Integrated Approach to Decommissioning within a Multi-Facility Site

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FOREWORD

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

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

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

Information and guidance on decommissioning of nuclear facilities, provided in the IAEA publications, is fully applicable to multi-facility sites. However, not too many publications address specifically decommissioning on multi-facility sites, providing detailed consideration of aspects and challenges typical to such situations. Thus, readers might benefit from the additional focused information and guidance provided in this IAEA publication. With the growing experience in the decommissioning of nuclear installations, including the completion of several large-scale decommissioning projects over the last few years, it is timely to review and consolidate the worldwide experience available on the technical and organizational aspects of multi-facility decommissioning in a dedicated publication. This one is therefore intended to broaden the range of IAEA publications in the sector of nuclear decommissioning, which to date counts some 100 technical publications and documents, safety standards, conference proceedings, brochures and others.

Following the preliminary drafting by a consultant from Italy, Michele Laraia, a series of consultants’ meetings, which included the participation of a number of international experts, were held to review, amend and finalize this publication. The IAEA officer responsible for the compilation of this publication was Vladimir Michal of the Division of Nuclear Fuel Cycle and Waste Technology.
1. INTRODUCTION

1.1. BACKGROUND

Multi-facility sites are sites that accommodate independent or interdependent facilities with separate or combined licenses and organizational structures. The need and opportunity of installing several facilities at a given site result from a number of factors. Firstly, ancillary facilities are often needed in support of a major facility on the same site. Additionally, production lines often need several facilities of similar type (e.g. nuclear power reactors) being commissioned in sequence. Multi-facility sites result also from the opportunity of grouping resources (and facilities) in one site in support of national nuclear programmes. Benefits include the factor of scale and the availability of shared services and infrastructure.

Multi-facility sites exist in a number of the Member States, both in developed and developing countries, and can be numbered worldwide by the hundred. Such sites may house a wide range of nuclear and/or radiation facilities such as nuclear reactors, medical, research and industrial facilities, isotope production facilities, fuel cycle facilities, waste processing and storage facilities. Typical examples include nuclear power stations (with five power reactors, see Figure 1, the Bohunice site in Slovakia) and nuclear research centres (with research reactors, hot cells, laboratories, waste treatment and decontamination stations etc., see Figure 2, the Pelindaba site in South Africa, and Figs. 3 and 4, the Dounreay and Sellafield site in the United Kingdom).

Fig. 1. The Bohunice site in Slovakia during V1 and V2 units in operation. It contains three reactors in decommissioning (single unit of A1 and two units of V1) and two reactors in operation (V2) (courtesy of JAVYS, a.s.)
Fig 2. The Pelindaba site, South Africa (courtesy of NECSA)

Fig. 3. The Dounreay site, Scotland, United Kingdom (courtesy of NDA)

Fig. 4. The Sellafield site, United Kingdom, contains around 200 significant nuclear facilities and has the most diverse portfolio of any nuclear site in the world (courtesy of Sellafield Ltd.)
Some sites have many 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 where facilities on such sites are notionally independent they will probably share services and infrastructure such as utilities, nuclear security and/or waste disposal routes.

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 approaching the decommissioning of a multi-facility site, many questions arise such as: Should the entire site be decommissioned at once? Does that make good business sense? Will the site remain profitable if one unit is shut down and a reduced staff is refocussed 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 were 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 of multi-facility sites needs to be implemented. Any decommissioning approach that would focus only on individual facilities is likely to incur logistical and technical mismatches, which may result in delays of planned activities and increased decommissioning costs.

Particularly in case of unplanned end of operation, shutdown facilities may quickly lose priority and focus by the site staff. In this situation, plant modifications may be stopped in mid-stream and existing operational capacities might be still in place while sustainable funding of forthcoming decommissioning activities might not yet be well established. With the site staff focussing on the operating units, structural conditions in 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 are assigned to decommissioning tasks. Design changes may be partially installed 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 multiple facility sites because of factors not necessarily present at a single facility site. Example of these factors include: facilities of similar designs 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 practical guidance available regarding safe, timely and cost-effective implementation of decommissioning at multi-facility sites. In particular, this publication highlights technical, organizational and financial factors that may affect the decommissioning of nuclear facilities when viewed in the context of multi-facility sites. Such factors may induce cost savings, synergies (e.g. factors of scale) and other favourable impacts, but may also induce additional constraints and complications. Interactions between facilities include aspects such as
the 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. The publication is particularly relevant for multi-facility site operators with nuclear facilities approaching the end of their foreseen lifetime. The publication should 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 should facilitate their final decommissioning. This requirement, which is now incorporated in many national legislations, should 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 on multi-facility sites. The scope of the publication includes various nuclear facilities in operation, under construction or in decommissioning at the same time on a given site. Sites addressed include multiple reactor sites, where the reactors are various stages of operation, as well as those sites housing a wide range of facilities, e.g. isotope production facilities, fuel reprocessing facilities, and smaller medical, research and industrial facilities, all located on the same site.

The publication deals with all phases of decommissioning, from the planning stage to periods of safe enclosure, execution of dismantling activities, and site release, and 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 (SSC), the publication recognizes that land, and surface- and ground-water near the buildings are often contaminated and should be paid attention in a multi-facility decommissioning context. However, the publication does not address in details remediation techniques. Uranium mining and milling facilities are not included.

The publication focuses on the potential interactions between the facilities on multi-facility 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 on a site where decommissioning operations are being undertaken;
- Prioritization of activities within a site.

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

The strategic approaches taken by a range of worldwide sites 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 (NPP), 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 in a site. By definition, interaction denotes mutual influence, in this case between a decommissioning facility and other facilities on a multi-facility site. Therefore, interaction is a two-way process. This publication considers both the impacts (actual or potential) from the decommissioning
facility towards facilities nearby and the impacts these facilities may cause to the decommissioning facility.

It should be also noted that a decommissioning project including two or more systems (e.g. a reactor, the spent fuel pool and ancillary facilities) within one facility is not an intrinsic part of this publication, although similarities with the main scope are identified. In fact, this point 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 Glossary) does not specify whether several (smaller) facilities associated with one main facility represent one and the same facility to all intents and purposes. For example, a nuclear reactor has waste treatment systems that are intrinsically linked to the operation of the reactor, are subject to the same license, and basically make up one facility: some, however, may view the waste treatment systems (e.g. a waste cementation plant or a waste store) as facilities independent from the reactor, which are decommissioned at a later stage. While recognizing the ambiguity, this publication assumes that smaller facilities closely associated (e.g. physically, within the same building, or operationally) with a larger facility are part of that facility. By contrast, facilities that are not directly linked (operationally or physically) would generally represent different facilities within a multi-facility site.

Part of the information and guidance imparted by this publication may also be relevant to entire 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 within one site may be readily extended nation-wide to other sites, especially when all the installations in question belong to the same owner or are similar in type. Likewise, the international transfer of decommissioning technologies and information is common practice nowadays. Although some references are given to these approaches (see Annex II-14), the publication does not expand in this direction and remains basically restricted to guidance and events within one site.

1.4. STRUCTURE

This document reviews the various aspects of decommissioning at multi-facility sites. Background material detailing the context of the document is given in the Introduction, together with its Objective and Scope. Section 2 further defines the categories of multi-facility site observed worldwide.

Section 3 then introduces the overarching aspects to be considered when developing an approach to multi-facility decommissioning. Section 4 further addresses specific technical factors impacting the decommissioning strategy, and Section 5 addresses specific organizational factors. Section 6 reviews financial aspects and Section 7 outlines approaches to integrate prioritisation and decision making. Summary conclusions are then provided in Section 8.

Annex I provides examples of the organization of decommissioning, and detailed technical aspects, in both large and small facilities being decommissioned on multi-facility sites within 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. The publication is complemented by a detailed list of references, a Glossary and a list of acronyms.

2. THE GLOBAL PICTURE

Worldwide there are a wide range of multi-facility sites as, in principle, any type of facility can be co-located with any other type at a given location. However, experience shows that in practice three associations are typical and are described in the following:

- 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);
– Minerals processing sites (Section 2.3).

The broad categories are further summarized below.

2.1. MULTI-REACTOR NPP 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 multi-facility sites is relatively uniform and lessons learned from decommissioning at one NPP site can be readily exported 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 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 wastes or doing nuclear research [2]. Some nuclear centres also house chemical plants aimed to support nuclear operation: again, there is a wide range of chemical plants, from fluoride plants (for fuel enrichment) to heavy water plants (for heavy water reactors). Chemical plants present a large variety of hazards from/to nearby nuclear facilities under decommissioning.

The common element here 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 the wide range of facilities the interactions during decommissioning of one or more facilities within the same site can be significantly different.

Some larger sites of this category can also house nuclear power reactors; in this way they overlap with those described in Section 2.1.

A non-exclusive overview of the examples of 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 below.

