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DECOMMISSIONING AT A MULTIFACILITY SITE: AN INTEGRATED APPROACH

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA NUCLEAR ENERGY SERIES No. NW-T-2.13

DECOMMISSIONING AT A MULTIFACILITY SITE: AN INTEGRATED APPROACH

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
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FOREWORD

The IAEA's statutory role is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Among other functions, the IAEA is authorized to "foster the exchange of scientific and technical information on peaceful uses of atomic energy". One way this is achieved is through a range of technical publications including the IAEA Nuclear Energy Series.

The IAEA Nuclear Energy Series comprises publications designed to further the use of nuclear technologies in support of sustainable development, to advance nuclear science and technology, catalyse innovation and build capacity to support the existing and expanded use of nuclear power and nuclear science applications. The publications include information covering all policy, technological and management aspects of the definition and implementation of activities involving the peaceful use of nuclear technology.

The IAEA safety standards establish fundamental principles, requirements and recommendations to ensure nuclear safety and serve as a global reference for protecting people and the environment from harmful effects of ionizing radiation.

When IAEA Nuclear Energy Series publications address safety, it is ensured that the IAEA safety standards are referred to as the current boundary conditions for the application of nuclear technology.

Information and guidance on the decommissioning of nuclear facilities provided in over 100 IAEA technical publications — including IAEA Safety Standards and conference proceedings — and brochures also apply to multifacility sites. However, much of this material does not specifically address decommissioning at such sites. With the growing body of experience in the decommissioning of nuclear installations, which includes the completion of several large scale decommissioning projects in recent years, it is now appropriate to consolidate this technical and organizational information and experience. This publication thus provides additional, specific information and guidance on this subject.

The IAEA expresses its appreciation to all contributors to this publication, in particular to M. Laraia (Italy) for the preliminary draft. The IAEA officer responsible for this publication was V. Michal of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Multifacility sites accommodate independent or interdependent facilities with separate or combined licences and organizational structures. The need to install several facilities at a site is the result of a number of factors. First, ancillary facilities are often needed to support a major facility at the same site. Second, production lines often need several facilities of similar type (e.g. nuclear power reactors) to be commissioned in sequence. Third, multifacility sites benefit from the grouping of resources (and facilities) at one site in support of national nuclear programmes. These benefits include economies of scale and the availability of shared services and infrastructure.

Numerous multifacility sites exist in both developed and developing Member States. These sites may house a wide range of nuclear and/or radiation facilities, such as nuclear reactors, medical, research, industrial, isotope production, fuel cycle, and waste processing and storage facilities. Typical examples include nuclear power stations (with five power reactors, such as Bohunice in Slovakia (Fig. 1)) and nuclear research centres (including research reactors, hot cells, laboratories, waste treatment and decontamination stations, such as Pelindaba in South Africa (Fig. 2), and the Dounreay and Sellafield sites in the United Kingdom (UK) (Figs 3 and 4)).

Some sites have facilities which may be interconnected in terms of production routes and/or services, may include several units of effectively the same design, may have single independent facilities, or may be a combination of the above. Even those facilities at sites that are notionally independent will probably share services and infrastructure such as utilities, nuclear security and/or waste disposal routes.

FIG. 1. The Bohunice site in Slovakia with V1 and V2 units in operation. The site has three reactors undergoing decommissioning (one unit of A1 and two units of V1) and two reactors in operation (V2) (photo courtesy of JAVYS, a.s.).

FIG. 2. The Pelindaba site, South Africa (photo courtesy of the South African Nuclear Energy Corporation (Necsa)).

FIG. 3. The Dounreay site, UK (photo courtesy of the UK Nuclear Decommissioning Authority (NDA)).

These sites tend to have been gradually developed over the years and changing demands, regulatory environments and objectives can result in a lack of coordination regarding facility purpose and life cycle management. This lack of coordination may become acute when one or more such facilities reach the decommissioning stage and require the mobilization of significant resources in a short time, while others remain operational.

It would be unreasonable to consider the decommissioning of one particular facility without recognition of the other facilities on the site. Therefore, when addressing the decommissioning at a multifacility site, many questions arise such as:

- Should the entire site be decommissioned at once?
- Does that make good business sense?

FIG. 4. The Sellafield site, UK, contains around 200 significant nuclear facilities and has the most diverse portfolio of any nuclear site in the world (photo courtesy of Sellafield Ltd).

— Will the site remain profitable if one unit is shut down and a reduced staff is refocused on operating the remaining units?

To understand how decommissioning activities on-site will be dealt with, organizational requirements for each facility will have to be considered. The focus of site personnel is safe, continuous operation. Do you maintain one operations department with staffing for both the operating units and for the decommissioning unit, or do you split responsibilities? Where do you draw the nuclear security boundary: is the site physically divided by a fence between the operating plant and the decommissioning area? Could the shutdown areas be reused for the purposes of the operating plant? Is the solid waste arising from decommissioning stored separately from the operational waste being generated? What costs need to be considered that would otherwise not be included if the entire site was in operation? How are decommissioning related costs accounted for in a site where other facilities are still in operation? Are there any cost savings possible?

To answer these and other related questions, an integrated approach to decommissioning at multifacility sites needs to be implemented. Any decommissioning approach that focuses only on individual facilities is likely to incur logistical and technical mismatches, which may result in delays of planned activities and increased decommissioning costs.

In particular, unplanned end of operation and shutdown facilities may quickly lose priority and the focus of the site staff. In this situation, plant modifications may be stopped in midstream and existing operational capacities might be still in place while sustainable funding of forthcoming decommissioning activities might not be yet well established. With the site staff focusing on the operating units, structural aspects of the shutdown plant may degrade. The configuration of the plant and associated materials and waste remains the same until shutdown planning is complete and dedicated staff members are assigned to decommissioning tasks. Design changes may be partially implemented and have to either be completed or halted at a safe point for systems still needed for decommissioning. Personnel reductions resulting from the plant shutdown might cause the unit to lose many skilled and experienced operational and support staff.

Regardless of these potential difficulties, savings in overall cost and radiation dose can be achieved for decommissioning at multifacility sites because of factors not necessarily present at a single facility site. Examples of these include facilities of similar designs, which allow comprehensive planning to be done once; the opportunity for sequential decommissioning; a favourable learning curve; technology transfer; use of existing waste management and storage facilities; available labour force trained in decommissioning; and use of central stores, equipment and support facilities.

1.2. OBJECTIVE

This publication is aimed at making information and guidance available for the safe, timely and cost effective implementation of decommissioning at multifacility sites. In particular, it highlights the technical, organizational and financial factors that may affect the decommissioning of nuclear facilities when viewed in the context of multifacility sites. Such factors may induce cost savings, synergies (e.g. economies of scale) and other favourable impacts, but may also induce additional constraints and complications. Interactions between facilities include sharing of common systems, staff utilization and the ownership and licensing of adjacent facilities. Prioritization of decommissioning projects is also an important consideration.

The target groups of this publication are decision makers, plant operators, contractors and regulators involved in planning, management, authorization and execution of decommissioning activities. It is particularly relevant for multifacility site operators with nuclear facilities approaching the end of their foreseen lifetime. The publication will ideally also be of interest for the designers and builders of new nuclear installations: it is the IAEA requirement [1] that the design and construction of new nuclear installations will ideally facilitate their final decommissioning. This requirement, which is now incorporated in many national legislations, will ideally also consider the presence of other nuclear or non-nuclear facilities on-site.

1.3. SCOPE

This publication provides advice and guidance on the approach to undertaking decommissioning at multifacility sites. Its scope includes various nuclear facilities in operation, under construction or undergoing decommissioning at the same time at a given site. The sites addressed include multiple reactor sites, where the reactors are at various stages of operation, as well as those housing a wide range of facilities, e.g. isotope production and fuel reprocessing facilities, as well as smaller medical, research and industrial facilities.

The publication deals with all phases of decommissioning, from the planning stage to periods of safe enclosure, execution of dismantling activities and site release, including both technical aspects (characterization, decontamination, dismantling, waste management, final surveys, etc.) and organizational aspects (preliminary and detailed plans, organizational schemes, roles and responsibilities, site release, funding, etc.). While decommissioning normally refers only to structures, systems and components (SSCs), the publication recognizes that land, as well as surface water and groundwater, near the buildings are often contaminated and will ideally be dealt in a multifacility decommissioning context. However, the publication does not address in detail remediation techniques. Uranium mining and milling facilities are also not included.

This publication focuses on the potential interactions between the facilities at multifacility sites, including consideration of:

— Shared services and shared human resources;

— The impact of action, or inaction, to/from an adjacent facility;
— Site-wide operations, including planning, emergency preparedness and nuclear security;
— Financial arrangements;
— Site-wide organizational structures;
— The introduction of new facilities at a site where decommissioning operations are being undertaken;
— Prioritization of activities at a site.

This publication applies principally to decommissioning under planned circumstances; post-accident decommissioning requires specific urgency in the approach and is out of the scope of this publication. However, some generic considerations are discussed in Section 4.9, based on lessons learned from severe accidents.

The strategic approaches taken by a range of sites around the world are described, as well as a wide range of activities and lessons learned. Although most examples provided in this publication relate primarily to nuclear power plants (NPPs), the decommissioning principles and the regulatory challenges apply to other facility types as well. Several sites at which a significant amount of legacy waste is stored and treated are also relevant examples to be considered.

This publication is about interactions between activities in progress concurrently at different facilities at a site. By definition, interaction denotes mutual influence, in this case between a decommissioning facility and other facilities at a multifacility site. Therefore, interaction is a two way process. This publication considers both the impact (actual or potential) from the decommissioning facility on facilities nearby and the impacts these facilities may have on the decommissioning facility.

A decommissioning project which includes two or more systems (e.g. a reactor, the spent fuel pool and ancillary facilities) in one facility is not addressed in this publication, although similarities with the main scope are identified. In fact, this is part of a more general discussion about the meaning of 'facility' and is clarified in national regulations. The IAEA definition of a nuclear facility (see the Glossary) does not specify, to all intents and purposes, whether several (smaller) facilities associated with one main facility represent the same facility. For example, a nuclear reactor has waste treatment systems that are intrinsically linked to the operation of the reactor, are subject to the same licence and basically make up one facility. Some, however, may view waste treatment systems (e.g. a waste cementation plant or a waste store) as facilities which are independent of the reactor, and which are decommissioned at a later stage. While recognizing the ambiguity, this publication assumes that smaller facilities closely associated with a larger facility (e.g. physically, within the same building, or operationally) are part of that facility. By contrast, facilities that are not directly linked (operationally or physically) would generally represent different facilities at a multifacility site.

Part of the information and guidance in this publication may also be relevant to national programmes. For example, aspects such as the sharing of technologies (e.g. equipment and know-how) and transfer of knowledge (e.g. training and lessons learned) between projects at one site may be readily extended nationwide to other sites, especially when all the installations in question belong to the same owner or are similar in type. Similarly, the international transfer of decommissioning technologies and information is currently common practice. Although some references are given to these approaches (see Annex II–14), this publication does not cover this area and is restricted to guidance and events at one site.

1.4. STRUCTURE

This publication reviews the various aspects of decommissioning at multifacility sites. Following Section 1 giving the background material and context of this publication, Section 2 defines the categories of multifacility site around the world. Section 3 introduces the overarching aspects to be considered when developing an approach to multifacility decommissioning. Section 4 addresses specific technical factors impacting the decommissioning strategy, while Section 5 focuses on specific organizational factors.

Section 6 reviews financial aspects and Section 7 outlines approaches to integrate prioritization and decision making. Summary conclusions are given in Section 8.

Annex I provides examples of the organization of decommissioning and detailed technical aspects for both large and small facilities being decommissioned at multifacility sites in various Member States. Annex II identifies events that have occurred in the course of multi-unit site projects and provides a range of lessons learned.

2. MULTIFACILITY SITES AROUND THE WORLD

There are a wide range of multifacility sites around the world as, in principle, any type of facility can be co-located with any other type at a given location. However, experience has shown that in practice three types of multifacility sites are typical:

— Multi-reactor NPP sites (Section 2.1);
— Mixed sites housing nuclear fuel cycle facilities and/or non-power reactors and/or industrial and support facilities (Section 2.2);
— Mineral processing sites (Section 2.3).

These broad categories are further discussed below.

2.1. MULTI-REACTOR NUCLEAR POWER PLANT SITES

This category typically includes from two to six nuclear power reactors co-located at one site, together with smaller facilities supporting reactor operation (e.g. solid waste treatment plants or stores, stacks and effluent discharge canals). These smaller facilities are normally part of the reactor facilities or provide a direct service to it. This category of multifacility sites is relatively uniform and lessons learned from decommissioning at one NPP site can be readily applied to other NPP sites.

2.2. MIXED SITES HOUSING NUCLEAR FUEL CYCLE FACILITIES AND/OR NON-POWER REACTORS AND/OR INDUSTRIAL AND SUPPORT FACILITIES

Unlike the NPP sites described in Section 2.1, this category is extremely diverse. It may include many different types of nuclear and radiological facilities, variously grouped at a given site. Typically, these facilities serve different objectives, ranging from the production of nuclear isotopes to the management of radioactive waste or conducting nuclear research [2]. Some nuclear centres also house chemical plants that support nuclear operation There is a wide range of such chemical facilities, from fluoride plants (for fuel enrichment) to heavy water plants (for heavy water reactors). Chemical plants present substantial hazards from/to nearby nuclear facilities being decommissioned.

The common element is the number of distinct facilities which can, in a small number of cases, extend to several hundred facilities on a single site. As a result of this wide range of facilities, the interactions during decommissioning of one or more facilities at the same site can be significantly different. Some larger sites in this category can also house nuclear power reactors. As such, they overlap with those described in Section 2.1.

An overview of the nuclear centres containing at least one decommissioning facility (including production, research and other purposes, but not limited only to NPPs) is provided in Table 1.

TABLE 1. EXAMPLES OF MULTIFACILITY NUCLEAR CENTRES IN SELECTED MEMBER STATES WITH AT LEAST ONE FACILITY UNDER DECOMMISSIONING (NUCLEAR POWER PLANT ONLY SITES NOT INCLUDED)

Member State	Nuclear centres
Argentina	Constituyentes Atomic Centre. Ezeiza Atomic Centre. Research reactors and other small nuclear facilities being prepared for decommissioning.
Australia	Australian Nuclear Science and Technology Organisation at Lucas Heights. Moata research reactor dismantled, HIFAR research reactor shut down for decommissioning.
Austria	Austrian Institute of Technology, Seibersdorf. ASTRA research reactor decommissioned.
Belarus	Institute of Power Engineering Problems, Sosny near Minsk. IRT-M research reactor decommissioned.
Belgium	Belgium Nuclear Research Centre (SCK CEN), Mol. BR1 reactor being decommissioned.
Brazil	Nuclear and Energy Research Institute, São Paulo. Dismantling of the Uranium Purification Plant.
Bulgaria	Institute for Nuclear Research and Nuclear Energy, Sofia. IRT-Sofia research reactor being decommissioned.
Canada	Chalk River Laboratories and Whiteshell Laboratories. Other nuclear facilities decommissioned or being decommissioned include research reactors, prototype power facilities, fuel cycle facilities, hot cells, etc.
China	China Institute of Atomic Energy, Beijing. Heavy water research reactor being decommissioned.
Czech Republic	Nuclear Research Institute, ÚJV Řež. Small nuclear facilities being decommissioned.
Denmark	Risø DTU National Laboratory. DR1, DR2 and DR3 research reactors decommissioned, as are hot cells, a fuel fabrication plant and other facilities.
France	French Alternative Energies and Atomic Energy Commission (CEA) Cadarache. CEA Fontenay-aux-Roses. CEA Grenoble. CEA Marcoule. CEA Saclay. Other nuclear facilities decommissioned or being decommissioned include research reactors, prototype power facilities, fuel cycle facilities, defence facilities, hot cells, etc.
Germany	Jülich Research Centre. Karlsruhe Research Centre. Research Centre Rossendorf. Rossendorf Central Nuclear Research Institute. Other nuclear facilities decommissioned or being decommissioned include research reactors, prototype power facilities, fuel cycle facilities, hot cells, etc.

TABLE 1. EXAMPLES OF MULTIFACILITY NUCLEAR CENTRES IN SELECTED MEMBER STATES WITH AT LEAST ONE FACILITY UNDER DECOMMISSIONING (NUCLEAR POWER PLANT ONLY SITES NOT INCLUDED) (cont.)

Member State	Nuclear centres
India	Bhabha Atomic Research Centre, Mumbai. Dhruva and Zerlina research reactors decommissioned, Apsara and Cirus research reactors shut down for decommissioning as are other nuclear facilities.
Iraq	Tuwaitha Nuclear Research Center. Other nuclear facilities are being decommissioned, including the IRT-5000 reactor.
Italy	Casaccia Research Centre. Saluggia Research Centre. Trisaia Research Centre. Joint Research Centre managed by the European Commission, Ispra. Other research reactors and nuclear facilities are being decommissioned.
Japan	Japan Atomic Energy Agency, Tokai Research and Development Center. Oarai Research and Development Institute, Tsuruga. Comprehensive Research and Development Center and Aomori Research and Development Center. Japan Power Demonstration Reactor and several research reactors decommissioned; other nuclear facilities are being decommissioned.
Kazakhstan	National Nuclear Centre, Kurchatov, near the Semipalatinsk Test Site.
Korea, Republic of	Korea Atomic Energy Research Institute, Daejeon. KRR-1 and KRR-2 research reactors decommissioned.
Philippines	Philippine Nuclear Research Institute, Manila.
Poland	National Centre for Nuclear Research, Otwock-Świerk. EWA research reactor partly decommissioned.
Romania	Horia Hulubei National Institute at Magurele, near Bucharest. VVR-S research reactor being decommissioned.
Russian Federation	Joint Institute for Nuclear Research, Dubna. National Research Center Kurchatov Institute, Moscow. Mayak Reprocessing Facility. Institute of Physics and Power Engineering, Obninsk. Research Institute of Atomic Reactors, Dimitrovgrad. Sverdlovsk branch of Research and Development, Institute of Power Engineering. St. Petersburg Institute of Nuclear Physics of the Russian Academy of Sciences, etc. Around 55 research reactors, critical and subcritical assemblies were shut down or are being decommissioned. Many other nuclear facilities were decommissioned.
Serbia	Vinča Institute of Nuclear Sciences. RA heavy water research reactor being decommissioned.
South Africa	South African Nuclear Energy Corporation, Pelindaba. Several research facilities decommissioned; the focus is on uranium enrichment and fuel cycle facilities.

TABLE 1. EXAMPLES OF MULTIFACILITY NUCLEAR CENTRES IN SELECTED MEMBER STATES WITH AT LEAST ONE FACILITY UNDER DECOMMISSIONING (NUCLEAR POWER PLANT ONLY SITES NOT INCLUDED) (cont.)

Member State	Nuclear centres
Spain	Research Centre for Energy, Environment and Technology, Madrid. JEN-1 research reactor decommissioned as well as other small nuclear facilities.
Sweden	EDF Cyclife (formerly Studsvik Nuclear AB), Nyköping.
Switzerland	Paul Scherrer Institute, Villigen. Research facilities being decommissioned.
United Kingdom	Aldermaston, Burghfield, Dounreay, Harwell, Winfrith, Sellafield, Springfields. Nuclear facilities decommissioned or being decommissioned include research reactors, prototype power facilities, fuel cycle facilities, defence facilities, hot cells, etc.
United States of America	Argonne National Laboratory (ANL) (east and west sites), Brookhaven National Laboratory, Hanford Nuclear Reservation, Idaho National Engineering and Environmental Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Nevada Test Site, Oak Ridge Reservation, Paducah Gaseous Diffusion Plant, Portsmouth Gaseous Diffusion Plant, Sandia National Laboratories, Savannah River Site, West Valley Demonstration Project. Nuclear facilities decommissioned or being decommissioned include research reactors, prototype power facilities, fuel cycle facilities, defence facilities, hot cells, etc.

The IAEA's reference information source on power reactors and NPP sites, used worldwide, is PRIS — Power Reactor Information System[1].

2.3. MINERAL PROCESSING SITES

Sites where uranium or thorium are mined and processed are often multifacility sites. The chemical process of the minerals (also known as 'milling') often takes place at the mining site, or close to it, to minimize material transport costs. This kind of site typically includes several nearby facilities. It will ideally also be noted that some parts of the site are commonly remediated, while other parts remain in operation. However, this publication does not discuss soil remediation as a component of the interactions between different facilities on the site.

2.4. DECOMMISSIONING ACTIVITIES AT MULTIFACILITY SITES AROUND THE WORLD

The global status with regard to decommissioning approaches is as varied as the range of sites. These include:

— Immediate dismantling, after completion of facility operation;
— Deferred dismantling;
— Sequential decommissioning of one facility after another;
— Simultaneous decommissioning of more than one facility;
— New developments at a site with existing decommissioning activities.

[1] See: https://pris.iaea.org/pris/

Each approach has been deployed at a range of sites. A number of examples are drawn from multireactor sites to consider why a particular approach has been selected and the high level implementation challenges.

2.4.1. Deferred versus immediate dismantling

There are a number of NPPs in the United States of America (USA) for which final dismantling was deferred, either to prevent disruption of the operation of other plants on the same site and/or to take advantage of the economies of decommissioning multiple reactors at once (Dresden Unit 1, Peach Bottom Unit 1 and Millstone Unit 1 all fit in this category since they are in SAFSTOR — the US term for safe enclosure in case of deferred dismantling strategy — and occupy sites that in all cases contain two other operating nuclear plants). In addition, deferral is intended to make it possible for the decommissioning process to be more efficient because it will allow a workforce to freely move between the facilities [3, 4].

