nuclear reactors from which the fuel elements have been completely removed, including from associated stores. The possibility of accidental criticality may be present, however, in the process equipment or waste storage tanks of facilities where fissile materials have been processed, such as fuel-manufacturing plants or spent fuel-reprocessing plants. Criticality must be assumed to be possible until all processed materials and fluids have been removed from all of the facilityís systems and storage tanks.

Loss of Containment

The possibility of inadvertent loss of containment of the radioactive materials present at a facility must be taken into account in all decommissioning project tasks. This is particularly important in the retrieval of radioactive materials from the various processing units in a facility, in the dismantling of its systems and in the later cleanup of areas where they were located. The containment and ventilation systems used during the operational life of a facility are generally not sufficient for dismantling operations, and special systems often have to be set up to contain and ventilate work areas. The safety features of such special containment systems must match the hazards and radionuclides present in each area and, in this regard, the presence of alpha-emitters is the most significant constraint.

External exposure

In situations where remote handling systems cannot be used and after all practicable steps have been taken to decontaminate an area or equipment, the exposure of staff undertaking dismantling activities from external sources should be optimised.

Ingestion and Inhalation of Radionuclides

If radionuclides are present in the work area in the form of removable surface contamination, staff may be subjected to internal radiation exposure by ingestion or inhalation. The potential for inhalation is of particular concern in the case of activities carried out in areas or premises contaminated with alpha-emitting radionuclides and appropriate measures must be taken to prevent or minimise the potential for inhalation. The ALARA-principle should be observed.

Non-Radiological Hazards

Fire

Fire is the conventional hazard that most frequently occurs in facility dismantling projects. The methods used for certain equipment dismantling operations (e.g. thermal cutting techniques) or for decontamination of surfaces (e.g. aggressive decontaminating solutions, etc.) are often the cause of localised fires. Moreover, while dismantling activities are in progress, the temporary accumulation of

1. ICRP-26 (1977): Recommendations of the International Commission on Radiological Protection

combustible materials and waste (plastic, cotton, etc.) is common, thus increasing the potential for fires in the area. Fortunately, such fires can be promptly detected and extinguished by appropriate fire protection measures, and are generally of little importance.

Although it has been assumed in this study that spent fuel is completely removed from the facility being decommissioned it is worth noting here, because of its possible consequences, that, where spent fuel elements remain in pools, rapid oxidation of zirconium in fuel cladding may be started if it is exposed to high temperature in water steam and/or oxidising atmosphere.

Fire hazards during decommissioning activities must therefore be examined thoroughly, specifically the techniques and reagents to be used, the conditions under which the activities will be carried out, and the arrangements for storage of materials that will be generated in the operation. Fire protection measures should then be determined on the basis of this analysis.

Explosion

In addition to normal fires, explosions may occur during decontamination and dismantling as result of the chemical reagents and equipment used, (e.g. decontaminating solutions, thermal cutting devices such as blowpipes fuelled by highly inflammable materials, etc.) Such explosions may even be caused by reaction of such reagents with radioactive materials remaining in tanks or associated with equipment due for decontamination, thus creating both radiological and non-radiological hazards.

Some materials generated in the process of dismantling a facility, such as inflammable dusts, may in certain circumstances acquire explosive characteristics. Also, at facilities where a considerable time has elapsed since shutdown and chemical reagents or liquid waste have been awaiting conditioning for lengthy periods of time, there is a possibility of auto-concentration phenomena that may cause explosive conditions, and special care must be exercised in such circumstances.

Toxic and hazardous materials

The dismantling of nuclear facilities sometimes reveals that they were built using materials that are now banned and whose removal requires special measures because of their toxic or hazardous properties of the building materials. It is common, for example, to find asbestos used in thermal insulation or in fire barriers, lead in paint, counterweights and shielding, and polychlorobiphenyls (PCBs) in oils and electrical insulation. Furthermore, some of the materials used in the decommissioning process, such as decontaminating solutions may, in and of themselves, be toxic and hazardous. All require appropriate protective measures to be taken.

Particular care should be taken when these non-radioactive hazardous/toxic materials are either chemically combined or contaminated with radioactive material. In these instances operators may need to devise safety and disposal strategies that address both the radiological and non-radiological hazard. In some instances, *albeit* rarely, implementing normal safety procedures for one hazard may increase the potential for the other. Thus, careful analysis of the safety (and disposal) requirements for this mixed material should be performed by specialists familiar with the inherent hazards. Safety and disposal practices should be implemented only after this analysis has been performed and practices developed that address the hazards from both materials.

Electrical hazards

The dismantling of electrical installations in an environment where live wiring may be present, and inadvertently cut, is a hazard that must be recognised and addressed effectively for decommissioning activities. For this reason, it may be prudent to use new, completely separate electrical systems and to disconnect the original ones.

Physical hazards

The physical hazards typically associated with demolition activities, or with the construction and use of temporary facilities, are also important, (e.g. collapse of structures, falling of heavy objects, working at heights, etc.) and need to be addressed.