TABLE 1. EXAMPLES OF MULTI-FACILITY NUCLEAR CENTRES IN SELECTED MEMBER STATES (NOT INCLUDING NPP-ONLY SITES) WITH AT LEAST ONE FACILITY UNDER DECOMMISSIONING

<table>
<thead>
<tr>
<th>Member State</th>
<th>Nuclear centres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>Constituyentes Atomic Centre, Ezeiza Atomic Centre, Several research reactors (RRs) and other small nuclear facilities in preparation for decommissioning</td>
</tr>
<tr>
<td>Australia</td>
<td>Australian Nuclear Science and Technology Organisation (ANSTO) at Lucas Heights, RR Moata dismantled, RR Hifar shutdown for decommissioning</td>
</tr>
<tr>
<td>Austria</td>
<td>Nuclear Laboratories Siebersdorf, RR ASTRA decommissioned</td>
</tr>
<tr>
<td>Belarus</td>
<td>Institute of Power Engineering Problems at Sosny near Minsk, RR IRT-M decommissioned</td>
</tr>
<tr>
<td>Belgium</td>
<td>Belgium Nuclear Research Centre (SCK•CEN), Mol Reactor BR1 under decommissioning</td>
</tr>
<tr>
<td>Brazil</td>
<td>Nuclear and Energy Research Institute (IPEN), Sao Paulo, Dismantling of Uranium Purification Plant</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>Institute for Nuclear Research and Nuclear Energy, Sofia, RR IRT-Sofia under decommissioning</td>
</tr>
<tr>
<td>Canada</td>
<td>Chalk River Labs and Whiteshell Labs, Multiple nuclear facilities decommissioned or under decommissioning including RRs, prototype power facilities, fuel cycle facilities, hot cells etc.</td>
</tr>
<tr>
<td>China</td>
<td>China Institute of Atomic Energy near Beijing</td>
</tr>
<tr>
<td>Country</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>Nuclear Research Institute, UJV Rez Small nuclear facilities under decommissioning</td>
</tr>
<tr>
<td>Denmark</td>
<td>Risoe National Laboratory RRs DR1, DR2 and DR3 decommissioned &amp; hot cells, fuel fabrication plant and other facilities</td>
</tr>
<tr>
<td>France</td>
<td>CEA Cadarache CEA Fontenay-aux-Roses CEA Grenoble CEA Marcoule CEA Saclay Multiple nuclear facilities decommissioned or under decommissioning including RRs, prototype power facilities, fuel cycle facilities, defence facilities, hot cells etc.</td>
</tr>
<tr>
<td>Germany</td>
<td>Jülich Research Centre Karlsruhe Research Centre Research Centre Rossendorf Multiple nuclear facilities decommissioned or under decommissioning including RRs, prototype power facilities, fuel cycle facilities, hot cells etc.</td>
</tr>
<tr>
<td>India</td>
<td>Bhabha Atomic Research Centre (BARC), Mumbai RRs Dratva and Zerlina decommissioned, RRs Apsara and Cirus shutdown for decommissioning &amp; multiple other nuclear facilities</td>
</tr>
<tr>
<td>Iraq</td>
<td>Tuwaitha Nuclear Research Center Multiple nuclear facilities under decommissioning including reactor IRT-5000</td>
</tr>
<tr>
<td>Italy</td>
<td>Casaccia Research Centre Saluggia Research Centre Trisaia Research Centre Ispra Joint Research Centre managed by the European Commission Multiple RRs and other nuclear facilities under decommissioning</td>
</tr>
<tr>
<td>Japan</td>
<td>Japan Atomic Energy Agency (JAEA) in Tokai Research and Development Center Oarai Research and Development Institute, Tsuruga Comprehensive Research and Development Center and Aomori Research and Development Center JPDR and several RRs decommissioned, many other nuclear facilities under decommissioning</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>National Nuclear Centre, Kurchatov, near the Semipalatinsk Testing Site</td>
</tr>
<tr>
<td>Philippines</td>
<td>Philippine Nuclear Research Institute (PNRI), Manila</td>
</tr>
<tr>
<td>Poland</td>
<td>National Centre for Nuclear Research, Otwock-Swierk RR EWA partly decommissioned</td>
</tr>
<tr>
<td>Romania</td>
<td>Horia Hulubei National Institute (IFIN-HH) at Magurele near Bucharest Research Reactor VVR-S under decommissioning</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>Joint Institute for Nuclear Research, Dubna National Research Center “Kurchatov Institute”, Moscow Reprocessing facility Mayak Institute of Physics and Power Engineering, Obninsk Research Institute of Atomic Reactors, Dimitrovgrad Sverdlovsk Branch of the Research and Development Institute of Power Engineering St. Petersburg Institute of Nuclear Physics of the Russian Academy of Sciences etc. About 55 research reactors, critical and sub-critical assemblies were shutdown or are under decommissioning. Multiple other nuclear facilities were decommissioned.</td>
</tr>
<tr>
<td>Serbia</td>
<td>Vinca Institute of Nuclear Sciences Heavy water research reactor “RA” under decommissioning</td>
</tr>
<tr>
<td>South Africa</td>
<td>South African Nuclear Energy Corporation (NECSA), Pelindaba Several research facilities decommissioned, the focus is on Uranium enrichment and fuel cycle facilities</td>
</tr>
<tr>
<td>South Korea</td>
<td>Korea Atomic Energy Research Institute (KAERI), Daejeon RRs KRR-1 and KRR-2 decommissioned</td>
</tr>
<tr>
<td>Spain</td>
<td>Research Centre for Energy, Environment and Technology (CIEMAT), Madrid RR JEN-1 decommissioned and some other small nuclear facilities</td>
</tr>
<tr>
<td>Sweden</td>
<td>Studsvik Nuclear AB, Nyköping</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Paul Scherrer Institute, Villigen</td>
</tr>
</tbody>
</table>
Research facilities under decommissioning

<table>
<thead>
<tr>
<th>United Kingdom</th>
<th>Aldermaston and Burghfield Sites, Dounreay, Harwell, Winfrith, Sellafield, Springfields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiple nuclear facilities decommissioned or under decommissioning including RRs,</td>
</tr>
<tr>
<td></td>
<td>prototype power facilities, fuel cycle facilities, defence facilities, hot cells etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>United States of America</th>
<th>Argonne National Laboratory (east and west sites), Brookhaven National Laboratory,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hanford Reservation, Idaho National Engineering &amp; Environmental Lab, Lawrence</td>
</tr>
<tr>
<td></td>
<td>Livermore National Laboratory, Los Alamos National Laboratory, Nevada Test Site, Oak</td>
</tr>
<tr>
<td></td>
<td>Ridge Reservation, Paducah Gaseous Diffusion Plant, Portsmouth Gaseous Diffusion</td>
</tr>
<tr>
<td></td>
<td>Plant, Sandia National Laboratories, Savannah River, West Valley …</td>
</tr>
<tr>
<td></td>
<td>Multiple nuclear facilities decommissioned or under decommissioning including RRs,</td>
</tr>
<tr>
<td></td>
<td>prototype power facilities, fuel cycle facilities, defence facilities, hot cells etc.</td>
</tr>
</tbody>
</table>

The IAEA worldwide used referenced information source on power reactors and NPP sites is PRIS – Power Reactor Information System (https://pris.iaea.org/pris/).

2.3. MINERALS PROCESSING SITES

Sites where uranium or thorium are mined and processed are often multi-facility sites. The chemical process of the minerals (a.k.a. “milling”) process often takes place at the mining site or close to it to minimize material transport. A site of this kind typically includes several nearby facilities. It should also be noted that some parts of the site are commonly remediated while other parts remain in operation. This publication however does not expand on soil remediation as a component of the interactions between different facilities on the site.

2.4. DECOMMISSIONING ACTIVITIES ON MULTI-FACILITY SITES WORLDWIDE

The global picture on decommissioning approaches is as varied as the range of sites. These include;

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

Each approach has been deployed on a range of sites. A number of examples are drawn from multi-reactor 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 USA that had decommissioning deferred either to prevent disruption of the operation of other plants on the same site and/or take advantage of 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 deferred dismantling – and occupy sites that in all cases contain two other operating nuclear plants). In addition, the deferral process 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 which operated with an authorized maximum steady state power level of 275 MWe until October 31, 1974. On June 19, 1980, the Nuclear Regulatory Commission issued a revocation of the authority to operate the facility. Units 2 and 3 are also pressurized water reactors which each produced in excess of 1,000 MWe. Since 1974, Unit 1 has been maintained in a Safe Enclosure Mode (SAFSTOR in US terminology). The original plan was to maintain Unit 1 in a SAFSTOR condition until it could be safely dismantled along
with Unit 2 at the end of the Unit 2 operating license 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.

![Indian Point site](image)

**Fig. 5. The Indian Point site, USA (courtesy of Entergy Corporation)**

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 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 Vapor 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 that will require periodic monitoring;
- The assessment noted several areas where rainfall/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. A thorough understanding of the basis for, and intended purpose of, these “retirements” had been lost over time. See Annexes II-1, II-4, II-5, II-9, 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 maintained quite a bit of “inherent knowledge”;
- As a result of this condition, the Assessment Team identified the following needs:
  - 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, lockdown contamination, and take measures to prevent reintroduction of water;
- Complete removal of high activity resin and sludge legacy wastes from Unit 1 tanks and dispose of wastes;
- Mitigate degradation to the containment enclosure building shield wall pre-stressing wire strands.