As an example, Indian Point Unit 1 [5] was powered by a pressurized water reactor (PWR) which operated with an authorized maximum steady state power level of 275 MW(e) until 31 October 1974. On 19 June 1980, the United States Nuclear Regulatory Commission (NRC) issued a revocation of the authority to operate the facility. Units 2 and 3 are also PWRs which each produced in excess of 1000 MW(e). Since 1974, Unit 1 has been maintained in a safe enclosure mode. The original plan was to keep it until Unit 1 could be safely dismantled along with Unit 2 at the end of that unit's operating licence in 2012. This required extensive review when the operating lifetime of Units 2 and 3 was extended until 2033. Figure 5 shows the Indian Point site.

A range of inspections and assessments were undertaken by the operator to investigate and document the condition of Indian Point Unit 1 and to identify remedial actions to ensure that it would not pose nuclear security concerns to Units 2 and 3 [5]. This included the following measures:

- All significant structures comprising Unit 1 were evaluated for structural integrity and were found to be sound. The one item identified as requiring near term corrective action was the repair of the vapour containment concrete enclosure building shield wall, which was noted to have areas of spalling that had exposed a number of high tensile strength pre-stressing wire strands.
- Several plant areas with minor concrete cracks and spalling were noted and will require periodic monitoring.

FIG. 5. The Indian Point site, USA (photo courtesy of Entergy Corporation).

— The assessment noted several areas where rainwater/groundwater was entering the inside of the concrete structures through defects in the concrete ceilings, walls, floors and their joints. This condition had the potential for initiating industrial safety hazards (slipping hazards and electrical safety issues), the potential for the spread of contamination and may have led to further degradation of the concrete structures over time.
— A number of Unit 1 systems and components were 'retired' through indeterminate processes decades ago. The basis for, and intended purpose of, these 'retirements' had been lost over this time period (see Annexes II–1, II–4, II–5, II–9 and II–11). Although Unit 2 has successfully operated in this environment for almost three decades without significant incident, it was postulated that this success might be difficult to maintain in the long term due the retirement of a number of senior staff members who possessed significant store of 'inherent knowledge'.
— As a result of this condition, the assessment team identified the following:
  - A need for more clearly defined boundaries between Unit 1 non-operational components and those components remaining active in support of Unit 2.
  - A need for a documented analysis of the potential risks associated with Unit 1 systems and components and their potential impact on Unit 2.

The assessment team issued the following highest priority recommendations:

— Continue efforts to transfer Unit 1 spent fuel to dry cask storage as soon as practical;
— Following fuel transfer to dry cask storage, clean and drain the Unit 1 spent fuel pools, lock down contamination and take measures to prevent the reintroduction of water;
— Complete removal of high activity resin and sludge legacy waste from Unit 1 tanks and dispose of the waste;
— Mitigate degradation to the containment enclosure building shield wall's pre-stressing wire strands.

The decommissioning of the San Onofre NPP offers an example of immediate, active dismantling that was started promptly after final shutdown while two more reactors on-site continued operation [6]. Under steady state conditions, Unit 1 produced 436 MW(e) and both units 2 and 3 produced in excess of 1000 MW(e). When Unit 1 of the San Onofre Nuclear Generating Station (SONGS 1) was retired in 1992, the operator planned to maintain the unit in SAFSTOR until future decommissioning of SONGS 2 and 3. The decision to begin the decommissioning work promptly was based in part on a desire to take advantage of San Onofre's main resource: its highly skilled workforce which could complete the project with limited reliance on outside consultants and vendors. The NRC also changed its policies to allow companies access to 3% of their decommissioning funds for preliminary planning efforts. These circumstances prompted the operator of SONGS to initiate earlier decommissioning of SONGS 1. In 1999, the regulatory bodies granted approval of the decommissioning plan, allowing the start of decommissioning activities. SONGS 1 became an active dismantling project which was largely completed in 2008. A small amount of work remains to be completed with the eventual decommissioning of SONGS 2 and 3. The latter were permanently shut down in 2013 and the entire site is now subject to decommissioning [6].

Figure 6 clearly shows that SONGS is a 'packed' site, closely spaced between the ocean and Interstate 5, a major highway. Examination of the site shows significant dependencies between the three units which affect decommissioning projects. Several systems were shared by both the shutdown and operational units as follows:

— The fire water system at SONGS 1, which was tied into and noted in the licensing basis of SONGS 2 and 3.
— The site common radio communication system, which had a series of antennas and associated electronics located in buildings throughout the entire facility, some of which were planned to be demolished.

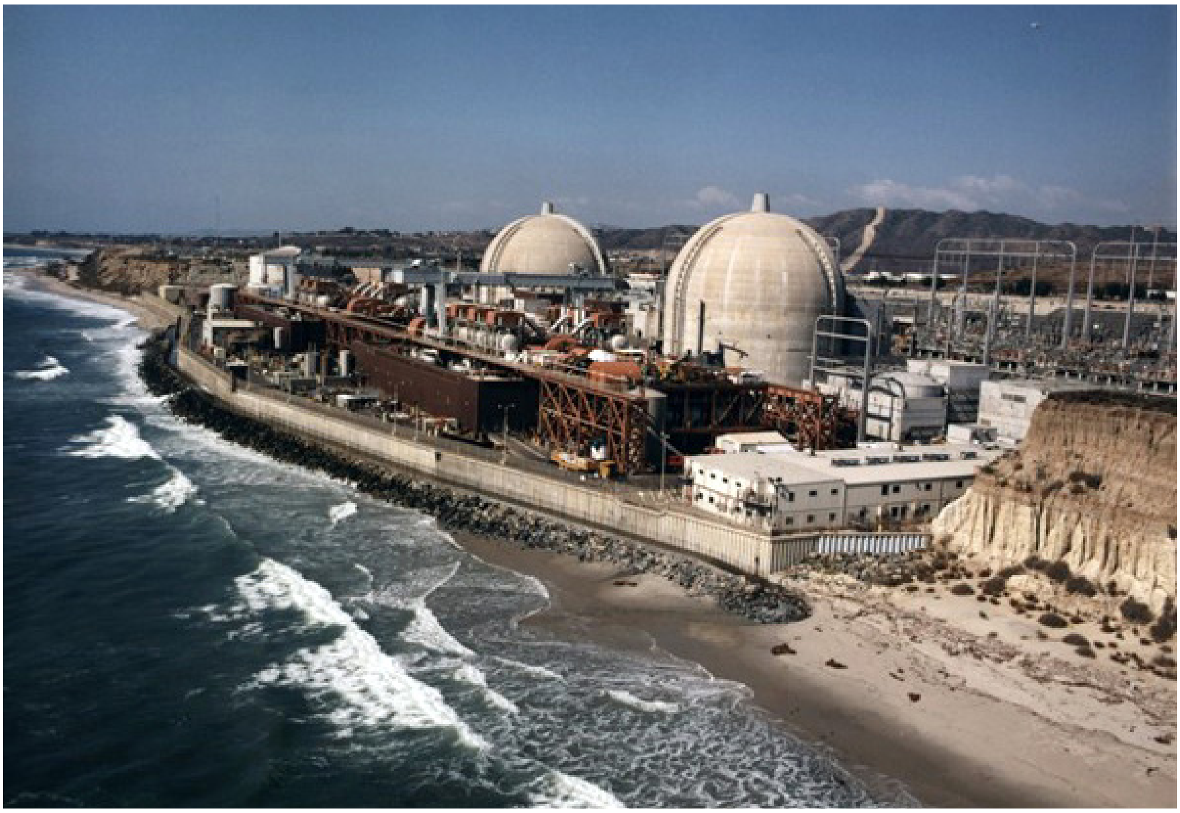

FIG. 6. The SONGS site, USA (photo courtesy of Southern California Edison).

— The meteorological tower, electricity, and communication lines, which passed through SONGS 1, as did the on-site emergency notification siren system.

Another area of significant interface between the shutdown unit and the operational units was nuclear security. The three units shared a common security boundary, with common entry, exit and security forces.

In addition, the process of ensuring that piping and conduits did not contain electricity or pressurized fluids (called ‘cold and dark’ in US terminology), necessary for the safety of the workforce during demolition, could not be practically implemented if the entire facility was required to remain continually in compliance with general lighting requirements [7].

The interactions between two reactors, one shut down and the other in operation (now also shut down for decommissioning), at the Barsebäck site in Sweden is another example. A study identified the need for the staff to give the same level of attention to both units in terms of motivation and improved integration. The shift crew covers both units based on the rotation policy and maintenance schedules; quality assurance (QA) and other service departments cover the requirements common to both reactors [8].

A key requirement is to ensure there is a clear separation between systems in non-operational facilities that support ongoing operations and those which can be decommissioned — accurate configuration control has to be maintained. Careful planning of the initial decommissioning process will ideally consider this separation. Long term management is necessary for redundant systems that are no longer needed to support operations and those systems which are needed. This planning will ideally also consider the timeliness for removal of inventory from a facility (also known as ‘post-operational cleanout’), particularly as deferral timescales can be extended by other factors. On a smaller scale, issues related to decommissioning a hot cell facility inside a building with operating laboratories are discussed in Ref. [9].

2.4.2. Sequential versus simultaneous approach to decommissioning

An example of several decommissioning projects on the same site is presented in Ref. [10]. The paper discusses the Reactor Interim Safe Storage Project within the decommissioning projects at the Hanford Site and reviews the lessons learned from performing four (F, DR, D, H) large reactor decommissioning projects sequentially (Fig. 7). The scope of each Interim Safe Storage activity was to remove all ancillary and support structures around the reinforced concrete secondary shield walls, seal all openings, place a new safe enclosure roof on the reactor facilities, and install lighting and a monitoring system in the remaining structure. Because the engineering and planning for the last four reactors was performed in groups of two, significant savings and efficiencies were realized. The analysis indicated that scheduling similar facilities for sequential decommissioning led to increased process efficiencies in the decommissioning project organization as the team looked for better ways to perform the work. However, some disadvantages were identified, as illustrated in Table 2 (adapted from Ref. [10]).

The benefits of simultaneous or sequential decommissioning need to be understood when developing the site decommissioning strategy and plan.

2.4.3. New development on a site with existing decommissioning activities

Constructing a new nuclear facility (e.g. a nuclear power reactor) on a site where other nuclear facilities are already situated is becoming common because of the considerable infrastructure (electrical grid, cooling water, etc.) already available and other advantages (skilled labour, support services like catering, worker transportation, etc.). It may be better to place the older facilities in a deferred dismantling mode until the construction of the remaining facilities has been completed. The construction at the

FIG. 7. Safe enclosure completed at the Hanford F reactor, which operated from 1945 to 1965 and was placed in interim safe storage in 2003 (photo courtesy of the United States Department of Energy (DOE)).

TABLE 2. ADVANTAGES AND DISADVANTAGES OF SEQUENTIAL AND SIMULTANEOUS DECOMMISSIONING

Process	Advantages of sequential	Disadvantages of sequential	Advantages of simultaneous	Disadvantages of simultaneous
Engineering and plannin	Excellent consistency in approach, estimating and scheduling of the project work. Efficiency in staff utilization after a good process is established.	Could be resource limited based on the sustained availability of qualified decommissioning engineers.	Quicker finish to overall site decommissioning.	Could be resource limited based on the peak availability of qualified decommissioning engineers. Potential negative socioeconomic impact.
Regulatory interfaces for project documentation	Issues are resolved once, rather than every few years, possibly with a different person with a different perspective. Consistency in approach and expectations regarding regulatory interpretation is achieved.	Regulator may not have responsibility for issues that may arise several years in the future relating to different facilities. Potential large time demand during initial phase of work.	Overall lower need for regulatory interface through time.	High peak demand on regulatory team. Learning more difficult to transfer to other projects.
Stakeholder interface for project(s)	Issues are resolved once, rather than every few years, possibly with a different group of people with a different perspective.	On rare occasions, the massive amount of information overwhelms the public. Changes in public representatives could impact on previous resolution of issues.	All issues are resolved at the same time to support progress of decommissioning.	Large amount of information could overwhelm stakeholders. Justification for simultaneous decommissioning may be more difficult to achieve.
Staff utilization	Efficiency in staff utilization after a good process is established. Familiarity with the facilities increases as project work moves between similar facilities (see Annex II–14).	When a problem is encountered at one facility, the ripple effect could delay all subsequent facilities without decisive management action.	High demand gives rise to reutilization of staff through redeployment to decommissioning projects.	Short term prospects only. Need significant levels of retraining of personnel simultaneously. Learning more difficult to transfer between projects.

TABLE 2. ADVANTAGES AND DISADVANTAGES OF SEQUENTIAL AND SIMULTANEOUS DECOMMISSIONING (cont.)

Process	Advantages of sequential	Disadvantages of sequential	Advantages of simultaneous	Disadvantages of simultaneous
Decommissioning equipment	Individual operator's technique and expertise increases as they move from facility to facility. Equipment utilization rates increase with proper scheduling.	When a problem is encountered at one facility, the ripple effect can affect all of the subsequent facilities. More difficult to find 'natural' downtimes to perform extensive preventive maintenance.	One-off procurement activity, at a very large scale.	High demand for specialized equipment over a short time period (need to procure more equipment in total compared with sequential decommissioning).
Design and construction	Lessons learned regarding subcontracts/ subcontractors are immediately applied to the next subcontract.			
Cost	Lower near term funding requirement. Predictability between different projects.	Longer overall funding requirement.	Shorter funding requirement (limited escalation).	Large near term funding requirement.
Safety	Takes advantage of decay. Provides ability to optimize the safety of subsequent project delivery.	Need to maintain safety systems and processes for much longer. Negative impact of decay for alpha plants and associated ingrowth (e.g. Am-241 and Tl-208).	Facilities reach safer end state sooner.	High demand for safety assessment resources. Lower priority projects may not attain suitable emphasis on safety. Learning more difficult to transfer between projects.

site needs to ensure the safety and security of the shutdown facility and vice versa. The impacts of the decommissioning of the shutdown facility need to be considered during planning and construction.

Some of the advantages of constructing additional NPPs on an existing site include [11]:

(1) Limiting the number of locations committed to long term restricted use and periodic surveillance and maintenance;
(2) Easing the burden of long term care and final disposition of retired NPPs;
(3) Reducing the overall environmental impacts from the construction and maintenance of these plants;
(4) Saving time and money in completing licensing proceedings.

A licensed site is an invaluable asset at a time when the licensing of new sites is a significant hurdle in many countries. Therefore, the case of a decommissioning project taking place concurrently with and in the vicinity of a construction project may be increasingly likely.

As examples, a number of new builds are under way at old nuclear sites in the UK (Bradwell (Fig. 8), Hinkley Point, etc.). Building new reactors at old sites is a national policy in the Russian Federation, with socioeconomic factors specified as being key in that policy. Due to the remoteness of certain sites in the Russian Federation, the limited mobility of the workforce, and the presence of population centres that were developed solely for the nuclear site, the job losses resulting from the decommissioning of one or more installations need to be compensated for by the construction of new installations [12].

Another noteworthy case is the Humboldt Bay Power Plant in Northern California, USA. Unit 3, one of the first commercial nuclear power reactors in the USA, was shut down in 1976, placed in SAFSTOR in 1983 and is now under full scale decommissioning. Except for the reactor containment being completely below ground level, the decommissioning process is similar to other sites. What makes this project particularly challenging is that there are two ageing fossil fuel plants connected to the Unit 3 reactor building and a new 160 MW(e) fossil plant that needed to be constructed less than 100 ft (30 m) away. To add to the challenge, the site is very small, with approximately 30 acres (12 ha) available for use for the three power units, switchyard structures, the intake and discharge canals, two 2.8 million gal (10600 m^3) capacity fuel oil tanks, an independent spent fuel storage installation (ISFSI), parking lots, and several support buildings.

The problem is that new construction at an NRC licensed facility is typically intended to support existing operations and will not normally extend beyond the NRC licence. If structures were to remain after licence termination, a Final Status Survey would need to be completed [13, 14]. However, as in the case of Humboldt Bay Power Plant, a non-NRC-licensed facility was being constructed on soil that was impacted by the operation of Unit 3, with future sampling of the soil underneath the foundation being virtually impossible. The key questions in this case were to demonstrate, whether:

(1) The licensee can prove whether the soils beneath the new plant are in compliance with the release criteria approved in the licence termination plan;
(2) The licensee can prove that the soils and structures of the new plant have not been radiologically impacted by the decommissioning process.

These issues were addressed by providing a historical site assessment, an associated characterization plan and a programme of detailed characterizations. The approach utilized is described further in Annex II–11.

FIG. 8. The two Magnox reactors at the Bradwell site, UK (photo courtesy of NDA).

A key consideration is to ensure the potential impact of new build preventing the completion of final decommissioning of a facility and any impact on its associated licence needs to be considered during the development of the site decommissioning plans and during the implementation of decommissioning activities.

2.4.4. Considerations on implemented decommissioning activities within the same plant

Some issues discussed in this publication also arise when decommissioning of SSCs is carried out in parallel within the same plant. Hence, it is beneficial to study the experience and lessons learned from these projects as well.

One difficulty arises from the interactions that can be generated through a combination of activities. This set of interactions is called 'co-activity' [15]. For example, the decommissioning plan can interfere with the dismantling areas and the other parts of the facility that are still in operation, creating conflicts that affect safety. A major issue is the state of the utilities, such as electricity, air or water supply: the planned dismantling operations can require the curtailment or isolation of these networks, whereas they need to remain operational for use by another part of the system.

Planning can also cause an overlap between the dismantling areas themselves. Conflicts can appear each time two tasks in separate yards are planned to be carried out at the same time and at the same place.

The possible risks include:

— Unexpected bottlenecks with a potential to delay activities and invalidate the general plan;
— Planning at the same location and time for tasks which could induce safety issues;
— Underestimation of the impact of potential incidents, for example failure of critical equipment or the occurrence of unexpected events.

3. OVERARCHING CONSIDERATIONS

The traditional approach to decommissioning has been to treat each facility at a nuclear site as separate and to manage decommissioning projects in a discrete fashion. Across the world, projects managed this way are often late and over budget, which can be due to limited attention to interactions to/from other site facilities. An integrated approach combines all site aspects that are relevant to the continued operation, construction or decommissioning of all facilities at a given site. Implementing an integrated approach is expected to improve efficiency in a decommissioning project, thereby making the outcome more predictable.

Decommissioning at a multifacility site might also benefit from the application of a phased approach, whereby the overall decommissioning project is divided into phases that are planned and implemented sequentially [16]. For example, the lessons learned from a project at one facility can be carried over to the next facility, avoiding the same mistakes and mitigating project risks. This brings predictability, as the project schedule and cost are underpinned by experience, and the risks can be better managed. When projects become more predictable, opportunities for efficiency and cost savings become apparent.

The concept of integrated decommissioning is expected to yield some or all of the following advantages:

— Improved learning of safety issues and transfer of good practices between projects;
— Improved technology development and deployment between projects;
— Skills and reorganization facilitated by delivering projects within longer term programmes;
— Uniform delivery of projects: Leadership and processes focus on ensuring that strategic goals are achieved consistently across the site;

— Reduced decommissioning duration due to reduced lead time for the various tasks between the facilities;
— Utilization of proven decommissioning tools and equipment across the site;
— Reduced construction burden: Development of combined waste management facilities;
— Common safety analysis for active wastes of the same category;
— Supply chain engagement: Close interaction with suppliers provides opportunities to form longer term arrangements and relationships;
— Stakeholders: Continuous process of open external communication with local communities and regulators who become familiar with the approach to decommissioning;
— Cost estimates from site decommissioning studies allow for cost savings through more efficient use of resources than in project specific studies, and provide a firm and realistic basis for the estimation of the likely financial costs of decommissioning.

At the same time, the integrated approach to site decommissioning requires consideration of a number of new factors which may complicate and slow down the planning and implementation of projects. For example, a firm decision on the end state of a nuclear site could be taken far in the future. To optimize the decommissioning projects in view of such an uncertain objective could be risky.

Three main categories of factors have been identified that highlight the potential considerations required for a multifacility site: technical (Section 4); organizational (Section 5); and financial (Section 6). The strategic plan will ideally incorporate all factors relevant to each option and, based on an optimization analysis, produce the optimal strategic route and end state for the site.

3.1. DEVELOPMENT OF A SITE-WIDE DECOMMISSIONING STRATEGY

The integrated approach to decommissioning at a multifacility site highlights the need for a strategic document describing the site-wide decommissioning strategy [17]. Such a document will ideally be at least submitted to the attention of the regulatory body, if not specifically approved (in some countries, decommissioning licences are granted on a facility specific basis). First and foremost, this document will ideally define a (physical and radiological) site end state and the site reuse/redevelopment state (or at least a range of viable options). Then the site wide decommissioning strategy will ideally define and justify priorities in the decommissioning of individual facilities. This will ideally normally be dictated by such factors as national policies, the anticipated short and long term profitability of each facility, decommissioning costs, and technical factors such as one facility supporting the continued operation or the decommissioning of another facility. For example, certain waste management facilities will be the last to be decommissioned on a given site.

Consequently, a time schedule will ideally be drafted and the critical path highlighted: the plan will ideally identify interactions between the operational and decommissioning phases of all facilities on-site and make sure that the needed infrastructure, services and utilities (including also other facilities on-site) are available at all times to support operations and decommissioning projects. Furthermore, the plan will ideally identify where new facilities or capabilities are required to implement decommissioning of the site. The site plan will ideally provide the essential elements characterizing the decommissioning of each facility such as the types and amounts of waste resulting from decommissioning, staffing and the costs and cash flows of all decommissioning projects.

As decommissioning is a multidisciplinary approach, there are many factors that influence the planning and implementation of a decommissioning project. The case of decommissioning a facility at a multifacility site is further complicated by the interactions of one facility with the other facilities. This gives rise to a number of factors which are relevant to multifacility sites.