Protection of the Public and the Environment

Any hazards to the public and to the environment, arising from nuclear facilities once their operating life has ended, will decrease progressively during the decommissioning process. An important part of the hazard reduction is the removal of the present radioactive materials. Spent fuel elements, operational radioactive waste and radioactive waste created during dismantling are generally removed to storage areas or to disposal facilities, as appropriate. Thus, they remain safely within the control regime that applies to operational facilities, and the hazards related to their subsequent storage or disposal are normally not associated with the activities of decommissioning. Controlled and licensed releases of liquid and gaseous effluents into the environment and clearance of solid materials containing trivial levels of radioactive contaminants for reuse or disposal as conventional waste needs another control regime, as described below.

Liquid and gaseous effluents

Some of the wastes generated during decommissioning of a nuclear facility may be different from that generated during operations. This is because some of the materials used in decommissioning and some of the activities involved (e.g. in cutting and decontamination) are quite different from those during the operating stage. Also, the quantity of liquid effluents generated from decontamination operations may be larger during decommissioning whereas the quantity of gaseous effluent generated from ventilation of work areas usually decreases. The waste management arrangements for decommissioning activities should be designed to minimise the volume and radioactive content of such discharges into the environment, with appropriate abatement systems being provided according to the chemical and radioactive characteristics of the particular waste stream.

Cleared materials

A substantial fraction of the materials arising during dismantling, of which metals are usually the economically most valuable, is not at all radioactive or very slightly contaminated. The release from regulatory control of such materials, follows a procedure often described as ìclearanceî. This procedure avoids unjustified allocation of resources to radioactive low-level waste disposal. Such materials may be returned to the environment by way of direct reuse, by recycling as raw materials, or can be disposed as ordinary waste.

Residual on-site contamination

When decommissioning of a nuclear facility is complete, there may be residual radionuclides left in the ground on buildings, or in other media. These may be released from subsequent regulatory control if the remaining radiological impact is within an acceptable level, according to the applicable radiological criteria.

Environmental impacts

In a number of OECD/NEA Member Countries, including all EU Member States, the environmental impact of certain activities, including decommissioning of nuclear facilities, needs to be examined by way of an Environmental Impact Assessment (EIA) An EIA involves the identification, description and assessment in an appropriate manner of the direct and indirect effects of the various activities on:

- Human beings, fauna and flora.
- Soil, water, air, climate and the landscape.
- Material assets and the cultural heritage.
- The interaction between all of the above factors.

An EIA requires meaningful involvement of the public and, where there are potential trans-boundary effects, the involvement of the neighbouring countries.

In most, although not all, EU countries it is likely that, in addition to physical impacts including the potential short-term and long-term effects of radioactive substances on the environment and on human beings, the assessments will also consider social, economic and health effects. Potential social impacts are likely to include effects on population demographics, social structure, and community image and cohesion. Potential economic impacts include effects on community services, employment, housing and business development. Potential impacts on community health may include psychosocial effects. This approach is also compatible with the methodology for environmental impact assessment adopted in the United States, Canada and Australia. These latter issues are likely to be of major importance in decommissioning of a nuclear facility located in or near a community whose livelihood and infrastructure depend upon it.

The Safety Case

The key issue in the decommissioning of nuclear facilities is the progressive removal of hazards, by way of a series of decontamination and dismantling activities that have to be carried out safely and within the boundaries of an approved safety case.

A safety case is a collection of arguments and evidence to demonstrate the safety of a facility or activity. A safety case reflects the actual work performed at the facility and the actual, prevailing conditions. The safety case is produced by the license holder of the facility and normally includes a safety assessment, but would also include information (including support evidence and reasoning) on the robustness and reliability of the safety assessment and the assumption made therein. It is nowadays common to supplement the safety case with an environment assessment.

The safety case for decommissioning of a facility will in some respects differ from the safety case for its operation. In this context it is helpful to distinguish between the terms ìsafety caseî and ìsafety, or environmental, assessmentî. The latter term generally implies a discrete action carried out at points in time, and at a level of detail, that depends on the particular stage in the lifecycle of the facility. The safety case, on the other hand, applies continuously to a nuclear facility throughout its entire lifecycle. It must be kept up-to-date as the circumstances of the facility, including its management, change and develop. In this regard, safety and environmental assessments are key inputs to maintenance and development of the on-going safety case.

Thus, regardless of the reasons for withdrawing a facility from operational service, the safety case for operation must be changed into a safety case for decommissioning, with appropriate analyses of hazards and preparation of plans for their elimination or avoidance. This process can benefit from the good practice of preparing preliminary decommissioning plans from the earliest stages of nuclear facility design and operation, and revising them in the light of experience with the plant and lessons learned from decommissioning developments elsewhere.

PREPARING FOR THE SAFETY CASE - CHARACTERISATION OF THE FACILITY AND HAZARDS

Characterization of the facility and hazards

Prior to development of plans for decommissioning, the radiological status of a facility must be determined or ìcharacterisedî. Characterisation may be described simply as the gathering of data, facts and information necessary to identify situations that may arise during the dismantling of a facility and that may affect workers, the public or the environment. It should precede the start of any decommissioning project and be maintained and up-dated as necessary throughout the implementation of the project. Broadly, it should comprise the following:

- Preparation of an inventory of situations that might be hazardous to workers, the public or to the environment.
- Analysis of structural conditions of the facility that may affect the safety or protection of workers.
- Determination of the extent, nature and concentration of radioactive contamination and conventional chemical contaminants.