To exemplify immediate dismantling, the following case has been selected [6]:

PREPARED FOR: Nuclear Energy Institute W-T-2.13
The decommissioning of San Onofre NPP offers an example of active dismantling that was started promptly after final shutdown, while two more reactors onsite continued operation. At steady state conditions, Unit 1 produced 436 MWe and both units 2 and 3 produced in excess of 1000 MWe. When Unit 1 of San Onofre Nuclear Generating Station (SONGS) 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 per cent of their decommissioning funds for preliminary planning efforts. These circumstances prompted SONGS operator to pursue earlier decommissioning of SONGS 1. Therefore in 1999 the regulatory bodies granted approval of the decommissioning plan, allowing the start of decommissioning activities. San Onofre 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 San Onofre 2 and 3. SONGS 2 and 3 were permanently shut down in 2013 and the whole site is now subject to decommissioning [6].

Figure 6 clearly shows that San Onofre is a “packed” site. It is closed between the ocean and Interstate 5, a major highway. A cursory look readily discloses that dependencies between the three units are significant and affects decommissioning projects. At San Onofre several systems were shared by both the shutdown and operational units. Those systems included the following:

- The fire water system at SONGS 1, which was tied into and taken credit for in the licensing basis of SONGS 2 and 3;
- The site common radio communication system, which had a series of antenna and associated electronics located in buildings throughout the whole facility, some of which were planned to be demolished;
- The meteorological tower, electricity, and communication lines, which passed through SONGS 1, as did the onsite emergency notification siren system.

![Fig. 6. The San Onofre site, USA (courtesy of Southern California Edison)](image)

Another area of significant interface between the shutdown unit and the operational units was nuclear security. The three units shared a common nuclear security boundary with one protected area. Common entry, exit, and nuclear security forces are shared to accomplish the mission of nuclear security.

Also the process of ensuring that all piping and conduit do not contain electricity or pressurized fluids – called “cold and dark” in US terminology – and necessary for the safety of the workforce during
demolition – could not be practically implemented if the entire facility must remain continually in compliance with general lighting requirements [7].

The interactions between two reactors, one shutdown and the other in operation (but soon to be shutdown for decommissioning), at the Barsebäck site in Sweden can be provided as an example. Analysed and identified has been a 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, QA and other service departments also cover the common needs [8].

A key consideration is to ensure clear segregation between systems within non-operational facilities that support ongoing operations and those which can be decommissioned is required – accurate configuration control must be maintained. Careful planning of initial decommissioning should consider this segregation and long-term management of redundant systems that are no longer needed to support operations and those systems which are needed. This planning should also consider the timeliness for removal of inventory from a facility (also known as Post Operational Clean Out); especially as deferral timescales can be extended through other factors.

On a smaller scale, the issues related to decommissioning a hot cell facility inside a building with operating laboratories are illustrated in [9].

2.4.2. Sequential versus simultaneous approach to decommissioning

A large scale example of several decommissioning projects on the same site is presented in [10]. This paper discusses the Reactor Interim Safe Storage (ISS) 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 – see Figure 7 below. The scope of each ISS 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 enabled increased process efficiencies within the decommissioning project organization as the team looks for better ways to perform the work. However, some disadvantages were identified as illustrated in the following Table 2 (elaborated from Reference [10]).

![Safe Enclosure completed at Hanford F reactor operated from 1945 to 1965 and was placed in interim safe storage in 2003 (courtesy of US DOE Hanford site)](image)

**Table 2. Advantages and Disadvantages Found for Sequential and Simultaneous Decommissioning**
<table>
<thead>
<tr>
<th>Process</th>
<th>Advantages of Sequential</th>
<th>Disadvantages of Sequential</th>
<th>Advantages of Simultaneous</th>
<th>Disadvantages of Simultaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering and planning</td>
<td>Excellent consistency in approach, estimating and scheduling of the project work. Efficiency in staff utilization after a good process is established.</td>
<td>This could be resource limited based on the sustained availability of qualified decommissioning engineers.</td>
<td>Sooner finish to overall site decommissioning</td>
<td>This could be resource limited based on the peak availability of qualified decommissioning engineers. Potential negative Socio-economic impact.</td>
</tr>
<tr>
<td>Regulatory interfaces for project documentation</td>
<td>Issues are resolved once, rather than every few years possibly with a different group of people with a different perspective. Consistency in approach and expectations regarding regulatory interpretation is achieved.</td>
<td>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.</td>
<td>Overall lower need for regulatory interface through time.</td>
<td>High peak demand on regulatory team. Learning more difficult to transfer to other projects.</td>
</tr>
<tr>
<td>Stakeholder interface for project(s)</td>
<td>Issues are resolved once, rather than every few years possibly with a different group of people with a different perspective.</td>
<td>On rare occasions, the massive amount of information overwhelms the public. Changes in public representatives could impact previous issue resolution.</td>
<td>All issues are resolved at the same time to support progress of decommissioning.</td>
<td>Massive amount of information could overwhelm the stakeholders. Justification for simultaneous decommissioning may be more difficult to achieve.</td>
</tr>
<tr>
<td>Staff utilization</td>
<td>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).</td>
<td>When a problem is encountered at one facility, the ripple effect could delay all subsequent facilities without decisive management action.</td>
<td>High demand gives rise to re-utilisation of staff through re-deployment into decommissioning projects.</td>
<td>Short term prospects only. Need to do significant levels of re-training of personnel simultaneously. Learning more difficult to transfer between projects.</td>
</tr>
<tr>
<td>Decommissioning equipment</td>
<td>Individual operator’s technique and expertise increases as they move from facility to facility. Equipment utilization rates increase with proper scheduling.</td>
<td>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.</td>
<td>One-off procurement activity, at a very large scale.</td>
<td>High demand on specialised equipment over a short time period (need to procure more equipment in total compared with sequential).</td>
</tr>
<tr>
<td>Design and construction</td>
<td>Lessons learned regarding subcontracts/subcontractors are immediately applied to the next subcontract.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td>Advantages of Sequential</td>
<td>Disadvantages of Sequential</td>
<td>Advantages of Simultaneous</td>
<td>Disadvantages of Simultaneous</td>
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</tr>
<tr>
<td>Cost</td>
<td>Lower near-term funding requirement. Predictability between different projects.</td>
<td>Longer overall funding requirement</td>
<td>Shorter funding requirement (limited escalation).</td>
<td>Large near-term funding requirement</td>
</tr>
<tr>
<td>Safety</td>
<td>Takes advantage of decay. Provides ability to optimise safety of subsequent project delivery.</td>
<td>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).</td>
<td>Facilities reach safer end-state sooner.</td>
<td>High demand on safety assessment resource. Lower priority projects may not attain suitable emphasis on safety. Learning more difficult to transfer between projects.</td>
</tr>
</tbody>
</table>

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

The practice of building a new nuclear facility (e.g. a nuclear power reactor) on a site where other nuclear facilities are already situated is becoming common, on account of considerable infrastructure (electrical grid, cooling water etc.) and other advantages (skilled labour, support services like catering, worker transportation etc.). It may be beneficial to place the older facilities in a deferred dismantling mode until the construction of the remaining facilities has been completed. The construction at the site needs to ensure the safety and nuclear security of the shutdown facility and vice versa. Impacts from the decommissioning of the shutdown facility need to be considered during the planning and execution of the construction.

Some of the advantages for constructing additional nuclear power plants 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 nuclear power plants; (3) reducing the overall environmental impacts from the construction and maintenance of these plants; and (4) saving time and money in completing licensing proceedings. A licensed site is an invaluable asset at a time where the licensing of new sites is a significant hurdle in many countries. Therefore, the case of a decommissioning project taking place concurrent with and in the vicinity of a construction project may be increasingly likely.

As an example, a number of new builds are underway at old nuclear sites in the UK (Bradwell (Figure 8), Hinkley Point etc). Building new reactors at old sites is a national policy in the Russian Federation with socio-economic factors specified as 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 must be compensated for by the construction of new installations [12].
Another noteworthy case is Humboldt Bay Power Plant (HBPP) in Northern California. Unit 3, one of the first commercial nuclear power reactors in the United States, was shut down in 1976 and placed in SAFSTOR in 1983 and is now under full scale decommissioning. Besides 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 aging fossil plants connected to the Unit 3 reactor building and a new 160 MWe fossil plant that needed to be constructed less than 100 feet (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 gallon (10 600 m³) capacity fuel oil tanks, an Independent Spent Fuel Storage Installation (ISFSI), parking lots, and several support buildings.

The problem is that new construction on NRC licensed facility is typically intended to support existing operations and will not normally “outlive” the NRC license. If structures were to remain after license termination, a Final Status Survey (FSS) would be completed [13, 14]. But in the case at HBPP, a non-NRC licensed facility was being constructed on soil that was impacted by operation of Unit 3 with future sampling of the soil underneath the footings 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 License Termination Plan (LTP);
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, as associated characterisation plan and a programme of detailed characterisations. The approach utilised is further described in Annex II-11.

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 same plant

It should be appreciated that some issues discussed in this publication arise also when decommissioning of SSC is implemented in parallel within the same plant. Therefore, the reader is advised to consult experience and lessons learned from these projects as well.

The difficulty is attached to the interactions that can be generated through a combination of activities. This set of interactions is called “co-activity” introduced in [15].