It is crucial that as decommissioning plans are being developed for single facilities, a clear link is established with the site decommissioning plan so as to ensure that coordination is maintained. This is certainly a matter of regulatory concern. Note that the optimization process can be subject to a number of iterations. Eventually even a past decision on the site end state can be reversed as a result of optimization.

3.2. IMPLEMENTATION OF AN INTEGRATED APPROACH TO DECOMMISSIONING

The term ‘synergism’ describes the approach that working together or cooperating in a combined effort by sharing information and resources to accomplish some project tasks can produce more benefits than are achieved through independent and consecutive efforts. Synergies are possible between construction, operation and decommissioning activities insofar as single activities are directed to a common objective for the site (e.g. in case of different owners running site facilities). The primary objective of decommissioning a nuclear facility is to remove (or reuse) the nuclear facility and to reduce any associated contamination levels to that appropriate to (or acceptable for) the future use(s) of the site. This objective will ideally be harmonized with the construction and operation of adjacent facilities. As a result, the successful design and implementation of decommissioning involves a number of common tasks, including strategic planning, project management, safety, materials and waste management, stakeholder involvement, the end state and financial aspects. Identifying potential synergies in each of these activities (e.g. site infrastructure, workforce and supporting management systems) makes it possible to complete projects in a more cost effective manner [17].

Strategic planning addresses the coordination of multiple activities for the decommissioning of facility buildings and structures and remedial actions at the site, if needed. Particular decommissioning projects and other site activities need to be recognized and prioritized. Support of the common tasks will ideally be in place to minimize costs while maintaining the importance of safety and nuclear security measures.

Project management refers to a series of management tasks involved in the planning and execution of projects aimed at accomplishing specific objectives. The same general project management principles apply whether the project is to decommission a specific building/structure or the task is to build a new supporting facility that will later require dismantling. There may be many opportunities for reducing the decommissioning cost, schedule, impact and risk, as well as potential operation/construction activities if they are developed in an integrated manner.

Safety and risk assessment refer to the systematic estimation of potential exposures and risks to human health and the environment from concentrations of radionuclides or hazardous chemicals at nuclear facilities. In addition, safety and risk assessment is used as a planning tool to identify, make provision for, or mitigate safety risks to workers involved in implementing the decommissioning project by identifying incidents, hazards and realistic impacts within the decommissioning facility and from nearby facilities. Similar considerations apply to nuclear security issues. On-site decommissioning workers and contractors need to be checked by site management whether and how occupational exposure has been considered in their planning and implementation by the different contracting companies.

Material and waste management needs significant attention through careful planning and sequencing of decommissioning activities. Large amounts of material and varying volumes of waste are typically generated during the dismantling of SSCs that are quite different from normal operational waste (also produced on-site). Most of the waste and material can be segregated into inactive material and low level waste. However, the different character of decommissioning waste may be a challenge to the installed waste management facilities, which were normally designed for operational waste.

For example, dismantling of large, highly activated components (e.g. reactor vessel, pressurizer, steam generator) would generate radioactive waste of a unique nature: different options are available depending on the site and national infrastructure. Removal of large components while keeping them intact or in situ segmenting are two options that would pose different management challenges at a multifacility site. For example, the logistics of transporting large containers on-site is a serious issue.

A significant reduction in the volume of contaminated waste can be achieved through a well formulated decontamination programme, appropriate dismantling techniques, contamination control and suitable radiological and administrative control measures. Consideration of the management of the resulting effluent, residues and secondary waste from decontamination and decommissioning activities is required to ensure that this approach is optimized site-wide. Reuse and recycle strategies can substantially reduce the amount of material that has to be classified as radioactive waste. Depending on the strategy chosen, there can be a need for new facilities/buildings on-site to install decontamination and waste treatment systems or new waste storage facilities.

Interaction with management systems for site operational waste is essential for multifacility sites. For example, waste treatment systems and facilities at a given site will ideally take into account the waste streams (physical–chemical characteristics and volumes) of both operational and decommissioning waste being generated or expected to be generated; there are different options, including designing the waste treatment to accommodate current and future demands or considering means to expand waste treatment as the need occurs.

Spent fuel management is especially critical at multifacility sites. Relevant factors are due, among others, to limited capacity of spent fuel pools at individual reactors, inability of spent fuel pools to accommodate fuels from other reactors on-site, on-site and off-site transport logistics and lack of off-site centralized stores or disposal options. Some of these factors may seriously impair the flexibility required to handle spent fuel on a site where operating and decommissioning reactors coexist.

Stakeholder involvement refers to the activities conducted during the design and implementation phases of the decommissioning project that attempt to determine the needs and concerns of various parties, including elected officials, interested citizens, workers, businesses and environmentalists. The goal is to foster a dialogue which helps to create positive relationships between project managers and stakeholders. The presence of several facilities on-site adds to the complexity of the stakeholder dialogue. An overview of stakeholder involvement in decommissioning is provided in another IAEA publication [18].

The end state of the site is one of the key factors determining the strategy plan for decommissioning a site [19]. It is generally recognized, and is consistent with IAEA recommendations [1], that the normal end state of a decommissioning project will ideally be the unrestricted release of the facility and its site. However, if the decommissioning facility is co-located with operating facilities, achieving unrestricted release could be problematic, or in some cases prohibitively expensive. This is due to the actual or potential contamination resulting from nuclear operation. Some sites are contaminated to such an extent that unrestricted release remains wishful thinking for the foreseeable future. The best option might then be to preserve the entire site as a nuclear site and construct new nuclear facilities on it (see the Chornobyl case in Annex I for reference).

Similarly, if the areas adjacent to the decommissioning facility are heavily contaminated, decontaminating one facility to unrestricted release levels while the surrounding areas are still contaminated (typical of legacy sites) may turn out to be a futile exercise due to the possibility of recontamination of the previously decontaminated area or the impossibility of reuse of the small clean 'island' for non-nuclear purposes. Under such circumstances, it may be more appropriate to decontaminate the facility being decommissioned to an acceptably safe state of restricted release, deferring full decontamination of the entire site to a time when no further contamination is expected or when resources for a larger scale exercise are available. A site under restricted release conditions can still accommodate facilities and activities compatible with residual radiation levels.

Appropriate levels of decontamination of facilities will ideally be considered within the overall site context when preparing the site decommissioning strategy and plan. It is also possible to clean up peripheral parts of a site to unrestricted release levels and delicensed while the rest of the site remains under institutional control (including remaining operations). To implement this option, it will ideally be demonstrated that recontamination of delicensed areas remains unrealistic.

Decommissioning funding, including how finances are collected, varies from country to country. For NPPs, decommissioning funds are collected on a percentage of the revenues resulting from the electricity generated and sold by the plant during operation. For multi-unit nuclear power stations, funds can be collected site-wide or, if the owner has several generating sites, on a fleet basis [20].

Typically, the fund is built up year by year, and is based on the decommissioning cost estimate and expected service life of the nuclear facility. However, there is a risk associated with unplanned, premature shutdown which may require additional financial resources or the continued collection of funds after permanent shutdown or even during the decommissioning phase. The funding status at the time of a facility's final shutdown may have a special impact on multifacility sites: operating site facilities may have to operate longer than anticipated to provide financial resources for decommissioning. Or the decommissioning strategy may result in long periods of safe enclosure for one or more site facilities.

4. TECHNICAL ASPECTS

The technical factors associated with a multifacility site relate to the opportunities and physical limitations presented by the characteristics of the site, national standards and financial possibilities. For example, the lessons learned from using a decommissioning technology on one facility and one country may imply that that technology will be applied (or discarded) on another facility in a sequence of decommissioning projects onsite.

4.1. SITE LAYOUT

Site layout contributes to the complexity of decommissioning of a facility. For example, a high density of site facilities will require careful planning to ensure that the facilities are decommissioned in an optimized manner and order. The development of the site over time may result in a facility which is ready to be decommissioned being located in a position where its proximity to other operational facilities makes decommissioning difficult. In such circumstances, it may be necessary to defer the decommissioning of that facility until the other operational facilities are also ready to be decommissioned. This complexity can result in the need to maintain redundant facilities, often for many years, with an impact on the site's overhead costs.

During a facility's decommissioning, the movement of personnel and vehicles in and out of the site will change in nature as well as in number. If the plant being decommissioned is fenced off, new or previously sealed-off gates may be opened. This is also a nuclear security issue. The local authorities and police may have to give permission for this change. They may also demand specific routes to be used on the public highways. Dust blowing from vehicles and mud on roads can become issues during demolition. Dealing with these comes within the terms of the demolition contract, as will ideally any routes on public roads specified by the local authorities or police [21].

It is generally expected that road traffic will increase during the active phases of decommissioning due to trucks carrying heavy machinery or decommissioning waste (both radioactive and non-radioactive). During certain phases of decommissioning it is also expected that a larger number of workers will be involved, thereby increasing private traffic. In turn, enhanced traffic conditions may require the establishment of new roads or alternative routes within the site. Vehicles may produce new hazards for site facilities (e.g. fire, crashes) not necessarily limited to the one being decommissioned.

It is also possible that the location of a nearby facility will prevent access to the decommissioning facility for the delivery of decommissioning equipment, installation of supporting building and services (e.g. a waste buffer store) or the removal of waste material or, at least, will result in increased cost of these activities. The impact of the decommissioning of a facility to the surrounding site road infrastructure also needs to be considered.

Decommissioning work on one facility in a research centre can impact work being carried out at facilities nearby due to the: generation of radioactive or other noxious effluents; traffic limitations or detours during active demolition; and temporary reassignment of site functions. The layout of the facility may change from the initial design through the subsequent project life cycle and operational phases. Care has to then be taken to ensure that the significance of any modifications to facility location or layout is fully considered from the standpoint of decommissioning.

4.2. SHARED INFRASTRUCTURE INCLUDING UTILITIES AND STRUCTURES, SYSTEMS AND COMPONENTS

Dependencies between shared systems at sites with multiple units during decommissioning need to be carefully considered. Mechanical and electrical interfaces to ensure that dismantling of one unit does not affect an adjacent operating unit require identification. Considering the decommissioning sequence at the time of design will facilitate isolation of these facilities without disrupting the operation of others which may still have an operational role. This is particularly true of multi-unit NPPs and chemical process plants where several chemical processes are carried out in sequence in connected plants.

A useful starting point is to obtain a drawing of the area to be decommissioned which also details all the adjacent areas and services such as drainage, electricity, pressurized gases and ventilation. It is wise to check the accuracy of any architect's drawings by carrying out a visual inspection of the area. Often it is helpful to take a series of pictures with scale markings so dimensions can be verified away from the area. It is also important to obtain drawings and specifications of all alterations to the building or the services in situ that have been made since the building was first constructed since these changes may have altered the connections to other buildings and facilities on-site. It is advantageous to talk to employees who have worked at the facility for a long time as they may have knowledge that does not appear in the records that are currently available.

In Member States where a long established and experienced regulatory regime for radioactive material is in place, a discussion with the regulator might be helpful. The regulator may have knowledge or information in the records of a past incident that occurred at the facility which may have resulted in radioactivity being dispersed and possibly affected other facilities. Laboratory records of accidents and incidents might be useful knowledge when determining the boundary of the decommissioning task, especially with regard to adjacent facilities. It is good practice that drains or ventilation systems are inspected to rule out the spread of contamination to adjacent facilities.

In general, characterization of a facility at a multifacility site will ideally include evaluation of all inter-related facilities so as to provide the maximum amount of information to aid decommissioning planning, change management and configuration management [22].

Stacks are quite common shared systems. Issues affecting how stack dismantling fits into the overall site decommissioning strategy can be demonstrated in the case of large scale stack demolition using explosives to fell the G1 reactor stack at Marcoule, France [23]. This project was unique in that it addressed a very large stack constructed of pre-stressed concrete. Directional control of the fall of the stack was critical to avoid damage to adjacent facilities. Figure 9 shows the toppling sequence of the stack.

Alternative approaches are also described in Ref. [23], e.g. the decision making process followed to dismantle a stack at the Savannah River Site (USA) which had to take account of the proximity of other building as well as of other factors. Another example of shared systems is the strategy selected for removal of pipes or underground components [24], which is linked to the general strategy for decommissioning and, in particular, to the planned end state and the site release criteria (from institutional control).

There are special cases of process services which can be provided by an off-site organization or even another company at the same complex, for example, fuel gas, steam or inert gas in a 'through the fence' supply. In all cases, some contracts will apply to the supply and often to the equipment that the suppliers provide on the site. These contracts need to be renegotiated not just to terminate them, but to provide for the 'unusual' conditions during the decommissioning.

On a practical level, the utility suppliers are often the only ones legally allowed to work on their equipment, pipework, cables, etc. Meters are a special issue here. It may be necessary to negotiate

FIG. 9. Stack dismantling at the G1 reactor, Marcoule, France (photo courtesy of CEA Marcoule).

diversions and temporary connections as well as facilities for major changes in off-take or flow and composition limits for effluent.

It may be that utilities pass through the site to other users. Whether this is the case, and whether it will ideally continue during and after decommissioning, requires investigation and renegotiation [21] (see Annexes II–1, II–4, II–9 and II–11 for relevant examples).

4.3. WASTE MANAGEMENT FACILITIES AND PROVISION

During the decommissioning period, some waste will be generated, usually in much larger amounts than during operation. A system is needed for the collection, characterization, sorting, conditioning and storage of radioactive waste. This waste will consist of filters, discarded equipment, concrete debris, steel scrap and general refuse. Many facilities operate with liquid radioactive waste which can be stored in tanks up to the start of decommissioning. Many years or even decades of storage of this waste have resulted in the formation of hard solids or wet solids inside tanks which have variable chemical, physical and radionuclide compositions in volume. These wastes need special technologies for recovery and treatment.

All waste streams will ideally be established and described in the decommissioning project. This part of the decommissioning project will ideally include detailed information, including the following:

— Characteristics of all radioactive waste streams, including physical and chemical composition;
— Volumes and amount of radioactive waste;
— Specific activity and classification of radioactive waste in accordance with local waste acceptance criteria (WAC);
— Procedures for collection, transport and preliminary storage of radioactive waste;
— Pre-treatment and treatment technologies if they apply in the decommissioning activity.

Regular shipments will ideally ensure the transport of radioactive waste to a centralized storage or disposal site in accordance with the WAC as applicable for these facilities.

Waste minimization includes four fundamental principles which will ideally be considered when planning and implementing the waste minimization programme. These principles are to keep the radioactive waste arisings to the minimum possible or practicable, to minimize the spread of radioactivity leading to the creation of radioactive waste, to optimize recycling and reuse options and to minimize the quantity of waste that has been created by applying the appropriate treatment technology (see Fig. 10).

A large number of processes are available for reducing the volume and immobilizing the low and intermediate level liquid waste which arises from the decommissioning of nuclear facilities. Waste management is an intrinsic part of decommissioning and the latter cannot be safely and cost effectively completed without the availability of a complete waste management infrastructure. This often implies that the decommissioning of a nuclear facility will ideally be preceded by the decommissioning, refurbishment or building of radioactive waste management facilities. In the case of building facilities, the considerations described under the site layout (Section 4.1) need to be borne in mind as part of the decommissioning strategy.

Interference between decommissioning and the management of waste needs to be taken into account in the planning and implementation of site activities. The following factors need to be considered [26]:

— The variable rate of waste generation due to the large amounts of decommissioning waste produced only during specific phases of decommissioning as opposed to more regular generation during operation;
— Unusual physical–chemical nature of certain types of decommissioning waste [27];
— The need to manage large components during decommissioning requires the associated capability in the waste management facilities to handle them;

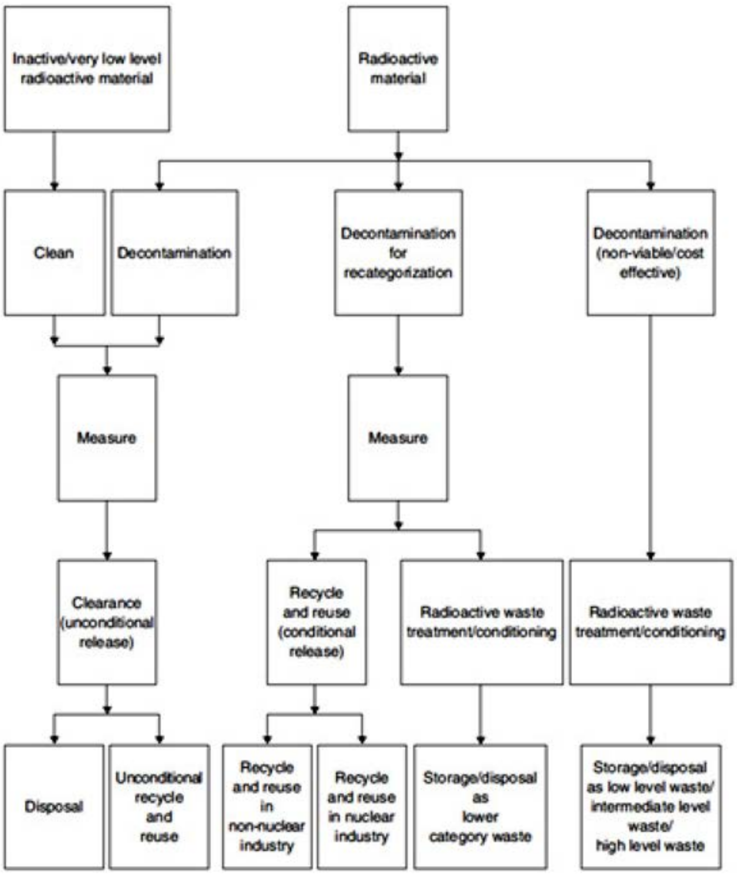

FIG. 10. Options for the segregation and characterization of suspect and radioactive material [25].

— Larger amounts of waste eligible for clearance.

Regarding airborne and liquid radioactive emissions, it is important to ensure that the effluent discharge limits (often relating to the entire site) are not exceeded by the ‘change-of-use’ of the decommissioning mode. This check is also necessary for any other plants on-site if they are to continue operation. The impact of decommissioning activities on facility and site discharge limits needs to be considered as part of the facility decommissioning plan and the site decommissioning strategy (see Annex II–12).

An example of managing the range of decommissioning waste generated is at the Vinča Institute of Nuclear Sciences, Serbia, where an IAEA technical assistance project on research reactor decommissioning has been in place since the early 2000s. A programme financed by the European Commission was launched a few years later consisting of the following tasks (some aimed at general upgrading of the infrastructure) in support of reactor decommissioning [28]:

— Repatriation of Serbian spent nuclear fuel to the Russian Federation;
— Equipping of the radioactive waste processing facility at Vinča;
— Management of sealed radioactive sources of category 3 and 4 at Vinča;
— Decommissioning of Hangar No. 1 at Vinča (a radioactive waste store) (Fig. 11);
— Radioactivity survey at the Vinča site;
— Operation of the radioactive waste processing facility at Vinča;
— Improvement of emergency preparedness at Vinča;
— Support to the Project Management Unit (PMU) at Vinča;
— Regional project on regulatory infrastructure;
— Decommissioning of the underground radioactive liquid waste tanks at Vinča;
— Implementation of the recommendations of the radioactivity survey at Vinča;
— Support to the Serbian nuclear regulatory body for the establishment of registries for radioactive material and occupational exposures;
— Decommissioning of the spent fuel storage pond at Vinča.

Arrangements for the management of waste and waste records will ideally be in place in the decommissioning organization. At a multifacility site, such arrangements (technical: measurement instruments and procedures; administrative: categorization) will ideally be compatible with the management of waste arising from other site facilities. International guidance on waste characterization is given in Ref. [29]. Waste may or may not be stored within the decommissioning facility or elsewhere on-site during the various phases of decommissioning depending on factors such as availability, adequacy and capacity of on-site storage or off-site disposal facilities, long term waste projections or the regulatory body’s position. Where waste is stored, it will ideally be fully recorded and safely managed. If on-site waste storage is not permitted, arrangements need to be made to prevent undue accumulation of waste, and it is necessary for waste routes to be established. Buffer stores will ideally be considered to prevent undue accumulation of decommissioning waste in working areas (see Annex II–6).

Air pollution through dust and aerosol release can create both radioactive and non-radioactive hazards. Normally, all buildings and construction will ideally be decontaminated before being demolished. However, practice demonstrated clearly that even residual activity after decontamination can create radioactive dust, which is the main danger for decommissioning personnel and for the environment. The selection of appropriate decommissioning and demolition techniques and the scheduling of activities need to consider the potential impact of air pollution on the surrounding site and any neighbouring facilities.

It is therefore important to plan activities, provide information to neighbouring facilities, and monitor air concentrations so that such issues are minimized. A typical measure to reduce dust during the demolition of buildings is to use fine mist sprays (Figs 12 and 13). However, even with proper equipment and well trained operators, fine mist spraying is not always effective in windy conditions or when there is a very large amount of dust.

FIG. 11. The old waste store at the Vinča Institute of Nuclear Sciences, Serbia (photo courtesy of the Vinča Institute of Nuclear Sciences).

FIG. 12. Fine mist sprays during demolition (photo courtesy of Omega III LLC).

FIG. 13. Water cannon used for fine mist spraying (photo courtesy of Omega III LLC).

4.4. DEVELOPMENT AND DEPLOYMENT OF DECOMMISSIONING TECHNOLOGIES

The selection of decommissioning technologies will not be greatly affected by whether the decommissioning project takes place within a single unit or a multi-unit site. Under normal circumstances, technologies are not expected to cause any spread of contamination within the boundaries of the decommissioning facility, let alone to external facilities and land. However, under accident conditions (unlikely), technologies have a lower or higher potential for contamination outside the facility's boundaries.

The technologies chosen will ideally provide safe decontamination of constructions and buildings, dismantling of large-size equipment and demolition of buildings and constructions. The basic indicators of accurateness of technology are protection of neighbouring buildings and facilities against any contamination and anything that interferes with its routine operation.