Gathering of information and performing hazards analyses

In order to facilitate the effective planning of decommissioning, the following information should also be gathered:

- Scope of the tasks that will be necessary for dealing with each situation.
- Techniques available for eliminating or reducing potential hazards.
- Method by which progress in the hazard reduction is to be verified.
- The nature and amount of waste expected to be generated.

The objective of planning is to eliminate or reduce the radiological and non-radiological hazards by allocating the necessary resources and implementing the technical or administrative means to counteract them. This may be further facilitated by grouping the hazards (i.e. looking for combination of effects), prioritising them in accordance with their health effects and with national legislation, and screening out those deemed small enough to be neglected.

In this general context, helpful advice is given in the Decommissioning Handbook, US DOE/EM-0383, January 2000 **[iv]**. Amongst other things, it offers the following observations in regard to identifying, analysing and categorising the hazards:

- A hazard for this purpose is a source of danger (e.g. material, energy source, or operation) with the potential to cause illness, injury, or death to personnel or damage to an operation or to the environment (without regard for the likelihood or credibility of accident scenarios or consequence mitigation).
- The hazard analysis should evaluate radiological, biological, and physical hazards, as

applicable, at the facility to be decommissioned. An experienced, multi-disciplined team should be assigned to conduct the assessment. In cases where hazardous materials are present, the hazard analysis should evaluate: 1) the type, form, quantity, and concentrations; 2) location; 3) conditions under which exposure may occur; and 4) the inherent harmful characteristics of the hazardous substance (e.g. toxicity or decomposition by-products).

- The hazard analysis should consider natural phenomena hazards and should identify safety structures, systems, and components that are needed to prevent or mitigate hazardous material releases due to natural phenomena events.
- The hazard analysis should rely on existing documented hazard analyses (if any) from prior phases of the facilityís life cycle.
- Documentation of the hazards analysis should provide a formal record of all identified hazards, including those that workers may encounter during decommissioning work activities. A formal record of controls needed to support safe work execution in light of the hazards should also be provided.î

The basic requirements of characterisation and the sources of information for it are described below.

Types of Characterisation

The radiological as well as the physical state of the facility has an influence on the strategy to be chosen for decommissioning, particularly if the structure is in a poor state and likely to deteriorate; hence the need for both physical and radiological characterisation. In addition, in regard to radiological characterisation at least, effective management of the decommissioning activity and proof of its success requires both final radiological status characterisation and confirmatory characterisation.

Physical characterisation

Physical characterisation normally involves an inspection of the facility by observers with sufficient experience to detect hazards and identify the arrangements required for protection against any abnormal radiological or conventional conditions. The purpose of such an examination is to document the current state of the facility through photographs, videos, maps and diagrams that may help determine what hazards are present, and to analyse in particular:

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

Radiological characterisation

The preliminary radiological characterisation involves identification of the radiological hazards to which the decommissioning workers might be exposed. This hazard identification helps to determine whether or not it is necessary to decontaminate any areas of the plant for direct worker access, and it facilitates the design of suitable radiological protection measures for later activities. Its scope is to quantify the hazards detected in order to make an initial selection of project activities and to establish what precautionary measures are required. The collected information is subsequently reviewed and supplemented to a degree of detail that will depend on the remedial actions planned. This preliminary characterisation work includes sampling of unknown materials, updating radiological maps, and estimating physical parameters and waste materials quantities arising from later decontamination and dismantling tasks.

A detailed characterisation is performed when the project activities have been selected and decided. The detailed characterisation plan would generally be subject to a quality assurance programme and, in the case of large facilities, would usually undergo prior evaluation by the relevant regulatory bodies. Ideally, this detailed characterisation should be planned on the same pattern as that planned for the final or confirmatory characterisation in order to provide a reliable benchmark for checking the results of decontamination activities for example.

The two purposes of the detailed characterisation are to confirm the information available from the preliminary characterisation and to provide any other required information. The plans for it should address aspects such as:

1. *Characterisation objective*. The objective is to highlight the most significant factors, (e.g. radionuclides of interest, detection limits, estimated volume of waste, measurements required, estimation and calculation of the radionuclide inventory, scaling factors needed for estimating radionuclides that are difficult to measure, etc.).
2. *Implementation.* Description of the methodology proposed for the various measurements to be made (gamma or beta-gamma radiation fields, alpha contamination, smear or material sampling, etc.). Description of instrumentation to be used, sample sequence and schedule, etc.
3. *Measurement location*. Identification and justification of the location of measurements taken at in each area to be sampled.
4. *Statistical considerations*. Identification and justification of the number of measurements taken at each location, statistical analysis of samples, representativeness of the area to be sampled, tolerable uncertainties, etc.
5. *Quality assurance*. Quality objectives for data (representativeness, precision and accuracy, etc.), provision for storage and management of samples taken, procedures and frequency of instrument calibration, and quality assurance of analytical procedures, methods for checking validity of results, methods for analysing results and producing final reports, auditing of the characterisation process, etc.