First, the decommissioning plan can produce interferences between dismantling areas and the other parts of the facility that are still in operation. These interferences can generate conflicts affecting safety. A staggering example is the state of utilities, such as electricity, air or water supply: on one part of the facility the planned dismantling operations can require to discontinue or isolate part of these networks whereas these must remain operational for another part of the system.

Second, the planning can cause overlapping between 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 induced risks are to:

– Generate unexpected bottlenecks with a potential to delay activities and invalidate the general planning;
– Plan at the same location and time for tasks which are technically conflicting, for example because they would induce safety risks;
– Underestimate 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 one by one (i.e. discrete). 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 to a decommissioning project thereby giving predictability of the outcome.

Decommissioning of a multi-facility 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 taken on 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 give some or all of the following specific advantages:

- Improved safety learning and good practice is transferred between projects;
- Improved technology development and deployment between projects;
- Skills and re-organization 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 durations 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 and provision;
- Common safety analysis for active wastes of the same category;
- Supply chain engagement – close working with suppliers gives 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;
- The cost estimates from the site decommissioning studies allow for cost savings through more efficient use of resources than in the project specific studies and provide a firm and realistic basis for the estimation of the likely financial provisions for 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 final end-state of a nuclear site could be taken in a far future, and 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 multi-facility site; these are that are described in the following sections: technical (Section 4); organizational (Section 5); and financial (Section 6). The strategic plan should 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 SITE-WIDE DECOMMISSIONING STRATEGY

The integrated approach to decommissioning within a multi-facility site highlights the need for a strategic document describing the site-wide decommissioning strategy [17]. It is likely that such a document should be at least submitted to the attention of the regulatory body, if not specifically approved (in some countries, decommissioning licenses are granted on a facility-specific basis). First and foremost, this strategic document should 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 should define and justify priorities in decommissioning of individual facilities: This should normally be dictated by such factors as national policies, 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, it is likely that certain waste management facilities will be the last to be decommissioned on a given site).

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

As decommissioning is a multi-disciplinary approach, there are a lot of different factors that influence planning and implementation of a decommissioning project. The case of decommissioning a facility within a multi-facility 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 multi-facility sites.

It is crucial that, as decommissioning plans are being developed for single facilities, a clear link be established with the site decommissioning plan so as to make sure that coordination is maintained. This is certainly a matter of regulatory concern.

One should also 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 the result of optimization.
3.2. IMPLEMENTATION OF AN INTEGRATED APPROACH TO DECOMMISSIONING

The term ‘synergism’ refers to the concept that working together or cooperating in a combined effort by sharing information and resources to accomplish some project tasks that 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 (which should not be taken for granted e.g. in case of different owners running site facilities). The primary objective of decommissioning a nuclear facility is to remove (or re-use) 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 should be harmonized with the construction and operation of adjacent facilities. As a result, the successful design and implementation of decommissioning involves number of common tasks including strategic planning, project management, safety and considerations, materials and waste management, stakeholder involvement, considerations regarding end-state and financial aspects.

Identifying potential synergies in each of these activities (e.g. site infrastructure, workforce and supporting management systems) may make it possible to complete projects in a more cost-effective manner [17].

Strategic planning addresses coordination of multiple activities on decommissioning of facility(ies) 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 should be in place to minimize costs while keeping top-level 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. Many opportunities might be in place for decommissioning cost, schedule, impact and risk reduction 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 provisions 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 facilities nearby. Similar considerations would apply to nuclear security provisions. On-site decommissioning workers and contractors should be under the site management control whether and how occupational exposure has been considered in their planning and implementation by the different contracting companies.

Materials and waste management needs significant attention through careful planning and sequencing of decommissioning activities. Large amounts of materials and varying volumes of waste are typically generated during dismantling of structures, systems, and components that are quite different from the normal operational wastes (that are being produced on the site as well). Most of the waste and material can be segregated into inactive materials 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 generators) would generate radioactive waste of unique nature: different options are available depending on site and national infrastructure. Intact removal of large components or in-situ segmenting are two options that would pose different management challenges in a multi-facility site. For example, the logistics of transporting large containers onsite is a serious issue.

Significant reduction in volumes of contaminated wastes generated 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 optimised site-wide. Re-use 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 onsite to install decontamination and waste treatment systems or new waste stores.

Interactions with management systems for site operational waste are essential considerations for multi-facility sites. For example, waste treatment systems and facilities at a given site should 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 occur.

Spent fuel management is especially critical at multi-facility 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 onsite, 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 co-exist.

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 onsite adds on the complexity of the stakeholder dialogue. An overview of stakeholder involvement in decommissioning is provided in a separate IAEA publication [18].

End-state of the site is one of the key factors determining a site decommissioning strategy plan [19]. It is generally recognized, and consistent with the IAEA recommendations [1], that the normal end-state of a decommissioning project should 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 a level that unrestricted release remains wishful thinking for the foreseeable future: the best option might then be to preserve the whole site as a nuclear site and conduct new nuclear facilities on it. See the Chernobyl case in Annex I for reference.

Similarly, if the areas adjacent to the decommissioning facility are seriously contaminated, decontaining one facility to unrestricted release levels, while surrounding areas are still contaminated (typical of legacy sites), may turn out to be a futile exercise, due to the likely chance of re-contamination of the previously decontaminated area or the impossibility of reuse the small clean “island” for non-nuclear purposes. Under such circumstances, it may be more appropriate to decontaminate the facility being decommissioned only to an acceptably safe state of restricted release and defer full decontamination of the whole site to a time when no more contamination is expected to be generated or resources for a larger scale exercise are available. A site under restricted release conditions can still allow installation of facilities and management of activities compatible with residual radiation levels.

Appropriate levels of decontamination of facilities should be borne in mind within the overall site context when preparing the site decommissioning strategy and plan. It is also possible that peripheral parts of a site are cleaned up to unrestricted release levels and de-licensed, while the rest of the site remains under institutional control (including remaining operations). To implement this option, it should be demonstrated that re-contamination of de-licensed areas remains unrealistic.

Decommissioning funding including the way finance are collected varies from country to country. For nuclear power plants, decommissioning funds are built 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 the provisions of 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 for multi-facility sites: 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.

4. TECHNICAL ASPECTS

The technical factors associated with a multi-facility 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 specific facility. For example, a high density of site facilities will require careful planning to ensure that the facilities are decommissioned in an optimised manner and order. The development of the site over time may result in a facility that 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 consequential 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 certainly change – in nature as well 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 could well 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 them should come within the terms of the demolition contract, as should 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, so 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 to site facilities (e.g. fire, crashes), not necessarily limited to the one being decommissioned.

It is also possible that the location of a near 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 materials, 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 generation of radioactive or other noxious effluents, traffic limitations or detours during active demolition, temporary re-assignment of site functions etc. The layout of the facility may change from the initial design right through the subsequent project lifecycle and operational phases. Care must 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, STRUCTURES, SYSTEMS AND COMPONENTS

System dependencies between shared systems at multiple unit sites during decommissioning need to be carefully considered. Mechanical and electrical interfaces to ensure that dismantling of one unit does not impact an adjacent operating unit should be identified. Considering the decommissioning sequence at the time of design, will enable isolations of these facilities to be carried out efficiently and with confidence so that buildings can be isolated in turn without disrupting the performance 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 get a drawing of the area to be decommissioned which also details all the adjacent areas and services such as drainage, electricity, pressurized gases, ventilation; etc. It is always wise to check the accuracy of any architect’s drawings by direct comparison with 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 in that these changes may have altered the connections to other buildings and facilities onsite. 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 materials is in place, a discussion with the regulator might be helpful. The regulator may have knowledge or information in his 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 scoping the boundary of the decommissioning task, especially in regard to adjacent facilities. It is good practice that drains or ventilation systems are inspected to rule out spread of contamination to adjacent facilities.

In general, characterisation of a facility on a multi-facility site should include evaluation of all inter-related facilities so as to provide the maximum possible amount of information to aid the 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, for example, demonstrated on the case of large scale stack demolition using explosives to fell the Marcoule G1 stack, 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 at G1 reactor.

Fig. 9. Stack dismantling at G1 reactor, Marcoule, France (courtesy of CEA Marcoule)
Alternative approaches are also described in [23], e.g. concerning the decision making process followed to dismantle a stack at the Savannah River Site (USA), that had to take account the proximity of other building as well as of other factors.

To cite another example of shared systems, the strategy selected for removal of pipes or underground components [24] is directly linked to the general strategy for decommissioning and in particular to the planned end-state especially to the site release criteria (from institutional control).

There are special cases of process services which can be provided by an offsite organization or even another company on 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 re-negotiating, 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 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: again, whether this is the case, and whether it should continue during and after decommissioning, requires investigation and re-negotiation [21].

See Annexes II-1, II-4, II-9, II-11 for examples relevant to this section.

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 should be in place for the collection, characterization, sorting, conditioning and storage of radioactive waste. The radioactive waste will consist of items such as filters, discarded equipment, concrete debris, steel scrap, and general garbage. Many facilities operated with liquid radioactive waste which can store in tanks up to start decommissioning operations. Many years or even decades of storage of these waste resulted creation of hard solids or wet solids inside tanks which had irregular chemical, physical and radionuclide composition in volume. These wastes need special technologies for recovery and treatment.