Technologies for dismantling and demolition are the same as for decommissioning of single facilities. Also, there is no single technique to address all dismantling needs for a decommissioning project. The selection of technologies depends on the following:

- The type of facility (power plant, fuel cycle facility, or research facility);
- The type of isotopes present;
- The activity level of the equipment and parts;
- The physical–chemical properties of the equipment/parts to be dismantled (e.g. concrete versus metal), and of the radioisotopes and contamination layer.

Most technologies can be classified into the following four main groups:

- Mechanical techniques;
- Thermal techniques;

— Electrical techniques;
— Adaptive technologies.

Most of the mechanical techniques are taken from industrial technologies after modification to work with radioactive material such as:

— Hydraulic shears;
— Power nibblers;
— Mechanical saws (various types);
— Milling cutters;
— Orbital cutters;
— Abrasive cutting wheels (disks), blades, wires and core drills.

Most of the thermal techniques are used in industry such as:

— Plasma arc cutting;
— Flame cutting;
— Powder injection flame cutting (‘thermite’);
— Thermic lance.

Similar to these thermal techniques is (high pressure) abrasive water jet cutting.

The following industrial processes, based on electrical techniques, are quite slow:

— Electro-discharge machining (‘sparkling erosion’);
— Metal disintegration machining;
— Consumable electrode cutting (in development);
— Contact arc metal cutting (in development);
— Arc saw cutting.

There are other techniques not so widely used in the industry which can be effective for the dismantling of contaminated parts in the nearest future. These include:

— Laser cutting;
— Liquefied gas cutting;
— Explosive cutting.

One example is the handling and lifting of heavy components from the installation being decommissioned. This is typically done with large cranes, which often have a potential range extending to nearby facilities. Figure 14 shows the removal of steam generators from the Windscale advanced gas cooled reactor (AGR), UK, although this project was not specifically relevant to the safety of nearby facilities.

The following example illustrates how the selection of technologies may depend on the proximity of nuclear or non-nuclear installations. Typically, stacks located near operational facilities are generally not candidates for explosive removal. These stacks will usually be removed from the top down. Conversely, isolated stacks, particularly those that are massive and easily decontaminated, are good candidates for explosive removal [23]. Systems for minimizing flying debris hazards during explosive collapse include vibration limiting structures (e.g. soil and sand heaps or ‘pillows’) and barriers.

FIG. 14. Removal of steam generators from the top of the Windscale AGR, UK (photo courtesy of NDA).

In terms of technology, the benefits of decommissioning at a multifacility site can be viewed in the following terms:

— Factors of scale, and therefore the demand for technology development and development of the associated R&D to meet this need.
— Ability to develop techniques through a trial in one (smaller) facility before deployment in another. This includes feedback and lessons learned. It should be noted that taking advantage of this opportunity requires a focal point where information is maintained and shared with all responsible parties as long as there are active decommissioning projects on-site.
— Demonstration of technology, and therefore safe utilization.
— Ability to transfer learning and technical know-how between facilities (i.e. human factors).
— Economies of scale for waste management and associated technologies. For example, a scrap smelting facility can be the optimal choice if the generation of scrap metals exceed defined volumes: this is more likely to happen during decommissioning of a large multifacility site rather than a smaller, single unit site.

4.5. GROUND CONTAMINATION

Ground contamination is another area where cross-facility impacts are likely to occur at a multifacility site. Surface and underground contamination may extend a significant distance beyond the borders of a single facility or decommissioning project. This requires careful consideration of technical (scope setting) surveys, soil sampling, cleanup, waste management, clearance criteria, and legal aspects (liabilities, stakeholder involvement). In addition, the decommissioning project could be enlarged to a site cleanup project, but to be efficiently managed, these two aspects will ideally be considered in an integrated manner whether or not they are part of a single project. IAEA guidance on this subject includes several publications, e.g. Refs [24, 30], but they are not focused on multifacility sites. As one example of interactions between site facilities, Fig. 15 shows a decommissioning project with a pneumatic line connecting several buildings at the ANL, USA.

The Building 200/205 pneumatic transfer tube was constructed in the late 1960s to transfer irradiated fuel specimens and other samples between Hot Cell M-4 in Building 200 (Fig. 15) and a glove box in Room F-131 in Building 205. The 1850 ft (615 m) tube was in operation until the mid-1970s. The project scope encompassed only the removal of the tube between the two buildings and not the facilities within the buildings. The decommissioning project is described in Ref. [31].

Building 53 at the A.A. Bochvar High Technology Research Institute for Inorganic Materials (VNIINM), Moscow, Russian Federation was used for research on the influence of high gamma radiation exposure of water and organic solutions for spent nuclear fuel reprocessing and for experiments in the radiological durability assessment of material using a ^{60}Co ‘gamma cannon’. While the ground can become contaminated during the operating life of a facility, there are many other ways this can happen during decommissioning (as illustrated in Fig. 16). Typical examples are spillages while emptying process tanks and pipelines when they are taken down; overflows when drains are blocked by debris; leaks from floors, bunds and drains which have been damaged in the course of decommissioning. The ethical and legal approach will ideally be to ensure such situations are avoided in the first place rather than ‘defended’ after the event [21] (see Annex II–5).

Access to the ground can be more difficult at a multifacility site, and consideration of the timing of expansion of individual decommissioning projects from one area to the next and ground remediation will ideally be carefully considered as part of the overall site decommissioning strategy.

4.6. SITE CLEANUP

The objective of decommissioning is to lower levels of residual radioactivity to the extent that the sites may be used for any purpose, without restriction. In some cases, however, this may not be practical and restrictions may be placed on future land use.

FIG. 15. Building 200/205 pneumatic transfer tube (photo courtesy of ANL).

FIG. 16. Opening and removal of contaminated ventilation system in Building 53, Moscow, Russian Federation (photo courtesy of VNIINM)

There are many cases where the site will no longer be used for nuclear purposes. This means that the old buildings, auxiliary systems and structures have to be totally dismantled and demolished, and the site remediated. Following decommissioning, for example, some sites may be reused for non-nuclear industrial activities, but not for habitation. Release from regulatory control can use two approaches based on radiological and non-radiological conditions: unrestricted and restricted.

Technologies for site cleanup are very different and their choice depends on the type of contamination, the site end state, budget and national legislation. Many technologies are available:

(1) Surface caps used for covering contaminated surfaces with protective material. There are three reasons for this kind of protection:
  - Protection from irradiation through to the new material level;
  - Prevention of distribution of radioactive substances from the surface with natural erosion processes;
  - Prevention of migration processes with atmospheric precipitation and water infiltration.

Capping is part of final closure activities intended to isolate residual activity in material for long term storage under institutional control. Caps can be:

- Multi-layered;
- Soil/clay caps;
- Asphalt and concrete caps;
- Synthetic membranes;

— Surface sealants/stabilizers.

(2) Cutoff walls are vertical subsurface impermeable barriers which redirect groundwater flow. There are two reasons for the construction of cutoff walls: prevent the distribution of contaminated groundwater from the site and isolation of the site ground from penetration by pure water which can dissolve or leach radionuclides in mobile form. Cutoff walls can be:
   - Bentonite slurry walls;
   - Cement based grout curtains;
   - Sheet piling walls;
   - Polymer based grout walls;
   - Soil freezing;
   - Synthetic membranes.

(3) Bottom barriers are horizontal subsurface barriers. Their task is prevention of vertical migration with impermeable material below the contaminated material layer.

(4) Stabilization technologies reduce the mobility of radionuclides in the ground with natural water streams (both atmospheric precipitation and groundwater). They can be divided into two groups: in situ encapsulation and compaction.

(5) In situ encapsulation technologies are designed to immobilize radionuclides through the injection of grout or polymers. These technologies are ready for industrial applications.

(6) In situ (or dynamic) compaction increases the density and impermeability of contaminated media to prevention of migration processes in ground. These technologies are available for different types of materials and contaminations.

(7) Physical and/or chemical treatments are more cost effective than immobilization processes, the main goal being to remove contaminated objects from the ground and segregating them until clean, with radioactive waste prepared for further treatment and disposal. In comparison with in situ compaction, physical and chemical treatments are more sensitive to soil composition and chemical properties of radioactive material. These methods are applicable for treatment of soils, sludges, sediments and groundwater:
   - In situ soil flushing is the extraction of radionuclides from the soil with aqueous or organic solutions;
   - In situ leaching of soil is a natural leaching process in the underground layer of soil with intensive irrigation of the soil with water or aqueous solutions of chemical reagents;
   - Electrokinetic remediation uses low level direct current between electrodes placed in the ground in an open flow arrangement;
   - Chemical oxidation/reduction involves injecting chemical reducing agents into contaminated soil for transformation of mobile forms of radionuclides to less soluble forms, which are more stable and prevent migration.

(8) Thermal treatment processes use different temperatures, from low to very high depending on the characteristics of the ground, its moisture level, organic content and chemical properties of radioactive contamination. The in situ vitrification process uses extremely high temperatures (approximately 1600–2000°C), destroying the organic material in the ground and immobilizing radioactive contaminants in a glass mass. The process normally requires 0.7 to 0.8 kW·h/kg of contaminated ground.

(9) Agricultural methods are used in the beginning, during liquidation work at accidents. These methods are easy in terms of application and relatively cheap, mainly because agricultural equipment and tractors are easily obtainable. There are two main reasons for the application of agricultural methods: removal of contaminated topsoil and deep plugging in combination with the addition of chemicals or adsorbents to reduce the transfer of residual radionuclides in plants and to reduce the dose rate from the surface.

(10) A relatively new method is phytoremediation, which uses the abilities of specific plants to extract radionuclides in soluble form from contaminated soil. The plants are then cut from the affected area

and treated as radioactively contaminated material. The main problem with the wide application of this method is the relatively low coefficient of transfer of radionuclides to plants.

Ultimately, the main problem in using cleanup technologies is the need to take into account the proximity of other facilities, buildings, communications and auxiliary systems.

4.7. AREA AND COMPONENT REUTILIZATION

The availability of new space that may already be heated and serviced is an advantage for space constrained sites. However, careful planning and review by utility accountants and decommissioning personnel are necessary. Capital expenditures on the shutdown and retirement of an area of the plant can have implications on the decommissioning fund and require regulatory approval since the configuration of both the shutdown and the operating unit will change.

Site management may consider alternatives for the shutdown unit areas. The management may view the shutdown as an opportunity for new areas for the growth of the operating unit (e.g. system modifications, staging areas or storage areas). For example, at the Dresden Generating Station in the USA, the Unit 1 (shutdown) high pressure coolant injection building was reused for the station blackout diesel generators and the support system for the operating units. Reference [32] describes the interactions between the shutdown Dresden 1 reactor and the other two on-site operating reactors (see Fig. 17).

Proper accounting for utilizing the shutdown space includes transfer of the area to the operating unit inventory [33]. As an example, the decommissioning of the Gundremmingen-A nuclear reactor in Germany left the buildings untouched and used as hot workshops in support of the operation of the other two on-site operating units, B and C [34] (Fig. 18).

Other potential savings of resources in the management of a multifacility site come from the reuse of components from the shutdown unit in other similar units on-site. This is the case at the Metsamor NPP in Armenia, where the shutdown unit is being ‘cannibalized’ to provide spare items for the twin operating unit [35] (see Annex II–9 regarding reuse/redevelopment).

Internationally, there are examples where previously operational facilities have been repurposed to become waste stores or key parts of waste routes that support the site’s ongoing operations. Decommissioning

FIG. 17. The Dresden-1 nuclear reactor, Illinois, USA (photo courtesy of Exelon Corporation).

FIG. 18. The Gundremmingen NPP site. The smaller Unit A currently under decommissioning is on the left, next to the two operating units B and C (centre) (photo courtesy of RWE Power AG and PreussenElektra).

of facilities at a multifacility site enhances the reutilization potential of these areas. Making available land or additional serviced internal space can provide useful capacity for ongoing operations or for further decommissioning of other facilities.

In many cases, there is little to gain in purely economic terms (social or cultural factors being excluded) for site reuse, since nuclear and other industrial sites are often remote and the land remains cheap. Cases of increased land profitability can be due to factors such as: expansion of nearby cities; promotion of attractions such as museums, business parks; or making use of existing infrastructure for new installations.

Lessons learned from the decommissioning of the Greifswald NPP in Germany showed that after decontamination, dismantling and retrieval of large size equipment, the turbine halls and NPP site were converted to an industrial park. The location of the NPP close to the sea allowed the construction of a 7 m deep harbour for the transport of ship parts and other large size items. Figures 19 and 20 show the successful conversion of the site from an NPP to a multifacility industrial park with an area of more than 170 ha.

In the UK, while there are sound financial grounds for redeveloping some high land value sites located within commuting distance of London (e.g. Harwell and Winfrith), the majority of nuclear installations are dispersed widely along the coastline [30]. However, existing nuclear sites could offer an opportunity for new builds. About 35 ha of the site were delicensed by the UK Office for Nuclear Regulation and the land declared to be available for any type of reuse because it contained no radiation hazard. Part of this delicensed land will be used by Horizon Nuclear Power — the RWE and E.ON joint venture. The 36 ha remaining under licence contain the site's operational plant, including the two 217 MW(e) Magnox reactors and essential plant infrastructure [36]. Moreover, the NDA, as the owner of decommissioning sites in the UK, has adopted the policy of maximizing the commercial value of those sites — either for nuclear or non-nuclear development — as a means to alleviate the escalating cleanup costs. Valuing nuclear sites for new builds is difficult, but in general the scarcity of supply will increase valuations of existing sites. According to a 2008 study [37], the nuclear development land could be worth between GBP 2 and 6 million per acre (0.4 ha) for a typical 40 acre (16 ha) footprint PWR nuclear power station — about the same cost as prime residential development land in London at the time. It was estimated that total revenue from the land sale was in the range of GBP 80–240 million ($120–360 million) per site.

FIG. 19. The Greifswald NPP in Germany (photo courtesy of EWN Entsorgungswerk für Nuklearanlagen GmbH).

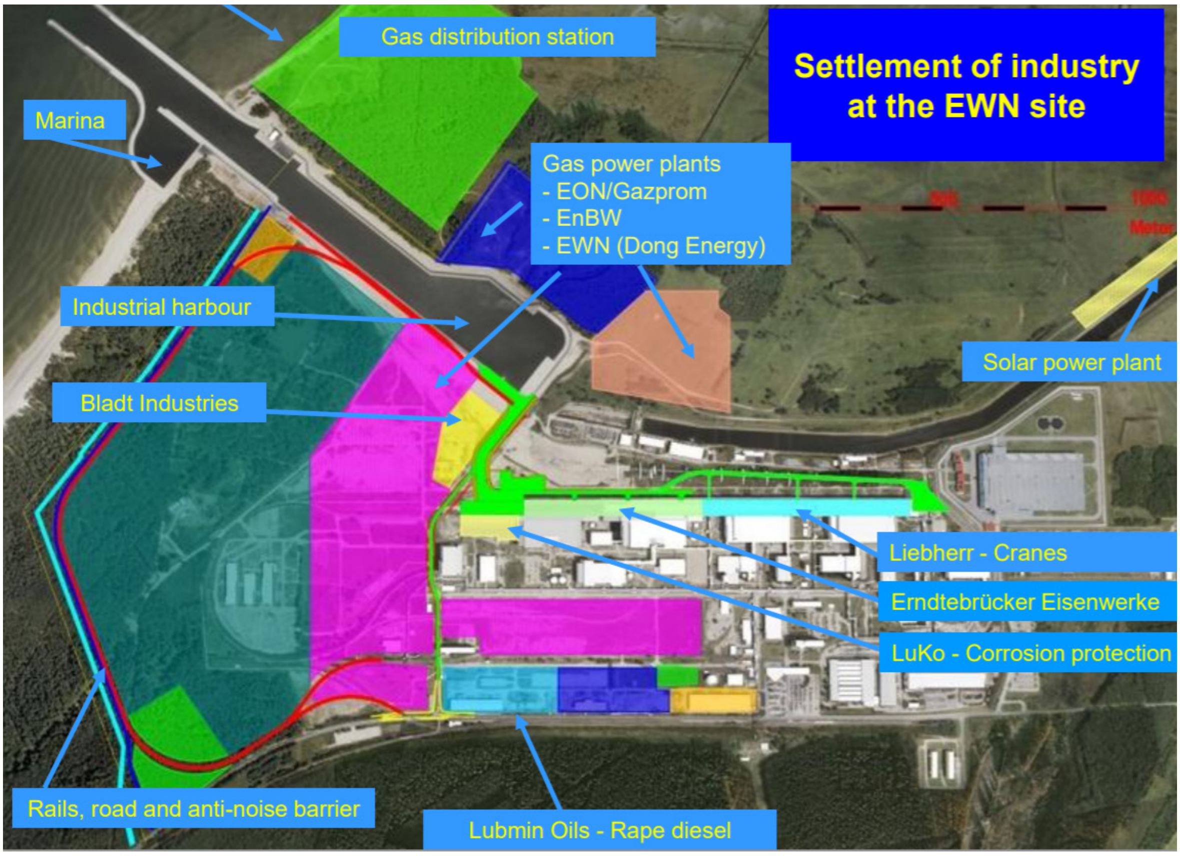

FIG. 20. Location of different industrial companies at the former NPP site and in the former turbine halls of the Greifswald NPP, Germany (photo courtesy of EWN Entsorgungswerk für Nuklearanlagen GmbH).

4.8. COMPLIANCE WITH END STATE REQUIREMENTS

While it is expected that in the long term the entire nuclear site will be eligible for unrestricted release, it is possible that peripheral parts of a site are fully cleaned up and delicensed, while the rest of the site remains under institutional control including the continued operation of existing facilities or even new builds. The safety case — supported by compliance monitoring — has to then prove that recontamination of delicensed areas is unrealistic. The Harwell and Winfrith sites in the UK are typical examples of delicensing projects [38, 39] (Fig. 21).

Site decommissioning and release from regulatory control might be achieved on a zone by zone basis. Any residual radioactive contamination in each zone has to meet the release criteria established by the end-state conditions. The less contaminated zones are typically addressed first, enabling the process to be proved, experience gained and trust within the decommissioning organization and with stakeholders enhanced. The processes associated with site release can be defined in the form of checklists, instruments and procedures.

While demolition removes the majority of hazards from the decommissioning facilities, it is up to later cleanup activities to manage the residual contaminants, including soil, surface and groundwater, and subsurface structures and infrastructure. It is during this phase that assurance will ideally be given that decommissioning activities have not transferred contamination to other site facilities and building, and that no contamination from past operation has remained undiscovered by previous surveys. Restoration is also intended to ensure that the site is left in a physically safe condition, for example pits are backfilled and the surface landscaped.

Some site areas may be too complex to be regarded as a single area for the purposes of characterization and release, either due to contaminants present (e.g. contamination could have been caused by several facilities nearby), or to the scheduling aspects of the decommissioning work. These 'problematic' areas can be divided into subareas as defined by the configuration and layout of different facilities, infrastructure and areas of contaminated ground. Once the area has been divided into subareas, each subarea can be individually characterized for compliance with the site end-state requirements. It is possible that in some cases residual contamination within a subarea exceeds the cleanup criteria, but across the entire zone targeted for clearance the end-state criteria are still achieved on average. The averaging criteria for any residual contamination are important elements to be decided beforehand — and agreed to by the regulators. IAEA guidance on this subject can be found in Refs [19, 40].

FIG. 21. Aerial view of the Harwell campus, UK (photo courtesy of NDA).

4.9. SAFETY ASSESSMENT AND EMERGENCY PREPAREDNESS

In the case of multi-unit NPPs, the emergency responses need to be revised in line with the changes in plant conditions and configurations. The 2011 accident at the Fukushima Daiichi Nuclear Power Plant underlined the importance of initiating a comprehensive range of activities related to the safety assessment. The lessons learned from these accidents demonstrate that safety assessments will ideally take into account multiple hazards and how they may affect multiple units on a site, as well as assess potential common mode failures of protection systems (see Refs [41–48]).

Emergency preparedness can refer to hazards stemming from demolition work or dismantling of heavy equipment, such as health and safety related hazards and fires. However, there could be many other different hazards, depending on whether there are still operating units at the site, whether spent fuel remains on-site, the way it is stored, etc. There is a need to conduct a comprehensive assessment of all the hazards present on-site, identifying consequences of events potentially occurring linked to those hazards, including low probability accidents related to equipment malfunction or human error events, events stemming from external causes (such as earthquakes, floods and others) and events caused by malicious acts, based on the threat assessment that has to be conducted for every nuclear facility [49].

If spent fuel is stored in dry casks (fitted with passive cooling), the most relevant hazards are expected to come from nuclear security related events. If there is an operating power unit at the site, the bounding hazards will likely come from this plant. Thus, in general the provisions of the emergency response plan of this facility will ideally suffice, but with due consideration of the specifics of the unit being decommissioned that might have distinctive hazards (such as different fuel storage system) which will ideally be taken into account in the emergency response procedures.

Various approaches have been taken in performing decommissioning safety assessments, as summarized in Refs [50, 51]. It should be noted that a multifacility site may result in additional hazards, either to the facility being decommissioned (from nearby facilities) or vice versa (see Annex II–13 and Ref. [52]). In this case, a small metal piece discharged by shearing operations during the decommissioning stage might have caused hazards to nearby environments and workers.