Preparation of a radiological characterisation plan should involve optimisation of the estimated radiation doses to the workers performing the characterisation. In situations with high radiation and/or contamination levels, the acquisition of data could entail significant doses to the staff. Such measurements may not be justified by the benefits obtained and may not be consistent with the ALARA principle.

Final radiological status characterisation

When the tasks and activities set out in the decommissioning plan have been completed, appropriate measurements will be required to demonstrate that the residual radionuclides at the facility has been removed and that the acceptance criteria originally established in the plan have been met. This final radiological characterisation serves as a basis for the licenseeís final statement on the radiological condition of the facility. Note that radiological characterization made to determine the status of the facility prior to remedial activities may be appropriate to demonstrate the final radiological status of the facility, provided that it is of sufficient quality and scope and it can be demonstrated that re-contamination has not occurred.

Confirmatory characterization

When the facility owner/licensee has completed decommissioning and submitted its demonstration of the final radiological status of the facility to the regulatory authority, the regulatory authority may perform a confirmatory characterization survey. This characterisation is typically not meant to gather new or additional characterization/survey information but is intended to validate the information presented by the facility owner/licensee. Typically, a very limited number of samples are collected from locations sampled by the facility owner/licensee and the results of the regulatory authorityís samples are compared to the sample results presented by the facility owner/licensee.

Sources of Information for Characterisation

Facility characterisation is often understood to concern only information about equipment and the associated measurements. Although these are important aspects of the process, they need to be accompanied by other equally important items of information in order to achieve all the objectives of decommissioning.

In addition to the work of characterisation described above it is important to gather records and personal recollections of former workers. This last aspect is indispensable for old facilities that have been inoperative for a long time and whose records may have been discarded, as is sometimes the case for pilot or research facilities. In general, however, the history of facilities is in their records. Provided such records are still available when decommissioning begins, as is usually the case at nuclear facilities, they must be preserved and analysed in order to anticipate possibly hazardous situations that may arise during decommissioning. As regards the various types of records and other sources, the following are likely to be important.

Licence documents

The official documents associated with licensing of facility operation are a source of information that must be available from the start in the planning of any decommissioning work. These documents are generally required to demonstrate that the hazards posed by the facility operation to workers, the public and the environment are recognised, and that suitable precautionary measures have been taken to control them and to mitigate the consequences of possible accidents. The facility safety assessment and its functional technical specifications are the two key documents, though not the only ones, from which basic information may be gleaned about the hazards that may remain in a facilityís various installations when its operations cease.

Other operational safety documents

Another important source of information are safety reports and inspections describing actual and potential hazards and the measures taken to control them during the operating life of the facility.

The fire protection plan provides information about operational fire loads, fire systems and barriers, etc. This information can be used to keep certain protective measures in place during dismantling and also to identify the presence of certain materials whose removal will require special precautions (such as asbestos).

Reports on operating incidents or accidents may serve to identify and locate dangerous spots left over from the facilityís service life or as a result of operating incidents.

Records of the operational exposure of staff due to contamination during facility operation are a useful source in the planning of project activities and decontamination methods. In addition, they are useful in determining whether to use remote control methods in certain dismantling activities.

Records of spills and descriptions of prior cleanup tasks may be deduced from the functional specifications and descriptions of the systems and equipment already available on the facility for carrying out decontamination tasks. Equivalent information can also be gleaned from the specifications of supplies made to the facility.

Design records

The main sources of design information about a facility due to be decommissioned are the ìas builtî design drawings and documentation. The dismantling plan will rest on these engineering drawings and diagrams, and they should have been updated with records of modifications made during operation. As noted above, this basic information might not be available for old facilities that have been inoperative for a long time. This tends to make dismantling more difficult, and also more expensive if such documents have to be reproduced without access to the originals.

Construction records

Any surviving construction records will be of great value as a source of information in the planning of dismantling work, as during the dismantling of systems and structures it is common to find structures and materials that are not mentioned in the design records.

For example, construction drawings help locate structural and expansion joints in buildings. This is highly useful information for their demolition and for the dismantling of large equipment and systems. Descriptions and photographs of the various construction stages may also suggest sequences for dismantling.

Operating records

Operating records should contain important information about any modifications carried out on the facility during the operating phase. This information should be kept together with the original design records, especially if the original design drawings have not been updated. Also, information about nature and extent of contamination arising from routine operations or from incidents during the operational phase should be available here.

Changes in operating procedures are often made to take account of conditions not envisaged in the original design, and are sometimes prompted by the need for process improvement or by radiological situations arising from operating incidents. Hence, a study of the successive modifications made in operating procedures may also help to identify operating incidents that may not have been fully described in the operating record.

Personal accounts

Experience shows that a significant amount of information important for safety in dismantling is known only by the workers and managers employed at a facility during its operating life. This is because relevant information was originally contained in records that have been lost or destroyed, or it was not documented because it was not considered important during operation of the facility. Normally, the only way to recover such information is by way of the personal accounts of those people involved during operation of the facility. It is sometimes difficult to acquire and, in any case, is lost over time in the natural course of events.