All waste streams should be established and described in decommissioning project. This chapter of decommissioning project should include detail information but not only:

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

Regular shipments should ensure transport of radioactive waste to a centralized storage or disposal site in accordance with the Waste Acceptance Criteria as applicable for these facilities.

Waste minimization defines four fundamental principles which should 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 creation of radioactive waste, to optimize recycling and reuse options and to minimize amount of waste that has been created by applying adequate treatment technology (see Figure 10).
A large number of processes are available for reducing the volume and immobilizing the low and intermediate level liquid wastes which will arise 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 full waste management infrastructure. This often implies that the decommissioning of a nuclear facility should 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.

Interferences between decommissioning and management of generated waste should be taken into account in planning and implementation of the site activities. Following factors should be considered [26]:

- Variable rate of waste generation due to the large amounts of decommissioning waste produced only during specific phases of decommissioning opposite to more regular generation during operation;
- Unusual physical-chemical nature of certain types of decommissioning waste [27];
- Need to manage large components during decommissioning requires associated capability within the waste management facilities to handle these;
- Larger amounts of waste eligible for clearance.

Regarding airborne and liquid radioactive emissions, it is important to check that the effluent discharge limits (often relating to the whole site) are not exceeded by the “change-of-use” of the decommissioning mode. This should also consider any other plants on site if these are to continue in existence. 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 illustrative case in question on management of variety of generated decommissioning waste is the Vinca nuclear research centre, Serbia, where IAEA technical assistance project on decommissioning of a research reactor has been in place since the early 2000s. An EC-financed programme was launched a few years later, consisting of the following tasks (some aiming at general upgrading of Serbian infrastructure) in support of reactor decommissioning [28]:

1. Repatriation of the Serbian spent nuclear fuel to the Russian Federation;
2. Equipping of the radioactive waste processing facility at Vinca;
3. Management of sealed radioactive sources of category 3 and 4 at Vinca;
4. Decommissioning of Hangar No. 1 at Vinca (a radioactive waste store) (Figure 11);
5. Radioactivity survey at the Vinca site;
6. Operation of the radioactive waste processing facility at Vinca;
7. Improvement of emergency preparedness at Vinca;
8. Support to the Project Management Unit at Vinca;
9. Regional project on regulatory infrastructure;
10. Decommissioning of the underground radioactive liquid waste tanks at Vinca;
11. Implementation of the recommendations of the radioactivity survey at Vinca;
12. Support to the Serbian nuclear regulatory body for the establishment of registries for radioactive materials and occupational exposures;
13. Decommissioning of the spent fuel storage pond at Vinca.

Arrangements for the management of waste and waste records should be in-place within the decommissioning organization. In a multi-facility site, such arrangements (technical e.g. measurement instruments and procedures, and administrative e.g. categorization) should be compatible with the management of waste arising from other site facilities. International guidance on waste characterization is given in [29]. Waste may or may not be stored within the decommissioning facility or elsewhere onsite during the various phases of decommissioning depending on factors such as availability, adequacy and capacity of onsite stores or offsite disposal facilities, long term waste projections or the regulatory body’s position. Where waste is stored it should be fully recorded and safely managed. If onsite waste storage is not allowable, arrangements should prevent undue accumulation of waste and waste routes should be established. Buffer stores should 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 hazardous. Normally all buildings and constructions should be decontaminated before demolishing. But practice demonstrated clearly that even residual activity after decontamination can create radioactive dust which is main danger for decommissioning personnel and for environment. Selection of appropriate
decommissioning and demolition techniques and the scheduling of activities should consider the potential impact from 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 nuisances are minimized. A typical way for reducing dust during building demolition is by using fine-mist sprays (Figures 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's a very large amount of dust.

Fig. 12. Fine mist sprays during demolition

Fig. 13. Water cannon used for fine-mist spraying
4.4. DECOMMISSIONING TECHNOLOGIES DEVELOPMENT AND DEPLOYMENT

It is expected that 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 (unlikely) conditions, technologies have a lower or higher potential for contamination outside the facility’s boundaries.

Technologies chosen should provide safe decontamination of constructions and buildings, dismantling of large-size equipment and demolishing of buildings and constructions. The basic indicators of accurateness of technology are protection of neighboring buildings and facilities against any contaminations and against any troublesome for its routine operation.

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

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

Most technologies can be classified into 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 materials:

- 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 also industrial used ones:

- Plasma arc cutting;
- Flame cutting;
- Powder injection flame cutting ("thermite");
- Thermic lance;
- Powerful and fast, but spreads contamination;
- Similar to those thermal technique is the (high pressure) abrasive water jet cutting.

The industrial processes based on electrical techniques are quite slow. These are as follows:

- Electro discharge machining (sparkling erosion);
- Metal disintegration machining;
- Consumable electrode cutting (in development);
- Contact arc metal cutting (in development);
- Arc saw cutting.
Some other techniques not so widely and routinely used in the industry for specific purposes, but potentially they can be effective for dismantling of contaminated parts in the nearest future. These can be as follows:

- Laser cutting;
- Liquefied gas cutting;
- Explosive cutting.

One case in question is the handling and lifting of heavy components from the installation being decommissioning. 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 AGR, although it is not implied here that this project was specifically relevant to the safety of nearby facilities.

Fig. 14. Removal of steam generators from the top of the WAGR (courtesy of NDA)
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 must generally 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 limiting impact to minimize flying debris hazards during explosive collapse include vibration limiting structures (e.g. soil and sand heaps or ‘pillows’) and barriers.

As far as technology is concerned, benefits of doing decommissioning in a multi-facility site can be viewed in the following terms:

- Factors of scale and therefore demand for technology development and development of the associated R&D to meet this need;
- Ability to develop techniques through trial on one (smaller) facility before deployment on 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 to 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” on 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 in decommissioning of a large multi-facility site rather than a smaller, single unit site.

4.5. GROUND CONTAMINATION

Ground contamination is another area where cross-facility impacts are likely to happen in a multi-facility 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 (scoping) surveys, soil sampling, clean-up, waste management, clearance criteria, and legal aspects (liabilities, stakeholder involvement). In addition, the decommissioning project could be enlarged to a site clean-up project, but – to be efficiently managed – these two aspects should 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. [24, 30] but is not specifically focused on multi-facility sites. As one example of interactions between site facilities, Figure 15 shows a detail of a decommissioning project regarding a pneumatic line connecting several buildings at Argonne National Laboratory, USA.

![Building 200/205 Pneumatic Transfer Tube](fig15.jpg)

Fig. 15. Building 200/205 Pneumatic Transfer Tube (courtesy of ANL)
The Bldg. 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 Bldg. 200 (this photo) and a glove box in Room F-131, Bldg. 205. The 1850-ft (615 m) tube was in operation until the mid-1970s. 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 [31].

Building 53 of VNIINM used for researches on influence of high gamma-radiation exposure to water and organic solutions for SNF reprocessing and for experiments in radiological durability assessment of materials using Co-60 gamma-cannon.

The ground can become contaminated during the operating life of a facility, but there are also many ways whereby this can happen during decommissioning (as illustrated in Figure 16). Typical examples are spillages when emptying process tanks and pipelines when they are taken down; overflows when drains get blocked by debris; leaks from floors, bunds, and drains, which have been damaged in the course of decommissioning. The ethical and legal approach should be to ensure these are prevented in the first place rather than “defended” after the event [21]. See Annex II-5.

Fig. 16. Opening and removal of contaminated ventilation system, Building 53 (courtesy of VNIINM)

Access to the ground can be more difficult in a multi-facility site, and consideration of the timing of expansion of individual decommissioning projects from one area to the next and ground remediation should be carefully considered as part of the overall site decommissioning strategy.

4.6. SITE CLEAN-UP

The objective of decommissioning is to lower levels of residual radioactivity enough 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.

There are many cases where the site will not be used anymore for nuclear purposes. It means that the old buildings, auxiliary systems and constructions should be totally dismantled, demolished and the site should be 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 concern: Unrestricted and Restricted.

Technologies for site clean-up are very different and its choice depends from the type of contamination, from the site end-state, budget, national legislation. Many technologies are available at the time:

1. Surface caps use for covering of contaminated surfaces with protective materials. There are three reasons for this kind of protection:
   - Protection from irradiation thru new material level;
   - Prevention from distribution of radioactive substances from the surface with natural erosive processes;
   - Prevention of migration processes with atmospheric precipitations and water infiltration.

   Capping is part of a final closure activities which will isolate residual activity in materials for long-term storage under institutional control. Caps can be:
   - Multilayered;
   - Soil/clay caps;
   - Asphalt and concrete caps;
   - Synthetic membranes;
   - Surface sealants/stabilizers.

2. Cutoff walls are vertical subsurface impermeable barriers which will redirect groundwater flow. There are two reasons for construction of cutoff walls: prevention distribution of contaminated groundwater from the site and isolation of the site ground from penetration of pure water which can dissolve or leach radionuclide 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 apply for reduction the mobility of radionuclides in ground with natural water streams (both, atmospheric precipitations and groundwater). Stabilization technologies can subdivide to two groups: in situ encapsulation and compaction.