For the purposes of this publication, a fire event will be used as an example. The risk of fire in a decommissioning facility can be limited by removing combustible material and ignition sources as far as possible during the transition phase to decommissioning. However, this may not completely rule out the risk of fire, especially with regard to fires originating outside the facility. Therefore, a firefighting plan and equipment need to be in place. It should be noted that the firefighting plan available for the operational phase has to be amended as fire risk, building layout, material conditions, water supply and access routes, etc., may have changed. For example, a fixed fire extinguishing system can be replaced by portable fire extinguishers without considering its extinguishing capability. In some countries, due to the limited fire risk; a fire brigade on-site is no longer required during the safe enclosure phase of decommissioning, while in other countries firefighting requirements may need to be increased due to the lack of the workforce on-site that can respond to any fire. For multifacility NPP sites, the decommissioning facility can benefit from the site fire brigade. The firefighting plans need to be updated to reflect any change in facility risks arising from decommissioning activities, subject to the appropriate approvals [53], and firefighters trained and briefed accordingly. Measures implemented by Atomic Energy of Canada Limited (AECL) to protect a nuclear facility from fire from adjacent facilities are described in Ref. [54].

4.10. ENVIRONMENTAL MONITORING DURING DECOMMISSIONING

It is necessary to monitor the decommissioning process to assess compliance of the safety level of the work with the accepted safety criteria. Prior to identifying the appropriate monitoring regime, the potential operational and accidental impacts will ideally be assessed. The impact of the site's activities (including additional activities undertaken as part of decommissioning) on the public and the environment needs to be monitored in accordance with an approved environmental monitoring programme. Environmental monitoring includes sampling from specific stations and through various media related to identified exposure pathways and analysis of such samples in accredited laboratories. The monitoring stations are required to be equipped with stationary equipment for continuous evaluation of dose rates and specific air activity concentration levels. The results of monitoring are then transmitted for continuous assessment to allow intervention, if appropriate. The samples assessed in the laboratory are taken in accordance with the (evolving) monitoring plan, which is approved by the state regulatory authority [55, 56].

The environmental monitoring programme has to be proportionate to the hazards at the site. In case all site facilities have been permanently shut down and are being progressively decommissioned, these programmes can be gradually reduced from those in place during operation. During the transition to decommissioning, it is advisable to keep some components of the programme in place, such as gamma dose measurements in air and sampling deposition on grass and water. As soon as the decommissioning activities are complete for some facilities on the site, the environmental monitoring programme may be modified, in agreement with the regulatory body. After a trial period, assuming that the decommissioning programme has operated steadily without incident or uncontrolled releases, a further reduction in the environmental monitoring can be considered, especially if all facilities have reached a passive condition (safe enclosure).

In general, off-site environmental surveillance will be typically controlled by requirements associated with still operating facilities. Special attention has to be given to managing areas of land contamination, radioactive and conventional, and the leaching of material into groundwater. It is also possible that uncontrolled leakages occur from contaminated buildings, tanks and pipes (especially underground): these leakages might lead to recontamination of already decontaminated or clean structures. The groundwater will ideally be monitored for an appropriate period, at least until the radioactive inventory has decreased to safe levels. As the amount of easily leachable isotopes is higher initially, more sampling needs to be performed during the early years of the decommissioning programme.

5. ORGANIZATIONAL AND MANAGERIAL ASPECTS

The organizational factors associated with a multifacility site relate to the management of activities carried out on the site. The organizational structure that was originally in place to manage several operating facilities at one site will have to be adapted when one of those facilities reach the decommissioning stage, while preserving the processes, functions and competence needed to undertake remaining operations.

5.1. HUMAN RESOURCES

According to one school of thought, it is essential to allocate separate decommissioning staff for the permanently shutdown unit as soon as possible. This approach is beneficial for three reasons:

(1) It enables the site staff to focus primarily on the remaining operating units;
(2) It provides dedicated resources for safe and timely decommissioning;
(3) It provides assurance that the activities related to the shutdown unit will not impact the operating units.

The decommissioning workforce needs to be treated as a separate group or department on-site and ideally will not include technical personnel who support both the operating units and the decommissioning unit. However, there will be support personnel on-site who will be responsible for both the operating units and the shutdown unit for such functions as nuclear security, warehouse and supply management, and administration (e.g. recordkeeping, catering).

There is another organizational approach that recognizes the importance of merging inputs from the operational part of the site into the decommissioning part and vice versa. During the transitional period, the numbers of staff and the types and levels of competence needed to sustain the organization need to be maintained. These requirements will ideally be determined by an objective analysis of the organization's needs, including both decommissioning and operating facilities. It is therefore essential that the strategies for site management are developed with sufficient clarity to enable the associated human resource strategy and plans to be developed even for long term purposes.

The site management's human resource strategy/plan will ideally include, for example:

- Anticipating and addressing changes in staffing levels (the age profile is critical here as it affects retirements);
- The forecast personnel needs;
- Consideration of inducements to retain key staff;
- Developing inducements to encourage staff to leave voluntarily;
- Ensuring that the staff who leave the nuclear site does not result in a competence shortfall;
- Developing and implementing effective succession planning for key positions (including briefing/debriefing sessions);
- Enabling the organization to obtain and retain the skilled, committed and well motivated workforce it needs;
- Allowing sufficient time for individuals to turn over job responsibilities and allow for continuity in the conduct of duties in advance of planned changes;
- Maintaining enough flexibility or contingency plans in case of unexpected losses of personnel (e.g. due to resignation, sickness or death) [57].

The decommissioning organization may need to have (or have access to) competent staff to cover the following topical areas (not an exhaustive list):

- Fuel handling (unless these activities are carried out before decommissioning begins and operations personnel are in charge);
- Dismantling and demolition, including related waste management;
- Decontamination;
- Handling of large components;
- Robotics and remote handling.

All of the following skills are required at different levels:

- Workers: Dismantling, decontamination, waste packaging and robotics.
- In-the-field technicians: Maintenance, radioprotection, waste characterization, nuclear measurements and robotics.
- Designers, drafters of operating procedures, QA specialists.
- Engineers: Equipment and tool design, technique development, nuclear safety analysis and R&D.
- Operations managers and supervisors.
- Senior project managers: Site managers and project directors.
- Staff responsible for interacting with nuclear and other regulators (licensing and clarification of regulations.
- Public relations specialists responsible for interactions with the general public and other stakeholders.

All personnel in charge of decommissioning require specific training on issues related to the entire site and inter-facility links to ensure safe and effective implementation of a decommissioning project, especially in relation to actual or possible impacts to/from other site facilities. The competent staff need not necessarily be from the original operations organization; however, any newly established decommissioning organization needs to work as a team.

The consequences of this optimized approach are given in the following: When facilities on-site reach a state of safe enclosure, the operations staff members are often redistributed to the facilities that are still in operation. The experience of this staff can be effectively used should any technical problems occur with the safe enclosure. Personnel need to be always available for maintenance and surveillance of the safe enclosure. Alarms from the safe enclosure are never to be ignored or considered less important because of other priorities from the facilities that are in operation.

The same caution has to be exercised with regard to maintenance issues. Although giving priority to maintenance work at the facilities in operation is understandable, care has to be taken that maintenance of the safe enclosure is also regarded as being important, has to be regularly scheduled and carefully performed. Poor maintenance can easily lead to premature degradation, more alarms and, in the longer term, jeopardizing the stability and safe management of the safe enclosure. During the preparation for safe enclosure, a dedicated maintenance crew can be assigned to the enclosure; they could also be responsible for future maintenance work at the safe enclosure. This crew can be composed of workers from the former operational facility.

Training is particularly relevant in this context. The training of staff and contractors has to be able to meet the objectives of the facilities regardless of their status and current/planned activities. As site facilities evolve, from construction to operation and finally decommissioning, and since each facility has different programmes and schedules, training cannot remain static (except basic training, e.g. in radiation protection) and will ideally instead respond to demands. Also, unlike operation, decommissioning is dynamic in nature. Activities will be intrinsically different over time and training will ideally be capable of ensuring the availability of proper skills if and when required. Moreover, training is based on the qualifications of candidate trainees, which will constantly change due to age or voluntary retirements, new staff, contractors, etc. The profile of those available for training may change at any time. Therefore, qualifications and training will ideally be constantly readjusted on an individual basis (see Annexes II–3 and II–14).

5.2. ORGANIZATIONAL STRUCTURES AND SYSTEMS

Installations on interdependent multifacility sites that have been shut down prematurely can cause problems during all facility phases (siting, design, construction, commissioning, operation and decommissioning). The design of the site organizational structure and associated functions need to clearly reflect the intended site management model. Key resources need to be effectively employed so that decommissioning activities are delivered efficiently while operations are ongoing.

The following example shows the establishment of a separate dedicated decommissioning organization. At the Ignalina NPP (INPP) site in Lithuania (Fig. 22), the decision to shut down Unit 1 at the end of 2004 and Unit 2 at the end of 2009 meant that decommissioning could commence in parallel with continued station operation.

This prompted INPP to establish two organizations, one for station operation (Technical Directorate (TD), INPP) and the other (Decommissioning Service (DS), INPP) for managing the decommissioning work. INPP DS initially lacked personnel familiar with the engineering, project management and commercial skills to cost effectively run the decommissioning work. Consequently a PMU was established within INPP-DS at the end of 2001 which was managed by a consortium (the ‘Consultant’) of companies from the UK, Belgium and Sweden. The Consultant’s primary objective was to bring new technical and managerial skills to INPP with a strong emphasis on training and refocusing of the skills of INPP DS staff. As they gradually developed the necessary competences, responsibilities were transferred from the Consultant to them. In 2006, after four years of PMU operation, overall management was finally taken up by the INPP DS organization, with the Consultant implementing only certain tasks within INPP DS.

FIG. 22. The INPP, Lithuania (photo courtesy of INPP).

The approach of coupling a Consultant with INPP DS staff entailed considerable transfer of knowledge, but achieved its goals. Its success was based on good working relations, comprehensive training and development programmes and clear plans to transfer knowledge and responsibilities to INPP DS staff. Another major organizational issue for INPP regarding decommissioning was the relationship between INPP TD and INPP DS. While INPP DS had overall responsibility for decommissioning, most of the resources and knowledge resided with the INPP TD whose primary function was station operation. Conflicting demands on the staff's time, priorities and objectives created many new challenges for the senior management. This situation was resolved by clearly delineating roles and lines of responsibilities and communications between INPP DS and INPP TD and by defining what was required from each side [58]. The transitional aspects of shutdown and decommissioning at INPP are described in Ref. [59].

The Kozloduy Nuclear Power Plant (KNPP) (Fig. 23) is a multifacility Soviet-era design, with four water cooled, water moderated power reactors (WWERs)-440 and two WWER-1000 type units. In 1999, the Bulgarian Government and the European Commission agreed to shut down and decommission Units 1–4 of KNPP. The Kozloduy International Decommissioning Support Fund was established and is administered by the European Bank for Reconstruction and Development. The total decommissioning costs for KNPP Units 1–4 over the period 2003–2030 are estimated at €1.1 billion.

The State Enterprise Radioactive Waste (SERAW) was appointed as the organization responsible for the decommissioning programme and for the construction of the National Disposal Facility. A Decommissioning–Repository PMU (D–R PMU) was established to assist SERAW in the administration and management of the projects described below. The PMU is organizationally a part of SERAW, and the Head of the D–R PMU reports to the Executive Director of SERAW. The composition of PMU varies according to tenders launched every few years (as of May 2018, it is composed of two companies, one from the UK and the other from Spain). A Bulgarian consultancy company provides engineering support to D–R PMU staff through a subcontract. SERAW personnel are integrated with the D–R PMU at various levels of responsibility.

After shutdown and defuelling of Units 1–4, the NPP site was split into two parts — the area of decommissioning of Units 1–4 (the responsible institution is SERAW) and the energy generating site with Units 5 and 6 (the responsible organization is Kozloduy NPP). Both of these organizations are owned by the Bulgarian Government.

KNPP is supervised by the Bulgarian Nuclear Regulatory Agency (BNRA), Ministry of Environment and Waters, Ministry of Health, Ministry of Regional Development and Public Works, State Agency for Metrological and Technical Surveillance and State Agency of National Security. SERAW is responsible for the safe management of radioactive waste in Bulgaria; it is a legal entity under the Act on the Safe Use of Nuclear Energy. The management bodies of SERAW are the Minister of Economy, Energy and Tourism and the Management Board of the State Enterprise Radioactive Waste.

The SERAW is legally represented by the Executive Director. KNPP provided personnel for SERAW and transferred about 400 of its employees to the decommissioning organization in 2013.

Units 1 and 2 were licensed in 2010 for operation as radioactive waste management facilities; Units 3 and 4 had the same licence in 2013. The body responsible for implementation of decommissioning projects is D–R PMU and its activities include:

- Preparation of technical and commercial documents;
  - Tendering and tender evaluation management,
  - Contract and procurement administration,
  - Review and approval of technical documents from contractors.
- Risk management, both at programmatic level and at individual project level;
- Planning and scheduling of activities;
- Relationship with BNRA and other authorities regarding single projects.

FIG. 23. The Kozloduy NPP in Bulgaria, with WWER-440 and WWER-1000 type units before decommissioning (photo courtesy of KNPP).

The projects are executed by contractors/suppliers under SERAW contracts. The D–R PMU manages the decommissioning projects from preparation of tender documentation through project acceptance and completion. It should be noted that for both the Ignalina and Kozloduy projects the active involvement of foreign contractors/consultants and funding bodies, while providing international expertise, caused significant organizational complications, especially during the early phases of the projects.

The following example shows the creation of an integrated decommissioning organization. The Loviisa Nuclear Power Plant (LNPP) is located in the city of Loviisa, about 100 km east of Helsinki, Finland. The site includes two WWER-440 type PWRs (Loviisa 1 and Loviisa 2 (Fig. 24)). The plant is operated by Fortum Power Division, which has about 600 employees on-site. Loviisa 1 and 2 started operation in February 1977 and November 1980, respectively. The current operating licence of the LNPP is valid for 50 years, i.e. until 2027 (Loviisa 1) and 2030 (Loviisa 2).

Upon termination of the operation of Loviisa 2, the change from operating organization to decommissioning organization will follow that of Loviisa 1. The staff of the plant will be included in the decommissioning operations from the shutdown of Loviisa 2. The maximum number of decommissioning staff will be approximately 430 people. Three distinct person-power peaks can be identified in the overall site decommissioning process: (1) At the beginning of the preparatory phase of Loviisa 2; (2) at the launching of the active decommissioning of Loviisa 2; and (3) at the dismantling of the contaminated auxiliary systems after all spent fuel has been taken away from the plant [60].

The management of multifacility sites will ideally plan for and implement facility specific strategies in a coordinated effort to improve the overall outcome of decommissioning. The overall approach will ideally be the establishment of a site wide decommissioning management structure, including organizational arrangements, management systems and technical processes.

Strategic objectives and action plans associated with the organizational design and management systems need to be centred on the following focus areas:

- Site organization, which includes a group with overall responsibility for decommissioning and liability assessment;
- Site wide system for the planning and management of decommissioning throughout the life cycle of facilities;
- Site wide decommissioning project evaluation and approval process;

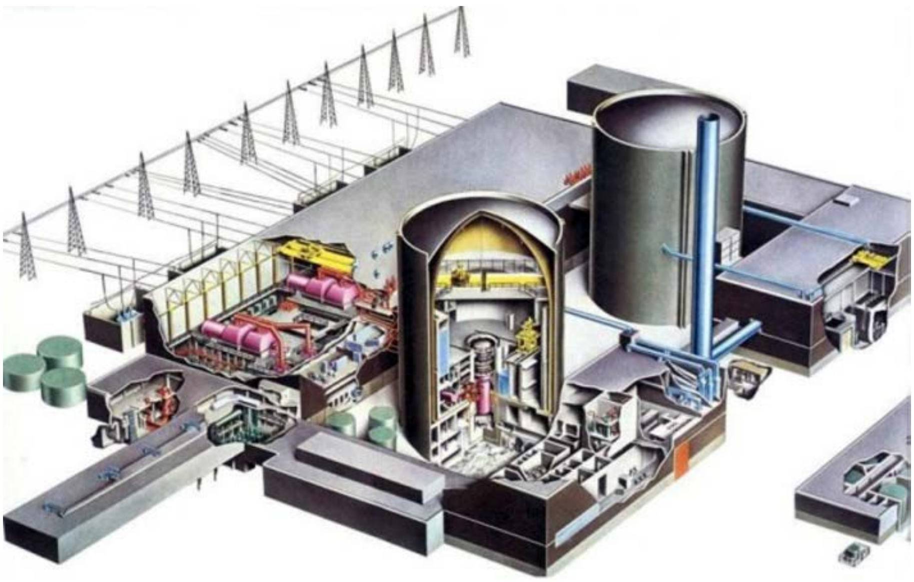

FIG. 24. General view of the LNPP, Finland (photo courtesy of Fortum).

— Interfaces between operating and shutdown facilities.

Note that the main focus areas generally apply also to single facility sites, though special arrangements are necessary to ensure effective management of the decommissioning of multifacility sites.

Another key point to be considered is whether the decommissioning project will mostly utilize in-house expertise or make extensive use of contractors. The choice will depend on multiple factors, ranging from national or corporate finances to local expertise in decommissioning. Socio-political factors can also be involved. Whatever the reasons for the approach selected, the implications for site wide management can be significant. By definition, external contractors are more flexible for decommissioning work and can be released as the work is completed (and perhaps recruited again for the next decommissioning project). This flexibility can help to fill gaps in skills as they occur during the decommissioning process or the transition from operation to decommissioning. The former operational staff will contribute their familiarity with the decommissioning plant (an invaluable asset in decommissioning), but may need more decommissioning related training than do contractors. Plant familiarity can be helpful for twin units which will be decommissioned in sequence. Conversely, contractors will ideally be trained to be familiar with the facility they are helping to dismantle and site issues (ranging from site traffic to the location of shared utilities). It is common experience that some contractors will be of great help even for in-house decommissioning projects.

Observations regarding regulation of two co-located units, where one continues to operate and the other is decommissioned, include the following. First, conducting demolition next to an operating plant creates some difficulties related to: (1) shared systems; (2) specific risks of dismantling activities (e.g. fire hazards); and (3) coordination and management. Dismantling dual units at the same time may be seen as creating fewer problems. Second, to decommission one unit while operating a co-located unit may result in less attention given to the decommissioning unit's activities. The Dresden 1 case discussed in Refs [61, 62] is a relevant example. While Dresden 1 was officially retired in 1984, Dresden 2 and 3 remained in operation (and are still operating today). Even though various decommissioning activities were completed at Dresden 1 from 1978 to 1993, there was a gradual deterioration in systems and structural conditions. In January 1994, a service water system pipe freeze event resulted in some 200 m^3 of water being released into the containment sphere. The NRC inspection team identified a pattern of declining management oversight and focus of the shutdown unit.

Despite potential problems, the existence of a co-located operating unit can be seen as improving the availability of resources and the continuation of safe practices at the decommissioning plant. Other observations about operating one unit co-located with a decommissioning unit are that plants may experience problems due to lack of communication, poor QA at the decommissioning plant, and incomplete audits (which were supposed to cover the entire site but were only made at the operating unit) [63].

5.2.1. Responsibility for decommissioning and execution of the work

Multifacility sites need to be organized and structured with dedicated site wide responsibility for overall site decommissioning. The main function of such a group will ideally be to: establish a site-wide decommissioning policy, strategy and plan; assess and periodically review decommissioning costs; and ensure that decommissioning funds are available or will be available at the appropriate time. The site decommissioning group will ideally also be responsible for the coordination and execution of decommissioning projects on the site with the appropriate inputs and involvement of operators of the facility(ies) to be decommissioned as well as of the operators of other facilities which may be impacted by specific decommissioning tasks (interface management).

The operators (licencees) are responsible for decommissioning planning (with involvement of the site decommissioning group), shut down and execution of at least the initial phases of decommissioning aimed at the removal of the fuel and the bulk of the radiological and other hazardous material inventories (also known as post-operational cleanout). The operators (with the assistance of decommissioning teams that will be appointed in accordance with national regulations) are also responsible for obtaining authorization for shutdown and initial decommissioning activities at their facilities. At a predetermined point the execution of tasks at the facility is transferred, within clearly defined boundaries, to the team responsible for decommissioning, which will generally retain key operations personnel. Legal responsibility stays with the former operator or licencee at all times (unless the licence is transferred to the decommissioning organization, as legally enforced in Spain and as more happened recently in the USA at the Zion and La Crosse NPPs).

A scheme showing how decommissioning activities will ideally be integrated with the life cycle of a nuclear facility is presented below. Note that in the case of multifacility sites each facility or group of facilities will have separate life cycles that are not necessarily aligned and therefore have multiple starting and transition points. Also, it may be possible to have different groups responsible for different facilities (e.g. owners, contractors and waste managers).

Justification for the establishment of an organizational structure that is responsible for decommissioning across a multifacility site can be based on the following factors:

— Consistent interpretation and execution of the site decommissioning plan and ability to coordinate and prioritize decommissioning projects on a site-wide basis.
— Consistent approach in terms of decommissioning project management.
— Consistent methodology in financial assessment.
— Consistent interpretation and application of site wide decommissioning management system requirements and project evaluation and approval processes (separate operators are likely to interpret site wide requirements differently).
— Site wide record of decommissioning liability and management of financial aspects associated with decommissioning, including cash flows for all site facilities.
— Consistent site and material clearance criteria and methodology, e.g. instrumentation, averaging criteria. The site decommissioning group is responsible for establishing and agreeing with the regulator on the clearance criteria for the entire site.
— Consistent management of decommissioning waste, from estimates of amounts generated to disposal provisions (e.g. consistent acceptance criteria and verification methods).
— Consistent involvement in operator's initial plans and management of decommissioning interfaces. This is also likely to produce more consistent and accurate decommissioning liability assessments.
— Consistent application of methodology, e.g. waste and land characterization, technology selection criteria.
— Provision of generic material/waste handling options (some material and waste handling options are only viable if considered in terms of the overall site wide needs, e.g. a centralized size reduction facility or a centralized waste store).
— Site wide implementation of surveillance, maintenance and nuclear security. This is especially relevant for land, systems and utilities shared by different facilities.
— Establishment of site wide measures that alleviate cultural and other problems associated with the transition from operation to decommissioning.
— Operation of site wide facilities that support decommissioning, e.g. decontamination and waste processing facilities.