Facility operating staff are usually the best source of information about a facility to be dismantled and some of them should be made available for dismantling tasks if possible. If this is not possible, efforts should be made to retrieve the relevant information from former employees even if it is only undocumented information.

Staff of the relevant regulatory bodies, and their records, may also be an important source of information, particularly at many small facilities originally operated by companies that may have gone out of business and left no records. Staff of regulatory bodies may be familiar with the facility to be dismantled and their personal accounts can facilitate the planning of dismantling.

TECHNICAL, MANAGERIAL AND ADMINISTRATIVE TASKS NECESSARY FOR ACHIEVING THE GOALS OF THE SAFETY CASE

Technical, managerial and administrative tasks

There is a wide range of equally acceptable strategic options available for the decommissioning of nuclear facilities. [**v**] These depend on the type of facility, the nature of the residual material in the plant and on individual national policies and priorities. In regard to planning, the range of radionuclides present in each facility has a direct influence on the strategy chosen for decommissioning. For example, in the case of nuclear reactors, after removal of the fuel elements and operational waste, relatively short-lived activated materials predominate in the reactor building and associated structures, and this may justify deferred dismantling with an interim period of safe storage if there are no other more important, overriding factors. Such a deferment may reduce the doses received by workers involved in dismantling activities. However, radionuclides may be found in facility soil and groundwater that may necessitate some remedial activities shortly after shutdown to prevent further spread of contamination. In the case of facilities containing alpha-emitters (e.g. spent fuel reprocessing plants), however, deferred dismantling does not bring any significant reduction in operational doses. Inevitably, however, practical implementation of most options depends on the same range of techniques for the technical, managerial and administrative tasks necessary for achieving the goals of the safety case for decommissioning, as described in Section 2.

Decontamination and Cleanup

Even when the fuel elements, waste and any other radioactive sources have been removed from a facility, it is usually still necessary to carry out radiological decontamination and cleanup of shut down systems or equipment, walls and surfaces, and storage areas. The objectives include the following:

- Reducing the exposures of workers involved in later manual dismantling activities.
- Decreasing the probability of aerosols being generated in later dismantling activities.
- Reducing the consequences of any incidents occurring during later dismantling tasks.
- Minimising the volume of materials generated that will be classified as radioactive waste.
- Permitting the reuse of equipment, materials or facilities under nuclear license control.
- Permitting the ìclearanceî of materials for recycling, reuse or removal as conventional materials.
- Reducing overall dismantling costs.

The applicability and effectiveness of candidate decontamination techniques should be evaluated before use, with trials on models where necessary, as should the possible hazards involved in their use. This is particularly important in selecting techniques for decontamination of plant and equipment that have a continuing role in safety systems, in order to ensure that safety is not compromised. Aspects to be considered in selecting a decontamination strategy include:

- Estimation of doses to the workers that will carry it out.

- Possible generation of aerosols and their effect on workers.
- Required decontamination factor and probability of achieving it in application.
- Method of assessing the decontamination factors achieved.
- Provisions for the dismantling of structures and equipment to be decontaminated.
- Estimation of the volume and radioactive content of the waste generated by decontamination, and provisions for conditioning, storage and disposal.
- Compatibility of the waste generated with the requirements for disposal.
- Non-radiological hazards involved, (e.g. fire, explosion, toxicity of compounds, etc.).
- Safety considerations.
- Potential radiological and non-radiological impacts on the environment.
- Cost/benefit analysis of the activities involved.

Another very important aspect of decontamination and cleanup concerns ìclearance,î or release from regulatory control, of nuclear sites that may have become contaminated with radioactive substances. Such contamination may be the result of historical incidents involving spillage or leakage, or the intentional emplacement of radioactive substances in the ground. Decommissioning plans need to include arrangements for the safe management of such ground, including remediation and disposal of the resulting radioactive waste. A key question in regard to the extent of remediation required is the standard to be achieved for the purpose of ìclearanceî. The ultimate requirement for release from regulatory control is limitation of the radiation dose to members of the public, or to subsequent users of the site. This may be achieved, however, by way of at least two forms of derived standard. One form is the dose-based standard typified by the USNRC Licence Termination Rule of 1997 **[vi]**. The other form, widely used throughout the EU for example, is the radionuclide concentration standard typified by the German Radiation Protection Ordinance of 2001 **[vi]**, which transposes the relevant EC Basic Standards Directive **[viii]** into national legislation.

Usually there are no restrictions concerning site use after ìclearanceî. In some cases, however, a regulatory release of a site can be coupled with a requirement for specified restrictions. In a second step these restrictions can be coupled with a provision on how to deal with the consequences if those restrictions were to fail.

In-process Surveys

In-process surveys involve making measurements on the plant, as work progresses, in order to evaluate the efficacy of the decontamination work carried out. This is often repetitive but serves to assist decisions about whether decontamination activities have been sufficient and successful or whether they need to be continued. Where contamination has penetrated into structural material, or into the surface of the site, for example, and where decontamination requires removal of a certain thickness from its surface, the measurements taken may indicate those areas where the penetration of contamination requires removal of material to continue.