   In situ encapsulation technologies designed for immobilization of radionuclides with injection of grout or polymers. These technologies already ready for industrial applications.

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

5. Physical and/or chemical treatment are more cost effective than immobilization processes, these main goals to remove contaminations from the ground and segregate it to clean material and radioactive waste for further treatment and disposal. In comparison with in-situ compaction physical and chemical treatment are more sensitive to soil composition and chemical properties of radioactive materials. 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 natural leaching processes 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. Chemical reducing agents injected into contaminated soil for effective transformation of mobile forms of radionuclides to less soluble forms which would be more stable and will prevent migration processes.

6. Thermal treatment processes use different temperatures starting from low to very high in dependence from characteristic of ground, its moisture, organic content and from chemical properties of radioactive contaminations. In-situ vitrification process use extremely high temperature (approximately 1600-2000°C) and serves to destroy the organic materials in ground and immobilize radioactive contaminants in a glass mass. The process normally requires 0.7 to 0.8 kWh per kg of contaminated ground.

7. Agricultural methods
Agricultural methods are the methods which are used in the beginning of works for liquidation of accidents. These methods are easy for application, relatively cheap; it is possible to find agricultural equipment and tractors anywhere. There are 2 main purposes for 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 plant and to reduce a dose rate from surface.
Relatively new method is phytoremediation. It uses abilities of specific plants to extract radionuclides in soluble forms from contaminated soil to plant. Then plant should be cut from the territory and treated as radioactively contaminated materials. The main problem in wide application of this method is relatively low coefficient of transfer radionuclides to plant.

The peculiarity and the main problem of using of clean-up technologies is the need to take into account the proximity of other facilities, buildings, communications and auxiliary systems.

4.7. AREA AND COMPONENT REUTILIZATION

New space availability that may already be heated and serviced becomes a relief for space-constrained sites. However, careful planning and reviews by the utility accountants and decommissioning personnel must be made. Capital expenditures to a shutdown and retired area of the plant can have implications for the decommissioning fund and require regulatory approval in that 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 found areas for the operating unit’s growth (e.g. system modifications, staging areas or storage areas). For example, at Dresden station the Unit 1 (shutdown) High Pressure Coolant Injection Building was reused for the Station Blackout Diesel Generators and support system for the operating units. Ref. [32] describes inter alia the interactions between the shutdown Dresden 1 reactor and the other two operating reactors onsite – Figure 17.
Proper accounting for the shutdown space utilization would include transfer of the area to the operating unit inventory [33]. As an example, the decommissioning of the Gundremmingen-A reactor in Germany left the buildings untouched and used as hot workshop in support of the operation of the other two operating units (B and C) onsite [34]. See Figure 18.

Other potential savings of resources in a multi-facility site management is the reuse of components from the shutdown unit in other similar units onsite. Such 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 about reuse/redevelopment of drains legacy.

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 of facilities on a multi-facility site enhances the reutilisation potential of these areas such that making land or additional serviced internal space available which can provide useful capacity to ongoing operations or to further decommissioning of other facilities.
In many cases, there is little to gain in pure economic terms (social or cultural factors being excluded for now) 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 etc., or making use of extant infrastructure for new installations.

Lessons learned from decommissioning of Greifswald NPP (Germany) shown that after decontamination, dismantling and retrieval of large-size equipment, turbine halls and NPP site were converted to industrial park. Location of NPP closely with the sea allowed to construct 7 m deep harbor for transportation of ship parts and other big size products. Figures 19 and 20 demonstrated successful conversion of the site from NPP to multi-facility industrial park with territory more than 170 hectares.

![Bird view of the Greifswald NPP (courtesy of EWN)](image19)

**Fig. 19. Bird view of the Greifswald NPP (courtesy of EWN)**

![Location of different industrial companies at the former NPP site and in the former turbine halls (courtesy of EWN)](image20)

**Fig. 20. Location of different industrial companies at the former NPP site and in the former turbine halls (courtesy of EWN)**
In the UK, while there are sound financial grounds for redeveloping a few high land value premises located within commuting distance of London (Harwell, Winfrith) the majority of nuclear installations are dispersed widely around the British coastline [30]. However, existing nuclear sites could offer an opportunity for new builds. About 35 hectares of the site were de-licensed by the UK Office of Nuclear Regulation (ONR) and the land declared to be in a condition fit for any kind of re-use because it contains no radiation hazard. Part of this de-licensed land will be used by Horizon Nuclear Power – the RWE and EOn joint venture. The 36 hectares remaining under license contain the site’s operational plant, including the two 217 MWe Magnox reactors and essential plant infrastructure [36]. Moreover, the Nuclear Decommissioning Authority (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 2-6 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. A total revenue from the land sale in the range 80-240 million GBP (120-360 million USD) per site can be estimated.

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 however possible that peripheral parts of a site are fully cleaned up and de-licensed, while the rest of the site remains under institutional control including also the continued operation of existing facilities or even new builds. The safety case – supported by compliance monitoring – should then prove that re-contamination of de-licensed areas is un-realistic. The Harwell and Winfrith sites in the UK are typical examples of de-licensing projects [38, 39] (Figure 21).

![Fig. 21. Aerial view of the Harwell campus (courtesy of NDA)](image)

Site decommissioning and release from the regulatory control might be achieved on a zone by zone basis. Any residual radioactive contamination in each zone must 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 the 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 the subsequent clean-up activities to manage the residual contaminants including soil, surface and ground water, and subsurface structures and infrastructure. It is in this phase that assurance should be given that decommissioning activities have not transferred contamination to other site facilities and building, and that no contamination from past operation has remained un-discovered 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 sub-areas as defined by the configuration and layout of different facilities, infrastructure and areas of contaminated ground. Once the area has been split into sub-areas, each sub-area can be individually characterized for compliance with the site end-state requirements. It is possible that in some cases, residual contamination within a sub-area exceeds the clean-up criteria, but across the entire zone targeted for clearance the end-state criteria are still achieved in 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 Ref. [19, 40].

4.9. SAFETY ASSESSMENT AND EMERGENCY PREPAREDNESS

In case of multi-unit nuclear power plants, the emergency responses must be revised in line with the changes in plant conditions and configurations. The Fukushima Daiichi nuclear accident 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 should 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 e.g. Refs [41-48].

Emergency preparedness may refer to hazards stemming from demolition works or dismantling of heavy equipment, such as health 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 and the way it’s stored, etc. There is a need of conducting 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 should be conducted for every nuclear facility [49].

If spent fuel is stored on 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, likely the bounding hazards will come from this plant, so in general the provisions of the Emergency Response Plan of this facility should suffice, but with due consideration to the specificities of the unit being decommissioned that might have specific hazards (such as different fuel storage system) that should be taken into account in the emergency response procedures.

Various approaches have been used in performing decommissioning safety assessments as summarized in the IAEA dedicated publications [50, 51].

It should be noted that a multi-facility site may induce additional hazards either to the facility being decommissioned (from nearby facilities) or vice-versa, see Annex II-13 and [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 utilised as an example. The risk of fire in a decommissioning facility can be limited by removing combustible materials 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 in regard to fires originating outside the facility. Therefore, a fire fighting plan and equipment must be in place. It should be noted that the firefighting plan available for the operational phase must be amended as fire risk, building lay out, 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 initiation. For multi-facility NPP sites the decommissioning facility can benefit from the site fire brigade. The firefighting plans must be updated to reflect any change in facility risks arising from decommissioning activities, subject to appropriate
approvals [53], trained and briefed accordingly. Provisions installed at AECL, Canada to protect a nuclear facility from the spreading of fire from adjacent facilities are described in [54].

4.10. ENVIRONMENTAL MONITORING DURING DECOMMISSIONING

Monitoring during decommissioning process is necessary to assess the 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 should be assessed. The impact of the site’s activities (including additional activities undertaken as part of decommissioning) on the public and the environment shall 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 shall be equipped with stationary equipment for continuous evaluation of dose rates and specific air activity concentration levels. The results of monitoring shall be transmitted for the purposes of continuous assessment to allow intervention if appropriate. The samples assessed in the laboratory shall be taken in accordance with the (evolving) monitoring plan, which is approved by the state regulatory authority [55, 56].

The environmental monitoring programme should be proportionate to the hazards residing on the site. In case all site facilities have been permanently shut down and being progressively decommissioned, environmental monitoring programmes are gradually reduced from those in place during operation. During the transition to decommissioning, it is advisable to keep some components of the environmental monitoring 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 to some extent modified, in agreement with the Regulatory Body. After a trial period, assuming that the decommissioning programme has operated steadily without incidents or uncontrolled releases, a further reduction of 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 should 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) what might cause a re-contamination of already decontaminated or clean structures. The groundwater should be monitored for an appropriate period, at least until then radioactive inventory has decreased to safe levels. As the amount of easily leachable isotopes is higher initially, more sampling should be performed during the early years of the decommissioning programme.

5. ORGANIZATIONAL AND MANAGERIAL ASPECTS

The organizational factors associated with a multi-facility 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 within one site will have to be adapted when one of those facilities will 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 would be beneficial for three reasons:

- It enables the site staff to primarily focus on the remaining operating units;
– It provides dedicated resources to safe and timely decommissioning;
– It provides assurance that the shutdown unit activities will not impact the operating units.