See Annex II–2 for more on this issue.

5.2.2. Site wide decommissioning management system

A site wide decommissioning management system that is aligned with the licensing process of single facilities will ideally be developed and incorporated into licensing or authorization documents. These documents cover the project management and QA arrangements to ensure that good decommissioning practices are followed for all existing and planned facilities in a given site. Site related objectives, outputs and processes are defined for decommissioning planning and projects which are verifiable at all stages of a single facility's life cycle. It should be noted that in most Member States licences are granted to individual facilities, not to sites: therefore, the licensing process for individual facilities needs to take account of the licences granted to other facilities on-site. The UK is one exception, where licences are granted to the entire nuclear site.

This documented system needs to include the following general arrangements:

- Definition of specific responsibilities regarding the management of decommissioning and related interfaces at a multifacility site, including the roles of the operators of facilities, the decommissioning department and the corporate department (safety, health, environmental and QA (SHEQ)).
- Multifacility site decommissioning organization and assignment of responsibilities where different operators coexist. These arrangements will vary depending on the site specific organization, activities of individual facilities and internal SHEQ functions.
- Decommissioning policy, principles and standards applicable to existing and planned facilities on the site.
- Specific approaches and requirements for management of interfaces that occur during decommissioning of facilities at a multifacility site.
- Decommissioning planning process covering the full life cycle of a facility.
- Decommissioning project management, including project close-out requirements.
- Transition arrangements/requirements, including training/retraining.
- Process for selecting and justification of facility specific decommissioning strategies compatible with the site decommissioning plan.
- Decommissioning arrangements for existing and new facilities as well as for existing non-operational facilities.
- Content of decommissioning plans at the various facility stages.
- Reporting, close-out and delicensing arrangements.
- Arrangements to ensure proper collation and retention of facility specific information and records (facility history) over the life cycle of the facilities.
- Facility specific surveillance and maintenance arrangements.

5.2.3. Site wide planning, evaluation and approval process for decommissioning projects

Decommissioning projects vary in intensity and scope and need to be evaluated on project specific bases to determine the appropriate SHEQ and internal approval requirements. A decommissioning project will ideally be reviewed, after its conceptual design phase, by a corporate specialist function that is independent of the facility's decommissioning team to determine the project specific requirements, including internal and external interfaces/requirements. This project will ideally then be approved by the regulatory body and could form part of a process based licensing system. The internal project approval process will ideally cater to all projects on-site, including decommissioning projects, and will ideally provide for a corporate project evaluation function, e.g. a safety evaluation committee, a financial committee and auditing functions. In the case of multifacility decommissioning projects, the process ensures the following:

- Consistent approval requirements for the projects within a given SHEQ category;
- Consistent application of the requirements of the site-wide decommissioning management system;
- Identification of decommissioning related requirements in all projects including projects to modify existing facilities and projects to establish new facilities.

For the development of the site wide project approval process, the following will ideally be considered:

- Definition of a 'project' and a project screening and categorization scheme to ensure that all relevant projects, including decommissioning projects, are subject to the site wide project approval process.

— Selection of appropriate projects to ensure delivery of the overall decommissioning strategy and plan for the site.
— Certification of suitable qualified and experienced persons to perform project screening and categorization of projects.
— A corporate structure and function to facilitate the project approval process, including a safety evaluation committee.
— A project evaluation process, for example where a project leader presents a planned project to a specialist group at an early stage of development with the objective of determining all SHEQ related requirements applicable to the project, including internal and external approval requirements (the specialist group will preferably be part of a corporate SHEQ support function). The extent of the identified requirements is also essential for project planning and scheduling purposes. The project evaluation process will ideally be documented as a management system. The process will ideally apply to each decommissioning project. Although every decommissioning project is evaluated separately and project specific approval requirements are established and specified, the following are typical approval criteria specified for decommissioning projects at a multifacility site:
  - Description of the decommissioning project structure and organization;
  - Decommissioning project description covering project definition, objectives (decommissioning end points) and plan and details of how this decommissioning project fits into and supports the overall site decommissioning programme;
  - How the project fits into the overall site programme and the potential impact any changes to the project have on any associated projects or activities that were to be undertaken at that time if there is insufficient resource (referred to as a deliverability assessment);
  - Project safety assessment also considering the impact on and of surrounding operating and shutdown facilities;
  - Level of environmental impact assessment that is required for a specific decommissioning project;
  - Project QA plan, including project close-out arrangements;
  - Applicability of non-radiological safety requirements, e.g. construction regulations;
  - Applicable work procedures and instructions also covering interfaces with other facilities and processes;
  - Personnel training and certification requirements commensurate with the complexity of a specific decommissioning project;
  - Project specific decommissioning waste and material management plans covering the applicable interface arrangements for generic waste and material handling;
  - Project specific environmental monitoring plan;
  - Preparation of project specific radiation protection and general safety programmes that include workplace and personnel surveillance plans;
  - External and internal approval requirements;
  - Project specific milestones.

Integration of decommissioning projects and other site activities is not necessarily straightforward. Decommissioning timing is the prime factor that is affected by the presence of multiple facilities on the same site. Some conflicting approaches may arise from a congregation of small facilities on a site, as illustrated by the following example from Cuba [50]. A large hospital presents a combination of: (1) a department of nuclear medicine; (2) tele-therapy services (with high activity sealed sources); (3) brachytherapy services (with different types of radioactive sources); and (4) radioactive waste storage. In the event that one of these facilities is decommissioned, the others will keep on providing medical services. The licencee responsibility for decommissioning activities is not to be diluted, for example the radiation protection officer and the administration of the hospital continue to be in charge for the proper functioning of hospital services while also becoming involved in decommissioning planning and safe implementation.

One typical issue in this case is prioritization of activities. As economic resources are limited, the question arises as to where to spend the available funds. Should they be spent on medical services or the decommissioning of an old (unusable) facility? This factor may lead to unwanted delays in the execution of a facility's decommissioning at a multifacility site [58].

There are well established project risk management methodologies used in many industries which are applicable to decommissioning. For example, there is the IAEA International Project on Decommissioning Risk Management (DRiMa) that was implemented between 2012–2015 [64]. It adapted ordinary project risk management methodologies to the needs of decommissioning. Decommissioning projects generally recognize project risks at two levels:

— *Strategic.* Project risk management at the strategic level focuses on the management of assumptions (uncertainties) and strategic decisions during planning for decommissioning (initial to final decommissioning plan); key assumptions have a fundamental impact on the decommissioning plan, and thus the uncertainties need to be reviewed as development of the plan progresses.
— *Operational.* Project risk management at the operational level focuses on risks to the decommissioning project associated with the project conduct (implementation of the final decommissioning plan).

During implementation of the decommissioning project all risks have to be continuously managed to increase the probability of success in achieving the decommissioning objectives. The tools proposed by the DRiMa methodology are as follows:

— Project risk categories supporting a systematic identification of assumptions/strategic decisions and their related uncertainties:
  - Initial conditions of installations;
  - End-state of installations;
  - Waste and materials management;
  - Organization resources (technical, scientific, human);
  - Finance;
  - Interface with contractors and suppliers;
  - Strategy and technology;
  - Legal and regulatory framework;
  - Safety;
  - Stakeholders.
— Project risk matrix, for risk evaluation.
— Assumption register, used for planning assumptions/strategic decisions.
— Project risk register, used for operational risks.

Project risk management is not mandatory (either by the IAEA Safety Standards or most national regulations), but it is considered as a good practice. When implemented within an organization, it will ideally be part of the integrated management system. Safety, cost, schedule and quality are typically the main factors to be considered when conducting project risk management. In addition, a strong safety culture within an organization is important for successful project risk management.

5.3. REGULATORY APPROACHES

The primary tasks of the decommissioning staff related to safety on a multi-unit operating site are to: (1) monitor and maintain the SSCs and the specified limits and conditions to prevent any events from threatening the safe state of the shutdown unit; (2) ensure the safe implementation of any ongoing activities; and (3) prevent the shutdown unit from having a detrimental effect on the safe and continued operation of the other units at the site.

The management of decommissioning activities, when based on approaches and strategies for single facilities, may be inadequate or inappropriate for multifacility sites. A site that houses several independent or interdependent facilities with separate or combined licences/organizational structures could complicate decommissioning management. A non-prescriptive regulatory framework that leaves ample room for flexibility through interpretation could result in inadequacies and inconsistent decommissioning management. On the other hand, prescriptive approaches to decommissioning are typically formulated for single facilities and may disregard interactions between several facilities on the same site.

In many countries regulators grant decommissioning licences on a facility basis (typically for the facilities that already have an operating licence). Regulators may wish to be informed about the status of facilities nearby and the proposed end state of the site, but they generally do not grant amended licences to other facilities except for those for which an application for decommissioning has been submitted. It should also be recognized that the state of adjacent facilities, the interactions and the site end state may change in several ways: changes can be technically and administratively hard to incorporate into individual licences in a timely manner.

In some instances, facilities at multifacility sites were in operation before legal and regulatory frameworks were fully implemented. Retrospective and fragmented licensing approaches were applied that did not necessarily result in the establishment of consistent and adequate site wide decommissioning management. Typically, licences were granted to individual facilities as they came into operation and interactions between site facilities were sometimes disregarded. Later updating of the regulatory functions, safety and QA standards, and the need to assess decommissioning liability costs, have resulted in a need to reconsider site wide decommissioning management arrangements. Of particular concern is the licensing of new facilities that are meant to support decommissioning. Ideally, these will ideally be co-licensed with decommissioning work to ensure that interactions are taken into account, but the timing may not make that possible. Similarly, licences granted to new builds will ideally include consideration of ongoing or future decommissioning work on-site.

A special problem in regulating decommissioning — especially in multifacility sites — is the simultaneous involvement of different regulatory agencies, e.g. those concerned with radiological, industrial and environmental safety, as well as safeguards, nuclear security and land planning. Their competing and sometimes conflicting demands may complicate the decommissioning at a multifacility site. One discrepancy could derive from the desire of one agency to speed up decommissioning work, whereas another agency might discourage the intensified environmental impact that would result from an accelerated decommissioning strategy.

Another regulatory issue is that typically regulators review decommissioning plans when they are submitted for regulatory approval of decommissioning licences, but they have limited control of the timing of such submissions (as long as safety is not at immediate risk). Thus, it may happen that a facility remains in a ‘limbo’ state for many years without a formal decommissioning licence in force, and this may result in long term implications for the safety of the entire site, including other facilities.

Another difficult factor to regulate is safety culture and improvements or downgrades of the culture. Section 5.9 presents a more detailed discussion of human factors, among which safety culture occupies a key position.

5.4. NUCLEAR SECURITY CONSIDERATIONS

From the nuclear security perspective, the two primary risks associated with the use of nuclear and other radioactive material and associated facilities and activities are those of the unauthorized removal of such material and the sabotage of the material and/or facility resulting in unacceptable radiological consequences. The management of these risks is the primary basis for the nuclear security of nuclear and other radioactive material and associated facilities. This also applies to the shutdown/decommissioning facility at a multifacility site. As recommended in Ref. [65], the risk management approach needs to address the three aspects for characterizing risk: threat, potential consequences and vulnerability.

Further guidance on nuclear security for nuclear material and nuclear facilities is found in IAEA Nuclear Security Series publications [49, 65–67], as well as in other relevant publications in this series.

5.5. SAFETY AND ENVIRONMENTAL IMPACT ASSESSMENT

The basic priority in the decommissioning of nuclear facilities, e.g. power and non-power reactors, while operating other nuclear facilities on-site such as radioactive waste decontamination stations, interim spent fuel storage facilities and radioactive waste repositories, is to carry out all activities, with special emphasis on compliance with nuclear and radiation safety, safety culture, industrial health and safety, fire protection, and protection of the population and the environment. The safety assessment needs to focus on the actual decommissioning activities as well as the impact on other facilities, and vice versa [51].

All activities related to the implementation of safety objectives and principles need to be in accordance with the operational requirements, integrated management system, international guidance, and especially with the country's nuclear legislation.

The environmental impact of decommissioning stems mainly from the range of decommissioning equipment operating in the controlled area, the mode of their operation and the volumes and management of radioactive material generated during decommissioning. To minimize the impact of decommissioning on the environment, a number of technical and environmental measures need to be considered during the planning of decommissioning and need to be implemented later.

The results of safety assessments and environmental impact assessments determine the development of the site’s decommissioning strategy. This is an iterative process associated with the strategy and development of the plan, and the need for associated monitoring and protection arrangements and programmes.

The treatment and conditioning of radioactive waste, decontamination of radioactive material and dismantling give rise to radioactive discharges. Gaseous, aerosol and/or liquid discharges are produced. The extent of these discharges (in terms of timing, volumes and nature) depends on a number of factors, including the selected technology, the part of the facility being decommissioned and the level of remaining contamination. For NPP sites, it is expected that the total annual discharges from decommissioning will be lower than those from power operation, but temporary peaks are possible.

For the residents living in municipalities nearby or in surrounding areas, the radiological risks resulting from the implementation of decommissioning activities are generally negligible. The non-radiological risks can be described as follows. The increased transport of material from the demolition of buildings to the surrounding landfills may increase noise levels and impact the quality of life, especially for the people living near the access roads to the nuclear facility under decommissioning. This disruption (measured in number of trucks passing through residential areas) can be largely reduced by using railways (which is also cheaper, but is not necessarily available at all nuclear sites) to transport large quantities of material. Note that the disturbance and disruption caused by demolition activities occur only in the immediate vicinity of the building under demolition (dust, noise and vibration). More distant areas are not affected by these activities. However, decommissioning at multifacility sites will cause constant inconvenience. It is important to avoid such environmental pollution by fulfilling long term and short term environmental goals and environmental management programmes.

Safety related aspects of interference at multi-unit sites include the following [67]:

— Collapse of structural parts;
— Failure of containers and energized parts of the facility;
— Failure and malfunctions of shared installations;
— Retroactive effects from temporarily existing installations (such as overturning of slewing and construction cranes).

One practical example is cutting activities that could trigger ignition or explosions because ventilation has to be disconnected for the use of other operations planned in the same area/site. To minimize this risk, these situations need to be anticipated and preventive or mitigation measures taken. Rescheduling the activities is one effective measure.

Safety considerations also require keeping some functional subsystems in an operational configuration, for example: utilities networks and safety functions. Parallel activities may then constrain the project schedule [15].

5.6. EMERGENCY PREPAREDNESS

A nuclear facility continues to present a radiation hazard during the decommissioning phases. That is why the basic principle of ensuring safety assurance — defence in depth — will ideally also be applied at this stage. An important measure of safety is the maintenance of emergency preparedness and the accident response regime. However, decommissioning generally presents a significantly lower radiological risk to the public and environment than nuclear operation.

The emergency preparedness and accident response at a nuclear site where decommissioning activities are being performed has to comply with national legislation and regulatory documents. Compliance with IAEA recommendations, for example those given in Ref. [49] is highly desirable. The emergency preparedness and accident response system is an interdependent complex of organizational, technical and legal–regulatory measures implemented by multiple bodies and teams to achieve the desired objectives, specifically prevention or mitigation of radiation effects on people and the environment in the event of an accident or emergency.

The main tasks of the emergency preparedness and response system are:

— Preparedness to eliminate accidents and emergencies at facilities;
— Response to accidents and emergencies at facilities;
— Implementation of measures for the protection of people and the environment.

A general emergency preparedness and accident response plan (the plan) is recommended to be available at each multifacility site. One task of the plan is to ensure the required level of emergency preparedness at the entire site, as well as to reduce a level of radiation effect on personnel, population and the environment in the event of accidents and emergencies at facilities.

The plan needs to be a basic guideline document on ensuring emergency preparedness at a site and to determine a unified approach to the: detection and classification of accidents at any facility situated at the site; protection of personnel; and prevention of accidents to establish responsibility between officials and emergency actions, and define the composition of forces and equipment for these objectives. The plan has to include:

— Emergency preparedness and accident response structure;
— Measures for emergency preparedness maintenance;
— Procedure for classification of accident conditions;
— Procedure for information notification and transfer;
— Basic measures for the protection of personnel and the environment;
— Emergency action plan.

The conditions at a site change continuously during decommissioning work. That is why the plan will ideally be frequently updated and will take into account the real and potential hazards of facilities at the site. The quality and applicability of the plan can be checked during drills that are integrated for the entire site.

The development of a unified plan for the entire site improves the efficiency of emergency preparedness. The advantages include:

— Common protective building;
— Common centre of medical assistance;
— Common firefighting unit;
— Integrated staff for prevention and management of accidents;
— Transport.

A decommissioning state for a single facility often does not imply per se the need for an external emergency plan. But if facilities are still in operation at the nuclear site, off-site emergency provisions are likely to be dictated by the operating facilities, which generally have a potentially greater impact on the environment than shutdown/decommissioning facilities. The level of emergency preparedness can be relaxed during transition to a new level of safety as a result of decommissioning. For example, the complete removal of spent nuclear fuel (SNF) from the site can permit significant downgrading, or even elimination, of the external emergency plan. However, the on-site emergency plan will remain a continuing requirement — and could be even more stringent than during operation — as long as decommissioning work continues. Compliance with the plan's requirements will ideally be obligatory for all personnel of all facilities, as well as for personnel of contracting organizations performing work at on-site facilities.

5.7. INDEPENDENT OWNERS/OPERATORS

It is common for facilities situated on the same site to belong to different owners or be managed by different operators. In such cases, the facility interactions described in previous sections can be even more problematic. For example, reaching an agreement between facilities on staff transfer or reutilization of dormant areas can be harder if the facilities have different interests and report to different owners. It may also happen that the optimal solution chosen by the management of facility A is contrary to the interests of the adjacent facility B. Even the tackling of interfacility safety issues may receive less attention insofar as such issues extend beyond a facility's borders into the realm of other owners/operators. Under such circumstances the coordinating role of the site management organization (including the decommissioning group) will be essential. Moreover, the regulatory body as an independent party will be essential to ensure equitable treatment of safety issues on either side of a facility's borders and generally over the entire site (see Annex I–2 on this issue).

5.8. KNOWLEDGE MANAGEMENT, LEARNING FROM EXPERIENCE AND RECORD KEEPING

The loss of information at any stage of a facility's life, including decommissioning, deprives operators of knowledge that could be important to the safe and cost effective completion of work or which could ease the analysis of problems and identification of suitable options. This can have implications on timely delivery of the work as conservative decision making means that conditions are often assumed to be far worse than they actually are; due to a lack of knowledge there is no way to confirm the true condition.

Knowledge management will ideally aim to ensure that dependency on individual (human) memory (i.e. tacit knowledge) is reduced, thereby protecting the organization against changes of personnel — an inevitable consequence of transitioning from operation to decommissioning. Knowledge management will ideally seek to preserve knowledge about plant design, construction, operation and maintenance so that this information can be transferred to the next generation of plant personnel [57]. In this regard, decommissioning activities at a multifacility site offers the opportunity of transferring information to adjacent facilities which are at an earlier stage in the facility's life cycle, especially when they belong to the same owner/operator. At a multifacility site the loss of knowledge can be more gradual than at a single unit site. Decommissioning a single unit site is more problematic as the storage and retrieval of useful knowledge may be separated by significant gaps in time. In any case the loss of knowledge is inevitable if specific provisions against it are not taken.

The IAEA has provided guidance in two publications on the establishment of decommissioning oriented records and their preservation for long periods of time [68, 69]. As in other IAEA publications on decommissioning, the focus is on single unit projects. In multi-unit projects the records relevant to the facility being decommissioned are selected from a broader database which includes other site facilities and are organized according to specific decommissioning issues. This process can entail challenges in addition to the selection of records from an operational database where the same facility is involved. Moreover, the record keeping functions for the decommissioning facility may have to be clearly separated from those associated with the remaining operational facilities. A multifacility site being gradually decommissioned also offers the opportunity to learn from experience, and the 'new' knowledge generated from decommissioning activities can be shared with others on-site (and off-site).

5.9. HUMAN FACTORS

Over the past 20 years, the nuclear industry has progressively developed and formalized the application of human resources to improve system and human performance in the operation of nuclear facilities. The standards, guidance and work practices established have evolved with respect to design and operation, but much less with respect to decommissioning.

Decommissioning projects are significantly different from the design or operation phases in terms of the outlook required by personnel. Consequently, some adaptation of current human resource practices may be beneficial in applying them to the decommissioning phase. As a facility moves from operation to decommissioning, life changes for the people working in or in association with that facility. The objective of the facility moves from the production of energy or research into safely and efficiently removing a workplace. The importance of human factors will increase as a site transitions into more decommissioning activities, as these include more 'manual' activities than those normally undertaken during the operation phase. The organization undertaking the new tasks will also change. Some of the staff will leave, while others will have new jobs and responsibilities. New staff will also join the organization, some for the duration of the decommissioning project, others for shorter periods or as contractors.

The required cultural change will normally not evolve without some effort in a decommissioning oriented organization. The 'soft' issues — motivational, psychological and personality driven — though contributing to a significant percentage of all incidents and mishaps including delays, need to nevertheless be addressed by the decommissioning community. Understanding these issues help decommissioning projects take a proactive approach, thus improving safety, predictability, efficiency, performance and organizational learning.