Dismantling and Size-reduction of Equipment and Demolition of Structures and Buildings

Dismantling and cutting up, or size-reduction, of equipment, components and systems are common requirements in the decommissioning of most nuclear facilities. Their objectives are:

- Reduction of the size of individual components in order to facilitate their decontamination and subsequent handling and management.

- Provision of access to encapsulated radiation sources or to other types of radioactive or inactive materials requiring special management.

- To allow segregation of waste in order to minimise the quantity that needs further treatment or processing.

The various techniques available for dismantling and size-reduction of equipment include mechanical cutting techniques. These generally include tough, heavy-duty systems and thermal cutting techniques, which are lighter but need fire protection and generate waste and aerosols that have to be controlled. They also include special underwater cutting techniques, which have the advantages of the shielding effect of water and of preventing the generation of aerosols, etc. Selection of the appropriate technique for each situation involves careful evaluation, having regard to the following requirements for safety:

- Simplicity and operational reliability of the techniques and equipment to be used.
- Use of proven technologies wherever possible.
- Ease of equipment maintenance and decontamination.
- Control of any aerosols or gaseous discharges into the environment.
- Minimisation of secondary liquid and solid waste generation.
- Control of any toxic or hazardous waste generated in the operation.
- Visibility of the operation if underwater segmentation techniques are used.

Those techniques intended for remotely controlled use, in particular, should be tested first under non-radioactive conditions. The selection of size-reduction and demolition techniques should also have regard to any possible effects on safety-related systems, structures or operations in adjacent areas and, so far as possible, the waste generated by their use should be capable of being conditioned and packaged directly into the containers in which they are to be stored or disposed, in order to prevent multiple handling and further contamination.

Containment of Contamination

Effective containment is necessary for preventing the movement and dispersion of residual contamination in facilities undergoing decommissioning. If practicable, dismantling activities should be organised in such a way that the original containment barriers remain operative for as long as possible after shutdown. Otherwise, effective temporary barriers will have to be constructed and maintained for as long as necessary to contain any residual radionuclides. This is particularly important in facilities that may be subject to lengthy periods of safe storage before the start of dismantling operations, and where original containment systems may deteriorate. In any case, however, a routine maintenance and surveillance programme to guarantee the integrity of containment throughout the storage period is essential.

Maintenance of other Safety-related Systems

Maintenance of safety systems is essential in any case but, as in the case of containment systems on a facility that may be subject to lengthy periods of safe storage before the start of dismantling operations, it is particularly important to ensure continuing provision and effective maintenance and surveillance of the following safety systems, at levels appropriate for the hazard and for as long as necessary:

- Physical protection systems.

- Systems for monitoring, surveillance and facility inspection including ventilation and other systems required for access.

- Equipment essential for material and equipment handling tasks.

Provision of Radiological Protection

All decommissioning projects should have an appropriate, sufficiently independent organisation for radiological protection in order to protect workers and the public from the effects of ionising radiation. This organisation should be responsible for radiological protection measures tailored to the various situations likely to arise at the facility undergoing decommissioning, and taking into account:

- The proximity of radiation sources to project staff.
- The potential for generation of radioactive aerosols by dismantling activities.
- Use of new techniques and procedures requiring specific controls and staff training.
- Possibility of encountering unforeseen radiological situations during dismantling.

Arrangements for radiological protection of workers should be based on knowledge of the work environment and the duration of project tasks, in order to determine the appropriate techniques to be used, the operating conditions and the necessary protective equipment for workers. Each task should be carried out as specified in a work order guaranteeing that foreseeable individual and collective doses have been estimated, that alternative options for achieving objectives have been considered, and that appropriate options have been chosen.

The general requirements for staff training, and the preparation and monitoring of the work environment, are particularly important for ensuring that dismantling work is done in suitable, radiologically safe conditions. For example:

- Training is particularly important because, in dismantling operations, it is often necessary to use special tools or equipment for monitoring or for personal protection, and to carry out procedures and actions not routinely performed during the operation of nuclear facilities.

- Preparation of the work environment is important where radiological protection requires decontamination of areas where work is to be done in order to reduce dose-rates. Such decontamination can be carried out using remote robotic techniques until conditions for the safe access of project staff are achieved.

- Dismantling tasks are generally performed in a radiological environment that is subject to continuous change, foreseen or unforeseen, in the radiological map, in airflows within the facility, etc. Hence, constant radiological monitoring of work areas is essential for design and maintenance of containment systems and for selection of appropriate techniques and personal protective equipment for each situation.

Management of Radioactive Waste

Given the amount of radioactive waste created in the dismantling process, good planning of waste management is a vital aspect of the safety case for decommissioning. Such planning must address the different categories of materials likely to be generated by the various activities, taking into account their radiological and other properties, the various strategies available for their management and the radiological impact on workers, the public and the environment.