The decommissioning workforce is recognized as a separate group or department onsite and should not ideally include technical personnel who support both the operating units and the decommissioning unit. Still there will be support personnel onsite that will be responsible for both the operating units and the shutdown unit regarding functions such as nuclear security, warehouse and supply management, and administration (e.g. recordkeeping, catering).

However, 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 whole organization must be maintained. These requirements should 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 should include, for example:

– How to anticipate and address changes in staffing levels (the age profile is critical here as it affects retirements);
– The forecast personnel needs;
– Consideration of the introduction of inducements to retain key staff;
– Developing inducements to encourage staff to leave voluntarily;
– Ensuring that the staff who leave the nuclear site do 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 these skills are required at different levels:

– Workers (dismantling, decontamination, waste packaging, robotics …);
– In-the-field technicians (maintenance, radioprotection, waste characterization, nuclear measurements, robotics etc.);
– Designers, drafters of operating procedures, quality assurance specialists;
– Engineers (equipment and tool design, technique development, nuclear safety analysts, R&D);
– Operations managers and supervisors;
– Senior project managers: site managers, project directors;
– Staff responsible for interacting with nuclear and other regulators (licensing, clarification of regulations etc.).
– 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 whole site and inter-facility links to ensure safe and effective conduct 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.

A few consequences from this optimized approach are given in the following. When one or more facilities onsite reach a state of safe enclosure (SE), the operations staff is 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 SE. Attention should be paid to the constant availability of personnel for maintenance and surveillance of the SE. It must be avoided that alarms coming from the SE are ignored, due to other priorities being given to the facilities that are in operation. Long standing alarms coming from the SE might be judged as less important by operations staff initially but they can easily become a serious problem later.

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

Training is particularly relevant in this context. First it should be ensured at all time and for all site facilities – regardless of their status and current/planned activities – that the training of staff and contractors is adequate to the objectives as they are at any point in time. As site facilities evolve from construction to operation and finally decommissioning, and each facility has different programmes and schedules, training cannot be static (except basic training e.g. in radiation protection) and should instead follow the demands. Also, unlike operation, decommissioning is dynamic in nature: activities will be intrinsically different over time and training should be capable of ensuring the proper skills if and when required. And training is based on 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 anytime. Therefore qualifications and training should be constantly re-adjusted on an individual basis.

See Annexes II-3 and II-14 on these issues.

5.2. ORGANIZATIONAL STRUCTURES AND SYSTEMS

Facilities on multi-facility sites that have been shut down prematurely can cause problems on sites with interdependent facilities simultaneously in all possible facility phases (siting, design, construction, commissioning, operation and decommissioning).

In any case, the design of the site organisational structure and associated function must be clear to reflect the intended site management model. Key resources need to be effectively empowered so that the decommissioning activities are effectively delivered whilst operations are also ongoing.

The following example shows the establishment of a separate dedicated decommissioning organisation. At Ignalina NPP (INPP) site, Lithuania (Figure 22), the decision to shut down Unit 1 at the end of 2004 and Unit 2 at the end of 2009 meant that decommissioning would commence in parallel with continued station operation.
This prompted INPP organization to establish two organisations, one for station operation (Technical Directorate, INPP TD) the other (Decommissioning Service INPP DS) 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 Project Management Unit (PMU) was established within the 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 re-focussing the skills of the INPP DS staff. As INPP DS staff gradually developed the necessary competences, responsibilities were being transferred from the Consultant to INPP DS staff. In 2006, after four years of PMU operation, the overall management was finally taken up by the INPP DS organisation with the Consultant implementing only specific tasks within INPP DS. The approach of coupling a Consultant with INPP DS staff entailed considerable knowledge transfer and 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 organisational issue for INPP regarding decommissioning was the relationship between INPP TD and INPP DS. While the 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 to 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 specifically was required from each side [58].

The transitional aspects of shutdown and decommissioning at Ignalina are described in detail in Reference [59]. This reference highlights the interactions between the two Ignalina units during the transitional phase.

The Kozloduy Nuclear Power Plant (KNPP, see Figure 23) is a multi-facility Soviet design plant, including 4 VVER-440 type units and 2 VVER-1000 type units. In 1999, the Bulgarian Government and the European Commission agreed to shut down and decommission Units 1-4 of the KNPP. The Kozloduy International Decommissioning Support Fund (KIDSF) was established and is
administered by the European Bank for Reconstruction and Development (EBRD). The total decommissioning costs for KNPP Units 1-4 over the period 2003-2030 are estimated at €1.1 billion.

State Enterprise Radioactive Waste (SERAW) was appointed as the organization responsible for the Decommissioning Programme and for the construction of the National Disposal Facility (NDF). A Decommissioning-Repository Project Management Unit (D-R PMU) was established in order 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, the other from Spain). A Bulgarian Consultant 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 defueling of Units 1-4, the NPP site was split in two parts – the area of decommissioning of Units 1-4 (responsible institution is SERAW) and the energy-generating site with Units 5-6 (responsible organization is Kozloduy NPP). These organizations are owned by the Bulgarian Government.

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

The State Enterprise Radioactive Waste is legally represented by the Executive Director. The KNPP acted as the provider of 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 (RAW) Management Facilities; Units 3 and 4 had the same license in 2013. The structure 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,

Fig. 23. Kozloduy NPP VVER-440 type Units 1-4 before decommissioning (courtesy of KNPP)
- 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 about single projects.

The projects are executed by Contractors / Suppliers under SERAW contracts. The D-R PMU manage the decommissioning projects from preparation of tender documentation through project acceptance and completion.

It should be noted – for both Ignalina and Kozloduy projects – that the active involvement of foreign contractors/consultants and funding bodies, while providing international expertise, inserted significant organizational complications, especially at early phases of the projects.

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

![Fig. 24. General view of the Loviisa NPP (courtesy of Fortum)](image)

Upon termination of the operation of Loviisa 2, the changes from operating organization to decommissioning organization will be similar to Loviisa 1. The staffing of the plant has been planned to be included in the decommissioning operations from the shutdown of Loviisa 2. The maximum number of the decommissioning staff will be almost 430 people. Three distinct person-power peaks can be identified in the overall site decommissioning process: one at the beginning of the preparatory phase of Loviisa 2; second, at the launching of the active decommissioning of Loviisa 2; and third, at the dismantling of the contaminated auxiliary systems after all spent fuel has been taken away from the plant [60, pp. 77-87].

Management of multi-facility sites should plan for and implement facility-specific strategies in a coordinated effort to improve the overall outcome of decommissioning. The overall approach should 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 main focus areas:

- Site organization that include a group with overall responsibility for decommissioning and liability assessment;
- Site-wide system for the planning and management of decommissioning throughout the lifecycle of facilities;
- Site-wide decommissioning project evaluation and approval process;
- Interfaces between operating and shutdown facilities.

Note the main focus areas generally apply also to single-facility sites but special arrangements are necessary to ensure effective management of decommissioning on multi-facility sites.

Another key point to be noted here is whether the decommissioning project will mostly be house-based or extensive use of contractors will be made. The choice will depend on multiple factors ranging from the national or corporate finances to local expertise in decommissioning, and socio-political factors can be involved. Whatever the reasons for the selected approach, the implications on site-wide management can be large. By definition, external contractors are more flexible to be engaged in decommissioning work and released as the work is finished (and perhaps recruited again for the next decommissioning project onsite): this flexibility can help to fill in skill gaps as they occur during the decommissioning process or the operation-to-decommissioning transition. 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 contractors. Plant familiarity can be helpful in case of twin units to be decommissioned in sequence. Vice versa contractors should be trained to become 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 in house-based decommissioning projects.

There are several observations regarding regulation of two co-located units where one continues to operate and the other is decommissioned. First, doing demolition next to an operating plant would create 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. Secondly, to decommission one unit while operating a co-located unit may result in inattention to the decommissioning unit activities. The Dresden 1 case quoted in [61, 62] can be 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 accomplished at Dresden 1 from 1978 to 1993, there was a gradual deterioration in systems and structural condition. In January 1994, a service water system pipe freeze event resulted in some 200 m$^3$ of water released to the Containment Sphere. The NRC inspection team identified a pattern of declining management oversight and focus on 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 (audits which were supposed to cover the whole site were only made at the operating unit) [63].

5.2.1. Responsibility for Decommissioning and execution of the work

Multi-facility sites need to be organized and structured with dedicated site-wide responsibility for the overall site decommissioning. The main function of such a group should be: to establish a site-wide decommissioning policy, strategy and plan; to assess and periodically review decommissioning costs; and to ensure that decommissioning funds are available or will be available at the appropriate time. The site decommissioning group should also be responsible for the coordination and execution of decommissioning projects on the site with the appropriated inputs and involvement of operators of the facility(ies) to be decommissioned as well as of the operators of other facilities that may be impacted by specific decommissioning tasks (interface management).
The operators (licensees) 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 (aka Post Operational Clean Out). The operators (with the assistance of decommissioning teams that will appointed in accordance with national regulations) are also responsible for obtaining authorization for shut down and initial decommissioning activities at their facilities. At a predetermined point the facility, within clearly defined boundaries, execution of tasks is transferred to the team responsible for decommissioning, who will generally retain key operations personnel. Legal responsibility stays with the former operator or licensee at all times (unless, as legally enforced in Spain, and as more recently occurring in the USA- Zion, Lacrosse NPP- the license is transferred to the decommissioning organization). A scheme of how decommissioning activities should be integrated with the life cycle of nuclear facility is presented below. Note that in the case of multi-facility sites each facility or a 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 responsible groups for different facilities (e.g. owners, contractors, waste managers etc.).