Motivational, psychological and personality driven issues include the following:

- *Teamwork.* Teamwork is essential in decommissioning because: (a) the working environment changes frequently and not all members of a team are familiar with the changes; (b) different organizations work together, typically operating staff and contractors; (c) different types of expertise are required concurrently (e.g. waste management and dismantling techniques). Harmonization of team members is therefore crucial to success. All of these aspects are expected to affect the motivation, reactions and, ultimately, the work performance of staff and contactors.
- *Trust.* The new teams, often short lived or ad hoc, cannot always rely on past experience and familiarity with each other's competences, work modes and views. Building trust between team members is essential for safe, timely and cost effective performance.
- *Goal conflicts.* The new targets, which often have strict requirements on economy, efficiency, documentation and flexibility, require people to balance and redress goals — safety goals versus

efficiency goals, workers' goals versus corporate or other stakeholders' goals, etc. It has been reported both in the nuclear and other industries that errors, incidents and accidents are more likely to occur when people or organizations experience goal conflicts. This is particularly relevant to decommissioning, which is dynamic and ever changing in nature as opposed to more static and repetitive operations in earlier plant phases.

— *Decommissioning mindset (change management specific to decommissioning).* Some elements of both change management and knowledge, skills and attitudes will need to be taken into account, including the following:
  - Decommissioning basically involves demolition and generation of waste. This simplification may lead to a perception of low priority and lack of interest, especially in a highly qualified team (e.g. researchers).
  - Decommissioning is often a 'one end' process. 'Working yourself out of a job' is hardly conducive to good motivation and performance.
  - The 'sense of belonging' can create problems in the course of decommissioning. A facility's staff may feel a sense of attachment to 'their' facility and feel less motivated to dismantle it.

It should be noted that all of the factors mentioned above have a special impact on decommissioning at multifacility sites. On the one hand, the presence of multiple facilities on-site will ideally favour the reallocation and rotation of staff to different projects and activities. In this way, typical decommissioning concerns such as working yourself out of a job will ideally be alleviated. However, on the other hand change factors may be exacerbated by the need to reassign staff to poorly known facilities and for the reassigned staff to work with entirely new teams (see Annex II–14 on the advantages of sharing human resources).

Deregulation of electrical utilities is a driving force pushing energy costs lower and plant capacity factors higher. For maintenance and operation personnel this means shorter, smaller scope outages and more on-line maintenance — again, less time and lower priorities for any shutdown unit on-site. Site priorities for the operating unit during outages and during plant operations by all departments will force the shutdown unit's activities to be delayed or cancelled, or may induce a sense of low motivation when work on the shutdown facility is required. In a competitive environment, this 'operational focus' is necessary; however, the site wide culture and professional attitudes will need to understand that there are still requirements and responsibilities for the shutdown unit. Even though there are decommissioning unit staff members, the site staff will have to provide support to the shutdown unit. Attitudes may need to be changed through training sessions, site awareness activities and, most importantly, by visible management support for the shutdown unit. It is important for the decommissioning team not to feel a sense of isolation and marginalization while priority is given to operating facilities. It has been reported [63] that if there is another operating reactor at the site, it increases decommissioning safety because the organizational culture is still strong, and facilities and staff are still available. However, it may decrease safety because attention tends to be focused on the operating unit. It is also important that safety culture acquired by staff at operating facilities be kept when they are transferred to the decommissioning facilities, a frequent case at multifacility sites. The opposite transfer of staff is also possible, and the implications for safety culture could be significant. The physical activities can be monitored, but safety culture is an elusive factor, which may demand more refined investigations.

5.10. ASSET MANAGEMENT INCLUDING POST-DECOMMISSIONING SITE REUSE

Asset management is used to help organizations optimize their plant and equipment operations and protect all types of assets to improve availability and productivity and reduce costs. Asset management provides information that empowers top management to make both tactical and strategic decisions for the utility. A utility will ideally adopt a clear asset management programme to achieve real and lasting improvements with the objective of long term decisions supporting the management of the overall site [57] .

When the plant has been decommissioned, the land and/or buildings will be put to a different use from that of the original plant. Depending on the remaining contamination and other factors, restricted or unrestricted use of the site is possible. The decision on post-decommissioning site reuse results from a cost–benefit or multiattribute utility analysis.

Site reuse implies that new permissions are needed from the regulators (some of them may not have been involved in the previous nuclear operations). It is the responsibility of the new operator or owner to obtain these approvals. It is important to ensure that the presence of the original plant is not tied to permissions to operate other plants on the same or adjacent sites. This could happen if there is a change in control or ownership of the land which the original plant occupied. An example is the removal of part of the safety zone around a highly hazardous plant (e.g. a plutonium plant) if its integrity was guaranteed by the integrity of the original plant. It is essential to investigate local legislation, regulations and the constraints in the land use permissions for the adjacent areas thoroughly, perhaps even for a considerable distance [18].

There may be situations where the facility owner may request that parts of the site be removed from the nuclear licence before decommissioning is complete. The regulator will want assurance that such portions of the site have been thoroughly surveyed, that they meet the site release criteria, that any new activities on the delicensed areas do not adversely affect site work, and, conversely, that ongoing site activities do not recontaminate the delicensed areas. A special case would be where the owner or other organization wishes to use a portion of the site for a new, non-nuclear facility, sometimes called repowering the site (see the Humboldt Bay 3 case in Section 2.4.3). In this case the regulator will want assurance that any new construction will not interfere with decommissioning and that any stored material such as chemicals or fossil fuel storage tanks will not present a hazard to the safe storage of nuclear fuel or material on-site [70].

Careful asset management is an integral part of the overall site management and is expected to assist with the site economics, e.g. the sale or rent of delicensed areas will, at least partly, offset the financial burden of decommissioning. In addition the timely release of land and reusable infrastructure (buildings, electrical grids, etc.) will ideally favour the integration of stakeholders into the decommissioning project. This may include other site owners who may view commercial opportunities to expand their activities with the availability of new land and infrastructure, or external stakeholders (local authorities, site planners, business developers, etc.). The renewed interest of stakeholders due to the acquisition of transferred assets may in turn result in benefits for all site facilities, even beyond the scope of the decommissioning unit. Two IAEA publications deal with the reuse and redevelopment of decommissioned facilities/sites and the non-nuclear industry [27, 71].

5.11. STAKEHOLDER ENGAGEMENT

The engagement of stakeholders in nuclear activities can contribute substantial improvements in safety and can enhance the general acceptability of the decisions made. Multifacility decommissioning sites are challenging examples to be considered, taking into account that dismantling activities will take place in parallel with other operations on-site. These can include parallel decommissioning projects, the ongoing operation of existing nuclear facilities and the preparation of part of the site for construction of new facilities to be commissioned in the future. The successful completion of a project usually depends on how the stakeholders view it.

The involvement of stakeholders is likely to be significantly wider when decommissioning takes place in a multifacility site than in a single facility site. Basically, the stake holders will view the decommissioning project as one activity among many others taking place or planned on-site. For example, stakeholders will view decommissioning of one facility as continued use of the site (e.g. a new, more powerful, facility planned to replace the decommissioned site), change in use of the site (e.g. from nuclear to non-nuclear), or cessation of all site activities. A wide spectrum of opinions will be offered by the stakeholders. Active communication with the stakeholders is necessary: mechanisms may include the establishment of a decommissioning oriented information centre, a hotline, the circulation of public information (periodic bulletins, brochures, TV), and/or the organization of regular events to share information about decommissioning progress.

It also has to be taken into account that multiple facility sites may offer better mid to long term job opportunities than single facility sites. In fact, jobs may be available even beyond the cessation of site operations. This implies a more favourable socioeconomic impact on local communities from facility decommissioning.

Decommissioning at multifacility sites usually implies different deadlines for completing work at various facilities on-site. Thus, while one facility can complete the process of decommissioning and begin the process of redevelopment, at another facility the work has just started. Therefore, old stakeholders (those interested in decommissioning) will be complemented by new stakeholders (those interested in post-decommissioning redevelopment, e.g. planners and investors). In this case, it may be necessary to organize separate discussions with different stakeholders to ensure the achievement of multiple objectives.

5.12. SUPPLY CHAIN ENGAGEMENT AND COMMERCIAL ARRANGEMENTS

Section 5.2 noted the importance of appropriate integration of organizational structures to ensure a coordinated approach across the site, and also recognized the importance of ensuring that drivers and goals for individual facilities are aligned, and constraints appropriately established, to make sure that progress in one area does not negatively impact the other. While these aspects are important at all sites, they are increasingly important at multifacility sites where the range of interfaces is likely to be greater.

At a multifacility site there is potentially a different level of operational focus in different areas, from a highly compliant nuclear safety culture in operating plants to one more focused on industrial safety in decommissioning work. This is related to a range of supporting factors, including the equipment that is required to support the task and the training and competence of the personnel to undertake the work. As the work scope broadens, supply chain main contractors may be directly delivering different activities within the site, with the requirements of the subcontractors becoming increasingly diverse.

As the range of support expands it will become increasingly important to control the procurement of equipment and services from the supply chain, and to ensure that goods procured for one project are not inadvertently utilized by another. Care will ideally be taken to ensure that commercial arrangements are sufficiently clear in this regard, and that procured equipment is appropriately specified, quality controlled and securely managed ahead of use.

Ensuring that individuals are suitably trained and qualified for the task they are undertaking will also become increasingly important. Monitoring systems may be required to ensure that the level of qualification can be quickly established and clear protocols established to define the accountabilities for undertaking and overseeing the delivery of work. At multifacility sites it is important that workers moving from one facility to another are trained for new functions.

6. FINANCIAL ASPECTS

The financial factors associated with a multifacility site relate to the availability (or lack) of the required funding for decommissioning of the site. For example, when active decommissioning is first being implemented at a nuclear facility, the overall site budget will have to make provisions for new expenditures and new cash flows.

For multifacility sites the financial aspects are further challenged by the range of priorities that are required to be undertaken on the site. Whereas this section focuses on decommissioning costing, consideration will ideally also be given to ensuring that appropriate asset care is undertaken to ensure the availability of those services required to maintain facility safety, e.g. the fire protection system, and also to ensure that those functional systems required to support decommissioning operations, e.g. overhead cranes, are appropriately managed. Consideration of integrated planning approaches is further detailed in Section 7.

6.1. COST ESTIMATION

The standardized structure described in Ref. [72], known as the International Structure for Decommissioning Costing (ISDC), is the internationally accepted model recommended by the IAEA and the other two co-sponsoring organizations, the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development and the European Commission. For this model, all costs within the planned scope of a decommissioning project are reflected in the ISDC, which may also be used as a point of departure for cost calculations relating to risks outside the scope of the project. Reference [72] provides general guidance on developing a cost estimate for decommissioning a nuclear facility, including detailed advice on using the standardized cost structure, with the aim of promoting greater harmonization.

It should be noted that ISDC does not provide specific guidance on how to apportion costs in a multifacility site decommissioning programme. The following list includes, but is not limited to, cost items that will need to be distributed among various decommissioning projects or operational activities at a given site:

- Decommissioning of shared systems;
- Installation and operation of supporting facilities whose usefulness extends beyond one decommissioning project;
- R&D (achievements may go far beyond the project at hand);
- Site assets may belong to different projects and activities;
- Stakeholder involvement;
- Nuclear security considerations.

In estimating the near simultaneous decommissioning of co-located reactor units there can be opportunities to achieve economies of scale by sharing costs between units and coordinating the sequence of work activities. For example, it is estimated [73] that during the safe enclosure period the number of staff ranges between 20 and 70, but for a multi-unit power plant site each unit in safe enclosure would require a staff of 20 or fewer by sharing common resources.

There will also be schedule constraints, particularly if there are requirements for specialized equipment and staff, or practical limitations on when final status surveys can take place. A detailed analysis of decommissioning costs for the Indian Point NPP is given in Refs [74, 75]. Of the three reactors at Indian Point, IP-1 has been shut down, while IP-2 and 3 are still in operation. The estimate for IP-3 considered that:

- Savings will be realized in programme management, in particular costs associated with the more senior positions from the sequential decommissioning of two essentially identical reactors. The estimate assumes that IP-2 is the lead unit in decommissioning through the disposition of its reactor vessel and primary system components, at which time IP-3 assumes the lead for its own reactor vessel and primary component removal. Costs for the senior staff positions are only included for the lead unit.

— It is assumed, for the purposes of this cost estimate, that IP-3 will not transfer spent fuel directly from its pool to the ISFSI. As such, the estimate for IP-3 includes the cost to transfer the fuel from the IP-3 pool to the IP-2 pool. The fuel would then be packaged in the IP-2 pool for storage at the ISFSI.
— Decommissioning on a congested site needs to be coordinated. As such, demolition and soil remediation, following the primary decommissioning phase (removal of major source terms and radiological inventory), are conducted as a site wide activity.
— Station costs, such as ISFSI operations, nuclear security, emergency response fees, regulatory agency fees, corporate overhead and insurance, are shared across the units, as appropriate.

It should be also recognized that there are factors that may complicate decommissioning of a single unit in a multi-unit site and increase costs. For example, the site's focus on the operating unit alone does not cause higher costs, but rather the indirect effects of this. Planning, scheduling and carrying out shutdown unit activities may become extremely difficult and inefficient. Limited resources in key site positions (work control and operations department) have a tendency to review the shutdown unit work package and out of service requests after all other site activities have been taken care of regardless of the work priority and previously scheduled dates. This results in low workforce productivity and work scope extensions. Additionally, the shutdown unit workforce becomes a peak period work pool. Costs can significantly increase for jobs that start and stop because the operating unit requires workers for an emerging issue.

Reutilization of the shutdown plant areas, although beneficial to overall site management, has the potential to cause increased decommissioning costs. The use of dormant areas of the shutdown unit for operating unit purposes can result in contaminating previously clean areas or general area services (heating, lighting) being maintained longer than otherwise would have occurred had the area not been reused. Both instances would cause higher decommissioning costs for the shutdown unit, and these will need to be considered against the wider site benefit of not providing new facilities.

6.2. SHORT TERM FUNDING

Most IAEA Member States have established funding mechanisms for the decommissioning of their nuclear facilities. An overview of national legislations in this regard is given in Ref. [76]. However, setting funds aside during a facility's service life is only one part of the problem: releasing the funds at appropriate times during (and to some extent, in preparation for) decommissioning is equally important. National provisions differ widely. For example, greater flexibility in using accumulated funds is expected when the operating organization keeps decommissioning funds under its control than when management of the funds is entrusted to an independent body.

Funding of decommissioning activities at multifacility sites may present some specific issues. For example, if these funds are managed by the operating organization, a 'conflict of interest' may occur between the funding of decommissioning projects and of major refurbishment/upgrading of operating facilities on the same site. An especially controversial issue is the use of decommissioning funds for facilities (e.g. waste stores) that can serve the purposes of both decommissioning and operating facilities on-site, but possibly with different timings and different technical requirements.

Alternative steps can be undertaken instead of the normal planning course and using decommissioning funds. A typical alternative is to bring forward certain decommssioning tasks to the operational phase. A typical task that can be put forward is the disposal of large components (e.g. steam generators) sitting at the plant site instead of waiting for the implementation of the decommissioning strategy. There can be certain advantages in shifting tasks from the decommissioning to the operating phase, including [77]:

— Reduced long term financial liability;
— Reduced on-site health and safety liability;
— Reduced nuclear security provisions;

— Better public perception;
— Assured disposition path for disposal of large components;
— Known life cycle disposition costs;
— Elimination of double handling of certain material and wastes;
— Reduced regulatory uncertainty;
— Reduced plant footprint;
— Partial site delicensing.

Most of the points mentioned above will have specific implications for multifacility sites in that the entire site is affected, not only a single facility under decommissioning. In Ref. [78] the IAEA encourages the early planning and execution of activities — including expenditures — conducive to the timely start and smooth progress of decommissioning.

To speed up decommissioning, advance use can be made of already allocated decommissioning funds. To some extent national legislations allow for this. In the USA, the licencee may use up to 23% of the amount (specified in 10/CFR/50.75) of the decommissioning trust funds for decommissioning activities before submitting a site specific cost estimate. Included in this 23% is an initial 3% that the licencee can use, even before permanent cessation of operation, for planning the decommissioning. The licencee may use the remaining 20% for actual decommissioning or for readying the facility for long term storage before it submits a site specific decommissioning cost estimate [79].

In the context of a multifacility site the opportunity of putting forward certain decommissioning expenses could also serve to ensure a timely start of, and keep momentum of, decommissioning projects that could otherwise be perceived as being of lower priority than other site activities.

6.3. LONG TERM FUNDING

Uncertainties in the long term funding of decommissioning can be due to:

— Regulatory changes;
— Inadequate performance of investments affecting decommissioning funds;
— Deterioration of infrastructure aimed to support decommissioning activities (e.g. cranes, roads, harbours);
— Closure of certain support facilities (e.g. waste disposal sites, scrap smelting factories);
— Loss of competent staff and contractors;
— Changes in government policy.

The impact of these factors on facilities at multi-unit sites can vary. For example, a lack of funds may induce the site licencee to postpone a decommissioning project and divert available funds to more profitable projects elsewhere, or to less expensive decommissioning projects on-site. The resulting delay in decommissioning a given facility, however, may exacerbate certain issues (e.g. deterioration of plant or other infrastructure and the loss of key plant knowledge) and ultimately result in increased costs at a later stage.

Conversely, the occurrence of factors impacting decommissioning priorities at a multifacility site (including lack of funds) may force a revision of the overall site use strategy. For example, instead of dismantling all site facilities and ultimately delicensing the site, new nuclear facilities may be installed next to the shutdown facilities and the site will retain its nuclear status. A key element of the strategic changes mentioned above is the legal possibility for the site owner to use decommissioning funds for other purposes. This can be subject to time or administrative constraints.

6.4. OPTIMIZATION OF SCOPE TO REFLECT FUNDING SHORTFALLS

In the event of a shortage of available funds there are a range of approaches that could be considered to ensure that the best value is derived from the available funds. The following list is identified for consideration and is not deemed to be comprehensive:

- The overall site programme is reviewed and activities prioritized accordingly.
- Redundant facilities have been taken to an appropriate interim state with the continued surveillance costs reduced to reflect the inherent safety risk deriving from the facility, i.e. the ongoing ‘hotel costs’ have been appropriately controlled.
- Reducing the short term decommissioning scope to focus on managing the highest hazard components, rather than delivering against the full decommissioning plan.
- Generation of waste into more secure interim storage, rather than fully processing the waste.
- Consideration of alternative private financing models to enable progress to be maintained.

Note that the experience worldwide has been that deferring decommissioning activities resulted in significant increases in life cycle costs, and that interim storage options resulted in challenging projects being required to make them safe in the longer term. It is thus important to maintain appropriate oversight of any deferred tasks to ensure that any degradation in safety is recognized and appropriate managerial options identified.

7. INTEGRATED PLANNING AND DECISION MAKING

Given the potentially complex interactions that may arise during the decommissioning of multifacility sites it is important to produce and maintain an integrated site strategy; this has been highlighted in Section 3. It is also important to integrate overall site decision making, prioritization and monitoring to ensure that decisions made in one area do not compromise the capacity to deliver the mission in another, and to ensure that cross-site opportunities for efficient delivery are recognized and implemented. The more complex a site the more important is an integrated approach.

7.1. PRIORITIZATION

There is a range of techniques for prioritizing individual projects. The general approach is to establish a project end point, identify a range of options to achieve the end point and then define a range of weighted criteria to judge the adequacy of each option. A multiattribute decision analysis approach is typically used and the criteria judged either by quantitative or qualitative scoring of each one, or by cross-comparing one against another. This approach can be tailored to encompass a single project as well as a much broader programme of work.

Potential criteria to differentiate between approaches include: (a) health, safety, security, and environment; (b) programmatic and (c) economic. For multi-unit site decommissioning, prioritization requires the sequencing and optimizing of the schedule of projects such that an optimized sequence can be implemented. Some of the benefits of proper prioritization are as follows:

- Identification of gaps in projects, required site capabilities, or funding;
- Identification of the required resources to fully implement the programme (including timely availability of human, scientific and technical resources);
- Forecasts of budgeting, waste forecasting, infrastructure, equipment;

— Optimized schedule to reduce maintenance/monitoring costs.

At the Chalk River Laboratory site in Canada (a large site with dozens of different facilities), 12 parameters were identified and used for the prioritization of decommissioning projects:

(1) Radiological contamination;
(2) Non-radiological contamination;
(3) Proximity to the public;
(4) Proximity to surface water;
(5) Condition;
(6) Technical feasibility;
(7) Experience and knowledge;
(8) Complexity;
(9) Uncertainty;
(10) Conformance;
(11) Rough order of magnitude cost estimate;
(12) Annual maintenance costs.

The scoring scheme included a combination of weighted parameters that allowed additional emphasis to be placed on selected parameters. Parameter weightings were developed with input from stakeholders in alignment workshops [80, 81]. Many different groupings and parameters have been used across the industry and it is recognized that different parameters may have specific relevance depending on the national and regional context.

A similar approach is used at the NDA sites in the UK. Here a 'value framework' approach is applied which utilizes a comprehensive set of factors for consideration during decision making. At the upper tier the main factors are health and safety, security, environment, risk and hazard reduction, socioeconomic impacts, finance and completing the mission. It is not necessary to quantitatively assess all factors for each decision, only selecting those that are considered to be most appropriate and provide the key differences between options.

As the interactions between separate projects increase it is also necessary to examine options and decision making at a high level, where individual projects may overlap. An example is the delivery of integrated capabilities to resolve an overarching topic, such as provision of a waste management capability for a suite of projects or for the site as a whole.

There are also site wide topics that need to be assessed, with a key example being the assessment of the overall site end state. Decision making at this level can be utilized to combine the cost and resources to achieve an overarching goal. This may challenge the assumed end point and could be employed to consider alternative through-life options for the site. Selection of a different site end state option could then drive revised end points for the subsidiary projects.

There are a range of situations where combined decision making may be appropriate. It is recommended that careful consideration be given to determine whether an individual project, cross-project, or site wide optimization approach is applied.