Solid radioactive waste

Dismantling projects should seek to minimise generation of solid radioactive waste and to avoid generating secondary waste and cross contamination. Significant reductions in the volume of radioactive waste can be achieved by appropriate selection of decontamination and dismantling methods, by reusing or recycling components or materials within the nuclear industry, by the clearance of slightly contaminated materials, or by processing waste with volume reduction techniques (compaction, melting, etc.). The radiological hazard to which dismantling workers and the public may be subjected can vary significantly according to the strategy chosen for minimising the generation of waste, so planning for waste management should balance carefully the objective of minimising radioactive waste and the impact on the public with that of keeping doses to workers as low as reasonably achievable.

Liquid and gaseous effluents

In the early stages of decommissioning, discharges of liquid and gaseous effluents are likely to be controlled by the original systems used during normal operation of the facility. As dismantling progresses, however, these systems may be partially dismantled or, in some cases, totally replaced. This needs to be recognised in good time and incorporated into the overall planning.

Planning for Emergencies and Physical Protection

Planning for emergency response to abnormal or accident situations, and for physical protection, must continue throughout the transition from the operating phase into and during the decommissioning phase. The plans should be continuously adapted to the evolution of residual hazards at the facility and will depend, during the transition phase, on whether fuel elements remain on site or have been removed. Emergency drills are of particular importance for testing the emergency preparedness of staff and for reviewing the currency of plans and associated systems.

Quality Assurance

Any decommissioning project should have a quality assurance plan covering all the important activities carried out as part of the project. In this context, the quality assurance plan has two purposes, i.e. guaranteeing the protection of staff working on the project, and ensuring that the tasks involved have been performed according to established work procedures and have achieved the objectives set for them. The latter point is relevant also to arrangements for eventual release of the facility from regulatory control, which is likely to depend on traceable documentary evidence of satisfactory completion of tasks, and of the satisfactory management of all the radioactive material originally present at the facility.

Traceability of documentation and information about relevant activities is an aspect of particular importance in all quality assurance programmes. It is particularly important with respect to decommissioning strategies that involve a lengthy period of safe storage before final dismantling where, for both of the above purposes, it is vital to ensure that all the information needed at a later stage is still accessible. If such a period is very long, it may be necessary to plan for periodic maintenance of the record system.

Project Management

The decommissioning project organization and management structure must be designed so that the at the licensee or site owner will exercise adequate control over the decommissioning project and will have the personnel resources to ensure that the decommissioning of the facility can be completed safely and in accordance with applicable requirements. This includes having:

- A management structure for the project, including individual organizational unit reporting responsibilities and lines of authority.

- A strategy for how radioactive material work procedures/practices (such as Radiation Work Permits) are developed reviewed, implemented, and managed.
- Minimum qualifications necessary for individuals performing the various project management and safety functions.
- A clearly defined relationship between the various organizational units within the decommissioning organization (such as remedial activities and health and safety units), including the responsibilities and authority to revise or stop work.

Task Management

Management of decommissioning tasks must ensure that all decommissioning activities will be conducted in accordance with written, approved procedures and that the licensee or site owner has a methodology in place for managing the development, review and maintenance of the procedures including:

- A plan for how the decommissioning tasks will be managed, such as through the use of Work Permits (WPs) or other written procedure used to manage individual decommissioning tasks.
- A methodology for evaluating decommissioning tasks and for how written procedures are developed for each task including how they are reviewed and approved by the decommissioning project management organization.
- A process for managing written procedures throughout the decommissioning project (i.e., how they are issued, maintained, revised, and terminated).
- A process for informing those individuals performing the decommissioning tasks of the written procedures or WPs, including how they are initially informed and how they are informed when a procedure or WP is revised or terminated.

Personnel Management

The transition of a nuclear facility from the operational phase to the decommissioning phase may, or may not, involve a transfer of ownership or of the organisational responsibility for delivering the requirements of the site licence. In any case, and even if such transfer is not involved, the functional regime and administrative and management arrangements are likely to change. These changes are likely to involve changes in personnel and the following matters need to be taken into account.

Use and control of contractors

An organisation in charge of a decommissioning project, and responsible for compliance with the site licence, should have enough in-house staff qualified to take responsibility for the key aspects of project safety. However, expert contractors or other types of outside personnel may be brought in to perform the various tasks involved but, regardless of who is actually carrying out the tasks, the facility licensee remains responsible for securing overall safety. It is essential, therefore, in the event of outside contractors or personnel being employed, that the chain of authority and the various responsibilities of all the staff involved are clearly defined.

Retention of knowledge and training of personnel

It is desirable that staff assigned to the decommissioning project be thoroughly familiar with the facility, as they will be better prepared to carry out the tasks entrusted to them. This may not be possible for various reasons, and new staff may have to be introduced, as is inevitable with the passage of time in any case. Therefore, it is desirable to retain, for as long as possible, some of the key staff from the operating phase of the facility. Their knowledge and experience may be essential to ensure, in the first instance, that the safety of certain activities is not compromised by inadequate knowledge of the facility and its operating history and, in the second, that there is a source of relevant knowledge and experience available for the training of new staff.

In any case, however, special training is likely to be required for certain complex or unfamiliar tasks, and it may require the use of specific training models or simulators. Appropriate provision for this needs to be considered.