7.2. INTEGRATED OVERSIGHT

Facilities that are spatially constrained, or where individual facilities are dependent on a shared infrastructure, may also require enhanced oversight of the interfaces between individual activities. At the Sellafield site in the UK, a ‘masterplanning’ approach has been introduced [82] which utilizes an approach similar to that used in general municipal planning. This method:

— Develops a spatial map of the overall site using detailed mapping approaches, including geographical information system techniques.
— Breaks the site down into a number of zones where similar activities are being undertaken, or where similar future capabilities to support the overall mission could be constructed.
— Identifies key enterprise features contained within a zone, i.e. those features within the zone that supply a service to other zones, or to the site as a whole.
— Identifies the key demands that a zone may draw from elsewhere, e.g. power supplies.
— Identifies the key activities that will be undertaken within the zone and what materials will be generated by completing the planned activities within the zone.
— Identifies any specific resource requirements that may be required to support the planned activities. This could include additional infrastructure demands, such as laydown areas, interim waste storage areas and specific resource requirements, including human resources and the transport infrastructure to move people and materials into and out of the zone.
— Develops and maps a timeline of all the key activities that will be undertaken within the zone. This enables a time lapse approach to be deployed to visualize how the overall site infrastructure demands change.

Cutting across the features mentioned above is an integrated assessment of existing facility asset conditions, including the opportunities to reuse assets once their existing mission has been completed. Supporting this mapping, enhanced governance approaches have also been introduced. These include enhanced governance on the allocation of land and tiered and integrated decision making.

The master planning approach is a relatively recent innovation, but it is already informing strategic and tactical land management decisions highlighting:

— Lack of early consideration of what infrastructure requirements are required to lay down materials and to house resources to support both decommissioning activities and future new builds.
— Opportunities to integrate infrastructure requirements to support future projects.
— A more focused approach to clearance of land to support future new builds.
— Opportunities to accelerate decommissioning activities in one zone as a means of enabling an enhanced range of new build or decommissioning options to be considered within another zone.
— Options to undertake land preparation activities from a site perspective.
— Opportunities to relocate certain functions to one area of the site to minimize transport within the site and ease the transport of material away from the site.

8. CONCLUSIONS

There are multifacility sites in many Member States, including a wide range of nuclear and/or radiation facilities such as nuclear power and research reactors, front end and back end facilities of the nuclear fuel cycle and smaller installations. These sites are subject to complex interactions which include:

— A number of independent licensed operations;
— Individual facilities at different stages of their operational life cycle, and more facilities being planned or being constructed at the site;
— Site facilities sharing infrastructure;

— Limited financial, human and technical resources to carry out all needed work (operations and decommissioning) in parallel on-site;
— A number of individual operators, or contractors managing different facilities.

These interactions are significant factors which impact decommissioning in addition to the factors observed for a single facility. Site relevant factors may induce cost savings and other favourable impacts, but may also impose additional constraints and complications. An integrated approach to decommissioning combines all aspects that are relevant to facilitate the eventual decommissioning of the entire site. Implementing an integrated approach has specific advantages and is expected to improve the efficiency and predictability of decommissioning outcomes. The following conclusions may be drawn, and guidance provided, from this review.

A key overarching finding is the need to maintain at all times strategic oversight of the site. This needs to be based on a full understanding of site priorities, clear accountability for facility oversight, clearly observed technical and organizational interactions between facilities, and resources available to support any planned work. The individual facility plans will ideally be understood, and modified as appropriate, to reflect the overall site priority.

Detailed consideration of the shared infrastructure between facilities is required, particularly how the demands of the planned work may impact on it, as well as assurance that the infrastructure is maintained for as long as required. A critical point is that the required infrastructure has to be maintained in functional form if decommissioning of one or more facilities is deferred.

Multifacility sites are likely to have facilities in the operational, shutdown, safe enclosure and dismantling phases at the same time. The impacts these facilities and their associated activities could have on each other need to be considered and managed to ensure safe operation, effective and efficient progress of decommissioning projects, and maintenance of a safe enclosure. The impact of new builds, e.g. preventing completion of decommissioning of a facility or requiring changes to its associated licence needs to be considered during the decommissioning planning phase. The results of nuclear security, safety and risk assessments will ideally be used to further develop decommissioning plans that minimize the risks during multifacility decommissioning.

The selection of appropriate decommissioning and demolition techniques and the scheduling of activities will ideally consider the potential impact on other facilities within the site, particularly with respect to noise, dust, contamination and vibration. Additional demands could be made of common site utilities and services during decommissioning of one or more of the facilities at a multifacility site. Other demands could involve waste management due to the appearance of new waste streams or the generation of larger amounts of waste. Waste management planning will ideally take all relevant waste routes and the associated waste acceptance criteria into consideration as part of the site decommissioning strategy.

A site wide decommissioning strategy will ideally define a site end state, or at least a range of viable options, and the path to reach that state. Consistent with IAEA recommendations, the normal end state of a decommissioning project will ideally be the unrestricted release of the facility and its site. However, if the decommissioning facility is co-located with operating facilities, achieving unrestricted release could be problematic or in some cases prohibitively expensive. This is due to the actual or potential contamination resulting from ongoing or past operations or the decommissioning itself. In the case of significant contamination, the best option might be to preserve the entire location as a nuclear site and construct new nuclear facilities on it.

As more than one facility may have to be decommissioned at the same time, simultaneous or sequential decommissioning options will ideally be considered. These decommissioning techniques may have advantages and disadvantages that need to be evaluated with regard to an optimum site wide decommissioning strategy and facility specific decommissioning plans.

Clear separation between systems that support ongoing operations and those which can be decommissioned is required: therefore, accurate configuration control has to be maintained. This planning will ideally also consider the timeliness for removal of inventory from a facility (known in the UK as post-operational cleanout), especially as deferral time scales can be extended through other factors.

Site layout contributes to the complexity of decommissioning of a specific facility. For example, a high density situation will require careful planning to ensure that the facilities are decommissioned in an optimized manner and order.

It will also be necessary to ensure accurate plant knowledge is retained, both from the operational phase and if any clean out operations or plant modifications have been undertaken. This is particularly important where there is a potential that a facility may be retained in a quiescent state for an extended period, and that key operators transfer to other roles.

Stakeholders may have a more general perception of the site that does not necessarily distinguish between operation and decommissioning. As a result, if time schedules for project completion permit, synergies may be obtained by having work on construction projects and operational activities proceed with decommissioning projects in bringing about stakeholder involvement and consultation [18].

The funding status at the time of a facility's final shutdown may have a special impact on multifacility sites. The operating site facilities may have to operate longer than anticipated to provide financial resources for decommissioning. Or else, the decommissioning strategy may result in long periods of safe enclosure for one or more site facilities.

Decommissioning of facilities at a multifacility site may enhance the reutilization potential of areas such as making land or additional serviced internal space available which can provide useful capacity to ongoing operations or to further decommissioning of other facilities. However, such reutilization could entail legal, financial and licensing issues that need to be considered. Another potential saving of resources in multifacility site management is the reuse of components from the shutdown unit in other similar units on-site, or for a treatment or conditioning plant to provide a decommissioning support function if its prime mission has been completed.

Design of the organizational structures and associated functions will ideally reflect an integral site management model. Key resources need to be effectively empowered so that the decommissioning activities are effectively delivered while operations are also ongoing.

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ANNEXES: SUPPLEMENTARY FILES

The supplementary files for this publication can be found on the publication's individual web page at: www.iaea.org/publications.

(1) ANNEX I: NATIONAL PROJECTS
(2) ANNEX II: LESSONS LEARNED

GLOSSARY

Definitions are taken from the IAEA Safety Glossary[1] and other IAEA publications[2, 3].

activation. The process of inducing radioactivity. Most commonly used to refer to the induction of radioactivity in moderators, coolants and structural and shielding materials, caused by irradiation with neutrons.

audit. An audit is used in the sense of a documented activity performed to determine by investigation, examination and evaluation of objective evidence the adequacy of, and adherence to, established procedures, instructions, specifications, codes, standards, administrative or operational programmes and other applicable documents, and the effectiveness of their implementation.

clearance. Removal of radioactive material or radioactive objects within authorized practices from any further regulatory control by the regulatory body.

clearance criteria (or level). A value established by a regulatory body and expressed in terms of activity concentration and/or total activity at or below which a source of radiation may be released from regulatory control.

configuration management. The process of identifying and documenting the characteristics of a facility's structures, systems and components (including computer systems and software), and of ensuring that changes to these characteristics are properly developed, assessed, approved, issued, implemented, verified, recorded and incorporated into the facility documentation.

contamination. Radioactive substances on surfaces, or within solids, liquids or gases, where their presence is unintended or undesirable, or the process giving rise to their presence in such places.

decommissioning. Administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility (except for a repository or for certain nuclear facilities used for the disposal of residues from the mining and processing of radioactive material, which are 'closed' and not 'decommissioned').

Decommissioning typically includes dismantling of the facility (or part thereof), but in the IAEA's usage this need not be the case. A facility could, for example, be decommissioned without dismantling and the existing structures subsequently put to another use (after decontamination).

The use of the term decommissioning implies that no further use of the facility (or part thereof) for its existing purpose is foreseen.

Decommissioning actions are taken at the end of the operating lifetime of a facility to retire it from service with due regard for the health and safety of workers and members of the public and the protection of the environment. Subject to national legal and regulatory requirements, a facility (or its remaining parts) may also be considered decommissioned if it is incorporated into a new or existing facility, or even if the site on which it is located is still under regulatory control or institutional control.

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decommissioning phase. A well defined and discrete set of activities within the decommissioning process.

decommissioning plan. A document containing detailed information on the proposed decommissioning of a facility.

decontamination. The complete or partial removal of contamination by a deliberate physical, chemical or biological process.

deferred dismantling. Sometimes called safe storage, safe store or safe enclosure, this is a strategy in which parts of a facility containing radioactive contaminants are either processed or placed in such a condition that they can be safely stored and maintained until they can subsequently be decontaminated and/or dismantled to levels that permit the facility to be released for unrestricted use or with restrictions imposed by the regulatory body.

design. The process and the result of developing a concept, detailed plans, supporting calculations and specifications for a facility and its parts.

dismantling. The disassembly and removal of any structure, system or component during decommissioning. Dismantling may be performed immediately after permanent retirement of a nuclear facility or it may be deferred.

disposal. Emplacement of waste in an appropriate facility without the intention of retrieval.

effluent. Gaseous or liquid radioactive material which are discharged to the environment.

end state. A predetermined criterion defining the point at which a specific task or process is to be considered completed. Used in relation to decommissioning activities as the final state of decommissioning.

environmental monitoring. The measurement of external dose rates due to sources in the environment or of radionuclide concentrations in environmental media.

integrated approach. A logical and preferably optimized approach for the planning and implementation of a radioactive waste management programme (for the purposes of this publication this coincides with a decommissioning programme) as a whole from waste generation to disposal such that the interactions between the various stages are taken into account so that decisions made at one stage do not foreclose certain alternatives at a subsequent stage.

knowledge management. An integrated, systematic approach to identifying, managing and sharing an organization's knowledge and enabling groups of people to create new knowledge collectively to help in achieving the organization's objectives.

licence. A legal document issued by the regulatory body granting authorization to perform specified activities related to a facility or activity.
The holder of a current licence is called a **licencee**.
The licencee is the person or organization having overall responsibility for a facility or activity (the **responsible legal person**). Also called **operator** in this publication.

maintenance. The organized activity, both administrative and technical, of keeping structures, systems and components in good operating condition, including both preventive and corrective (or repair) aspects.

(nuclear) facility. A facility and its associated land, buildings and equipment in which radioactive material is produced, processed, used, handled, stored, or disposed of on such a scale that consideration of safety is required. In this publication, 'plant' or 'installation' is used interchangeably for 'facility'.

nuclear security. The prevention of, detection of, and response to, criminal or intentional unauthorized acts involving or directed at nuclear material, other radioactive material, associated facilities, or associated activities.[4]

off-site. Outside the site area.

on-site. Within the site area.

operation. All activities performed to achieve the purpose for which an authorized facility was constructed.

operator (operating organization). Any organization or person applying for authorization or authorized and/or responsible for nuclear, radiation, radioactive waste, or transport safety when undertaking activities or in relation to any nuclear facilities or sources of ionizing radiation. This includes private individuals, governmental bodies, consignors or carriers, licensees, hospitals and self-employed persons. Sometimes used to refer to operating personnel. If used in this way, particular care will ideally be taken to ensure that there is no possibility of confusion.
Includes either those who are directly in control of a facility or an activity during use of a source (such as radiographers or carriers) or, in the case of a source not under control (such as a lost or illicitly removed source or a re-entering satellite), those who were responsible for the source before control over it was lost. Synonymous with **operating organization**.

radiological survey. An evaluation of the radiological conditions and potential hazards associated with the production, use, transfer, release, disposal or presence of radioactive material or other sources of radiation.

records. A set of documents, such as instrument charts, certificates, logbooks, computer printouts and magnetic tapes for each nuclear facility, organized in such a way that it provides past and present representations of facility operations and activities, including all phases, from design through closure and decommissioning (if the facility has been decommissioned). Records are an essential part of QA.

redevelopment. Planning, development, replanning, redesign, clearance, reconstruction, or rehabilitation of all or parts of a project area.

regulatory body. An authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby regulating nuclear, radiation, radioactive waste and transport safety.

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[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, IAEA, Vienna (2011).

remediation. Any measures that may be carried out to reduce the radiation exposure from existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans. Complete removal of the contamination is not implied. The more informal term cleanup is also used.

restricted use or release. The use of an area or of materials subject to restrictions imposed for reasons of radiation protection and safety. Restrictions would typically be expressed in the form of prohibition of particular activities (e.g. house building, growing or harvesting particular foods), or prescription of particular procedures (e.g. materials may only be recycled or reused within a facility).

reuse. The use of a facility or site for a purpose other than that for which it was originally intended and/or used, following the termination of its original use; or reuse for the original purpose but under new circumstances.

stakeholder. Interested party; concerned party.

surveillance. Activities performed to ensure that conditions at a nuclear facility remain within the authorized limits.

synergy. Combined, correlated or syzygetic action of a group of units or faculties that exceeds the sum of the individual effects; increased effectiveness, achievement, etc., produced as a result of combined action or cooperation. ‘Syzygy’ means a pair of connected or correlated things, such as safety and security.

transport. The deliberate physical movement of radioactive material from one place to another.

unrestricted use or release. The use of an area or material without any radiologically based restrictions.

waste management, radioactive. All administrative and operational activities involved in the handling, pre-treatment, treatment, conditioning, transport, storage and disposal of radioactive waste.

ABBREVIATIONS

AECL	Atomic Energy of Canada Limited
ANL	Argonne National Laboratory
BJC	Bechtel Jacobs Company
BNRA	Bulgarian Nuclear Regulatory Agency
CEA	French Alternative Energies and Atomic Energy Commission
CP-5	Chicago Pile-Five
D&D	decontamination and decommissioning
DAC	design analysis calculation
DOE	United States Department of Energy
D–R PMU	Decommissioning–Repository PMU
DRiMa	International Project on Decommissioning Risk Management
DS	Decommissioning Service
FCC	fibre–concrete containers
FCM	fuel containing material
HCF	hot cell facility
HP	health physics
IFTF	immobilized fuel test facility
INPP	ignalina nuclear power plant
ISDC	International Structure for Decommissioning Costing
ISFSI	interim spent fuel storage installation
KNPP	Kozloduy Nuclear Power Plant
LNPP	Loviisa Nuclear Power Plant
MSRE	Molten Salt Reactor Experiment
MVCP	Melton Valley Completion Project
NDA	United Kingdom Nuclear Decommissioning Authority
Necsa	South African Nuclear Energy Corporation
NFM	nuclear facility managers
NNSS	Nevada National Security Site
NPP	nuclear power plant
NRC	United States Nuclear Regulatory Commission
NRR	National Radioactive Waste Repository
NSC	new safe confinement
OSY	Old Salvage Yard
PMU	project management unit
PWR	pressurized water reactor
QA	quality assurance
R&D	research and development
RH TRU	remote–handled transuranic
RTR	real time radiography
SAFSTOR	safe enclosure
SAR	safety analysis report
SERAW	State Enterprise Radioactive Waste
SHEQ	safety, health, environmental and quality assurance
SNF	spent nuclear fuel
SSC	structure, system and component
ST	source term
TD	Technical Directorate

TFF	tank farm facility
TRU	transuranic
ÚJD SR	Nuclear Regulatory Authority of the Slovak Republic
URMA	Underground Radiological Material Area
USA	United States of America
VNIINM	A.A. Bochvar High Technology Research Institute for Inorganic Materials
WAC	waste acceptance criteria
WL	Whiteshell Laboratories
WWER	water cooled, water moderated power reactor

CONTRIBUTORS TO DRAFTING AND REVIEW

Kamahori, K.	Kansai Electric Power Company, Japan
Kuchinsky, V.	Chornobyl Nuclear Power Plant, Ukraine
Laraia, M.	Consultant, Italy
Ljubenov, V.	International Atomic Energy Agency
Mason, C.	Sellafield Ltd, United Kingdom
Matthews, E.	Sellafield Ltd, United Kingdom
Michal, V.	International Atomic Energy Agency
Mikheykin, S.	A.A. Bochvar High Technology Scientific Research Institute for Inorganic Materials, Russian Federation
Mlcuch, J.	JAVYS, Slovakia
Nishiyama, M.	Kyushu Electric Power Company, Japan
Stelmakh, D.	Chornobyl Nuclear Power Plant, Ukraine
Visagie, A.	Consultant, South Africa

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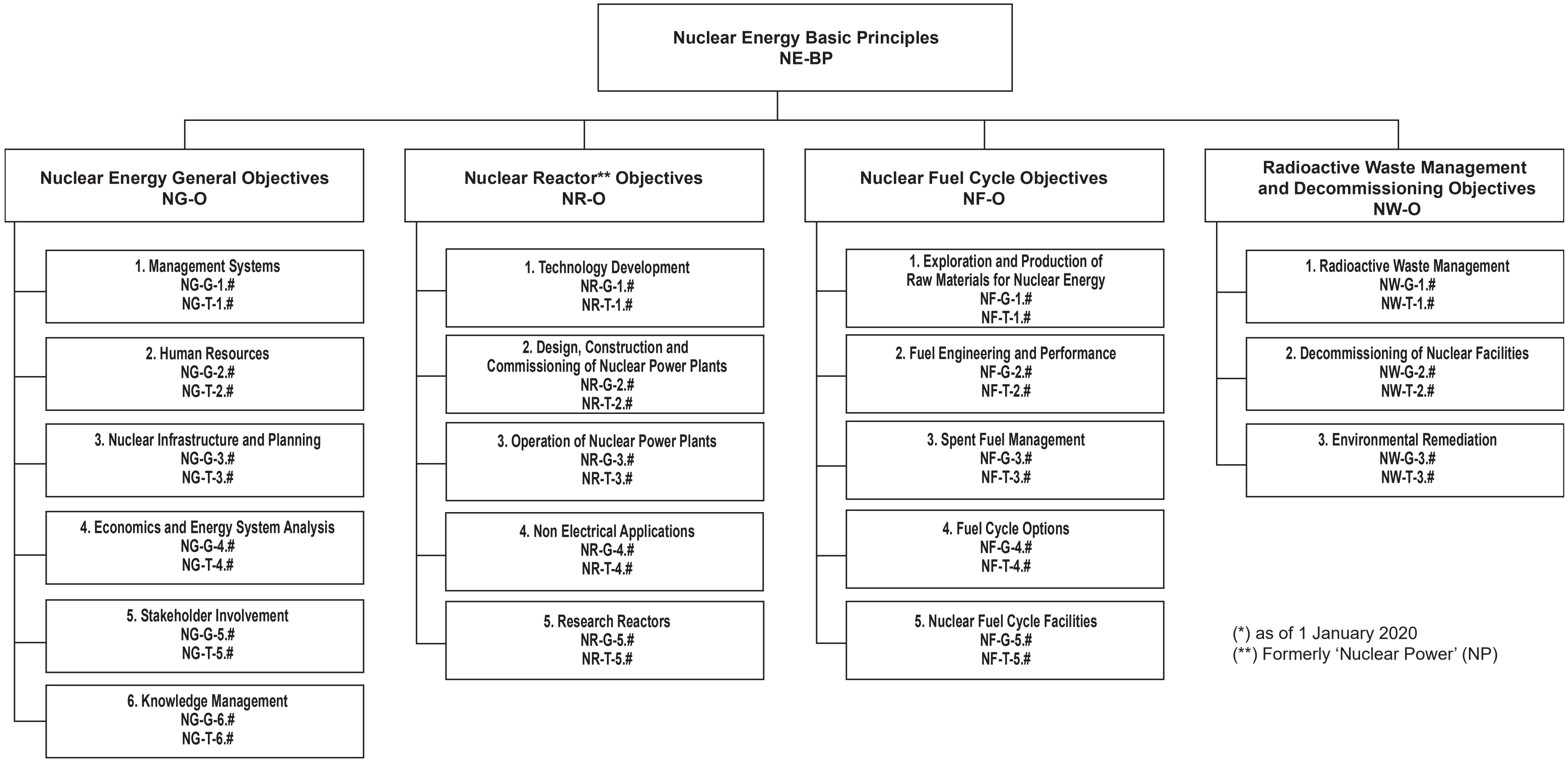

(*) as of 1 January 2020
(**) Formerly 'Nuclear Power' (NP)

Key

BP: Basic Principles
O: Objectives
G: Guides and Methodologies
T: Technical Reports
Nos 1–6: Topic designations
#: Guide or Report number

Examples

NG-G-3.1: Nuclear Energy General (**NG**), Guides and Methodologies (**G**), Nuclear Infrastructure and Planning (topic **3**), **#1**
NR-T-5.4: Nuclear Reactors (**NR**), Technical Report (**T**), Research Reactors (topic **5**), **#4**
NF-T-3.6: Nuclear Fuel (**NF**), Technical Report (**T**), Spent Fuel Management (topic **3**), **#6**
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