Prevention of loss of safety culture

Staff, whether former operating staff or outside contractors, may have a perception that the nuclear facility is much less hazardous during the decommissioning phase than it was during the operational phase. Although true to a certain extent, this should be guarded against as it may result in relaxation of the customary vigilance necessary to ensure continuing safety. As with the issue of knowledge retention, it is important to retain staff already imbued with the operational safety culture in order that it can be passed on to new staff. In this context, as well as in the matter of knowledge retention, it is prudent personnel management to identify the timescales of vulnerability to the loss of key staff by retirement, for example. It is also important to recognise that, as the project progresses and staff redundancy becomes an issue, morale may be affected with a consequent loss of vigilance or safety culture. This, too, needs prudent management.

Exchange of experience of decommissioning operations

Nuclear facility decommissioning is still relatively recent and because, unlike on-going, normal operation, it is a ìone-timeî activity on a particular plant, experience is still relatively scarce. Exchanges of information, or even of personnel, between various decommissioning projects are therefore likely to assist personnel development and help reduce the incidence of repetition of errors and avoidable accidents. This is not without difficulty, however, as decommissioning activities are subject to a number of characteristics that do not apply to routine plant operations. For example:

- Dismantling tasks are not repetitive at any one site.
- Assembly of data is troublesome during the decommissioning of a facility.
- Resources available to plants being decommissioned are usually scarce and devoted to the project in hand, not to the exchange of information.
- Contractors specialised in decommissioning treat their experience as intellectual property and are reluctant to disseminate it publicly. Also, when they expect to leave the nuclear industry, the incentive to assemble and document information on lessons learned is lost.

Stakeholder Involvement

A most important practical aspect for effective progress of decommissioning is the need for meaningful involvement of all stakeholders in the project. This includes the local community and staff. It means providing them with transparently valid information about plans and programmes, living up to commitments, being constantly available to answer questions and hear comments and developing confidence and trust. It also means providing valid information on safety and environmental matters including waste management and giving full consideration to concerns about the effects on society such as loss of employment, the need for alternative economic activity, and the future use of the site.

A particular aspect to be discussed with stakeholders is how and when the emergency preparedness system for on- and off-site consequences, implemented during operation of the plant, should be changed. This recognises that decommissioning is about step-wise removal of hazards, and that reducing the countermeasures and associated costs is a natural consequence.

As regards channels for communication of this information, all techniques have a place, from conventional meetings, seminars, debates and provision of information packages for local discussions to television programmes and websites, supported with ì chat-roomsî if appropriate. Timeliness is a key factor. Communities where facilities are shut down prior to the end of life have special communication needs as a result of termination of some employment.

CONCLUSIONS

The decommissioning of nuclear facilities may be defined as the administrative and technical actions whose purpose, once a facility has been removed from service, is to allow its release from regulatory control and relieve the licensee of the responsibility for its safety, which was necessary when the facility was a operating as a licensed nuclear installation.

It is widely accepted that the radiological hazards associated with a nuclear facility undergoing decommissioning are substantially less than when in normal operation. This so is because extraction of fuel elements, drainage of radioactive materials in systems, and conditioning and removal of operational radioactive waste, all has a major, beneficial effect on reducing the amount, composition and distribution of residual radionuclides at the plant.

The beneficial effect of radioactive inventory reduction is further enhanced during decommissioning by the removal or reduction of hazards such as high pressures and temperatures. Even though these hazards may be reduced, however, other more conventional hazards may become more important. Also, it is necessary to recognise that the inherent need to progressively remove confinement barriers and safety systems from service, in order to achieve the long-term reduction in hazards, can temporarily increase the short-term hazards. The various hazards and factors that need to be considered in regard to the main goals of a assuring safety are discussed below.

The key issue in the decommissioning of nuclear facilities is the progressive removal of hazards, by step-wise of decontamination and dismantling activities that have to be carried out safely and within the boundaries of an approved safety case. The decommissioning safety case is a strategic document specifically designed for analysing these hazards, and the separate stages required for hazard reduction. The provision of the safety case is one of three main pillars on which the safety of decommissioning rests. The other two being pre-assessment of the hazards and application of relevant technical and management approaches for hazard removal.

The safety case for decommissioning of a facility is different from the safety case for its operation. It must be kept up-to-date with the status and activities at the facility, including its management, changes and development. In this regard, safety and environmental assessments are important parts of the safety case.

The safety case for decommissioning will need its own facility characterisation, safety assessment and, in most cases, environmental assessment. In the context of safety assessment, it is important to address non-radiological aspects as, in decommissioning, they may outweigh some radiological aspects. It is also clear that the different strategic approaches to decommissioning, and the wide variety of facilities involved, will result in the need for safety cases that are both situation- and time-dependent. This will demand their development on a case-by-case and site-specific basis.

These materials that have been presented contribute to the content and substance of a safety case for decommissioning and will be helpful to those individuals and organisations about to prepare such a safety case. As regards guidance and information on matters of decommissioning safety, the healthy exchange of knowledge between countries and organizations is recommended. International organisations such as the IAEA, the OECD/NEA WPDD, and the European ALARA Network, ensure that information about good, safe practice is effectively disseminated and that earlier experience and good practices can be implemented in current decommissioning projects.

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