Justification for the establishment of an organizational structure that is responsible for decommissioning across a multi-facility site can further be based on the following factors which should be considered in role and responsibility:

- 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 to establish and agree with the regulator the clearance criteria for the whole 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 consistent and more 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 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 should be developed and incorporated into licensing or authorization documents. These documents cover the project management and quality assurance 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 licenses are granted to individual facilities, not to sites: therefore, the licensing process for individual facilities needs to take account of the licenses granted to other facilities onsite. The United Kingdom is one exception, where licenses are granted to the whole nuclear site.

This documented system needs to include the following general arrangements:

- Definition of specific responsibilities regarding management of decommissioning and related interfaces on a multi-facility site including the roles of the operators of facilities, the decommissioning department and the corporate (Safety, Health, Environmental and Quality Assurance (SHEQ) department;
- Multi-facility site decommissioning organization and assignment of responsibilities where different operators co-exist. 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 on a multi-facility site;
- Decommissioning planning process covering the full life cycle of a facility;
- Decommissioning project management including project close out requirements;
- Transition arrangements/requirements incl. training/re-training;
- 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 de-licensing arrangements;
- Arrangements to ensure proper collation and retention of facility specific information and records (facility history) over the lifecycle of 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 should after its conceptual design phase, be reviewed by a corporate specialist function that is independent from the facility’s decommissioning team to determine the project specific requirements including internal and external interfaces/requirements. This project should then be approved by the regulatory body and could form part of process based licensing system. The internal project approval process should cater for all projects on site including decommissioning projects and should provide for a corporate project evaluation function e.g. a safety evaluation committee, a financial committee, auditing functions etc. In the case of multi-facility 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 should be considered:
Definition of a “project” and a project screening and categorization scheme to ensure that all relevant projects including decommissioning projects are subjected 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 e.g. where a project leader presents a planned project to a specialist group at an early stage of development with the objective to determine all SHEQ related requirements applicable to the project including internal and external approval requirements (the specialist group should 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 should be documented as a management system. The process should apply to each decommissioning project. Although each decommissioning project is evaluated separately and project specific approval requirements are established and specified, the following are typical approval criteria specified for decommissioning projects on a multi-facility site:

- Description of the decommissioning project structure and organization;
- Decommissioning project description covering project definition, objectives (decommissioning endpoints) 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 impact on and of surrounding operating and shutdown facilities;
- Level of environmental impact assessment that is required for a specific decommissioning project;
- Project quality assurance 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 must be decommissioned, the others will keep on providing medical services. The licensee responsibility for decommissioning activities shall not be diluted, e.g. because of the radiation protection officer and the administration of the hospital still continue to be in charge for the assurance of the hospital services while additionally become 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: 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 within a multi-facility site [58].

There are well-established project risk management methodologies used in many industries and applicable to decommissioning. For example, IAEA Decommissioning Risk Management (DRiMa) project that was implemented in 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:
  1. Initial conditions of installations
  2. End-state of installations
  3. Waste & materials management
  4. Organization resources (technical, scientific, human)
  5. Finance
  6. Interface with contractors & suppliers
  7. Strategy & technology
  8. Legal & regulatory framework
  9. Safety
  10. 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 (by IAEA Safety Standards and also by most national regulations), but it is considered as good practice. When implemented within an organization, it should be part of the integrated management system. Safety, cost, schedule and quality are typically the main factors to be considered when doing project risk management; 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 (i) monitor and maintain the SSCs and the specified limits and conditions to prevent any events from threatening the safe state of the shutdown unit, (ii) the safe implementation of any ongoing activities and (iii) to prevent the shutdown unit from having a detrimental effect on the safe and continued operation of the other site units.

The management of decommissioning, where based on approaches and strategies for single facilities, may be inadequate or inappropriate in the case of multi-facility sites. A site that houses several independent or interdependent facilities with separate or combined licenses / 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 licenses on a facility basis (typically for the facilities that already have an operation license). 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 licenses to other facilities than the one that had applied for decommissioning. It should also be recognized that the state of adjacent facilities, the interactions and the site end-state may change in several different ways: changes can be technically and administratively hard to incorporate into individual licenses in a timely manner.

In some instances, facilities on multi-facility 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 licenses 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. In this regard, of particular concern is the licensing of new facilities that are meant to support decommissioning: ideally these should be co-licensed with decommissioning work to ensure interactions are taken in due account, but the timing may not allow so. Similarly, licenses granted to new builds should include consideration of on-going or future decommissioning work onsite.

A special problem in regulating decommissioning – especially in multi-facility sites – is the simultaneous involvement of different regulatory agencies e.g. radiological safety, industrial safety, environmental, safeguards, nuclear security, land planning etc. Their competing and sometimes conflicting demands may complicate the decommissioning of a multi-facility 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 licenses, but they have limited control on the timing of such submissions (as long as safety is not at immediate risk). So it may happen that a facility remains in a “limbo” state for many years without a formal decommissioning license in force, and this may pose longer term implications to the safety of the whole site including other facilities.

Another difficult factor to regulate is safety culture and improvements or downgrades of the culture. See Sectio 5.9 for a broader coverage of human factors, among which safety culture is an overwhelming one.

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 nuclear security of nuclear and other radioactive material and associated facilities. That also applies to the shutdown/decommissioning facility at multi facility site. As recommended in Reference [65], the risk management approach should address the three aspects for characterising risk: threat, potential consequences and vulnerability.

Further guidance on nuclear security for nuclear material and nuclear facilities could be found in the following the IAEA Nuclear Security Series publications [49, 65, 66 and 67] as well as in other relevant documents of 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 onsite, such as radioactive waste decontamination stations, interim spent fuel storage, radioactive waste repository and others, is to implement all activities with special emphasis on compliance with of 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 impacts on other facilities and vice versa [51].

All activities related to implementation of safety objectives and principles shall 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 mainly stems from the range of decommissioning equipment operating in the controlled area and mode of their operation, and volumes and management of radioactive material generated during decommissioning.

In order to minimize the decommissioning impact on all components of the environment, a number of technical and environmental measures shall be considered during the planning of decommissioning and 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 plan development 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 wider surrounding areas, the radiological risks resulting from the implementation of the decommissioning activities are generally negligible. The non-radiological risks can be described as follows. The increased transportation of material from the demolition of buildings to the surrounding landfills may have some impact on the acoustic comfort and housing quality, 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 area) can be largely reduced by using railways (which is also cheaper, but not necessarily available at all nuclear sites) to transport large quantities of material. Environmental comfort of the area during demolition activities is disrupted only in the immediate vicinity of the building under demolition (dust, noise, vibration). More distant areas are in no way affected by these activities. Decommissioning at multi-facility sites will cause these inconveniences repeatedly.

It is important to ensure continual improvement and prevention against environmental pollution by fulfilling long-term and short-term environmental goals and environmental management programs.

To quote a few examples, safety-related aspects of interference at multi-unit sites include, based on Ref. [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 risks of ignition or explosion because ventilation is required to be disconnected for the need of other operations planned in the same area/site. To minimize this risk such conditions should be anticipated and preventive or mitigation measures taken. Rescheduling the activities can be effective to this end.
Safety also requires keeping some functional sub-systems under control in an operational configuration, for example: utilities networks, safety functions etc. Parallel activities may then constraint the project schedule [15].

**5.6. EMERGENCY PREPAREDNESS**

A nuclear facility continues to be a source of radiation hazard during decommissioning phases. That is why the basic principle of safety assurance – defence-in-depth – should be applied also at this stage. One of the important bulwarks of safety is the maintenance of emergency preparedness and the accident response regime. However, it should be recognized that decommissioning generally implies a significantly lower radiological risk to public and environment than nuclear operation.

The emergency preparedness and accident response at a nuclear site, where decommissioning activities are being performed, should comply with national legislation and regulatory documents. Compliance with IAEA recommendations, e.g. [49] is highly desirable.

The emergency preparedness and accident response system is an interdependent complex of technical means and resources, organizational, technical and legal-regulatory measures implemented by multiple bodies and teams to achieve the desired objectives – which are prevention or mitigation of radiation effects on personnel and the environment in case of an accident or emergency. The main tasks of emergency preparedness and response system are:

- Preparedness to eliminate accidents and emergencies at facilities;
- Response to accidents and emergencies at facilities;
- Implementation of measures on protection of personnel and the environment.

A General Emergency Preparedness and Accident Response Plan (hereinafter – Plan) is recommended to be available at each multi-facility site. A task of the Plan is to ensure the required level of emergency preparedness at the whole site, as well as to reduce a level of radiation effect on personnel, population and the environment in case of accidents and emergencies at facilities.

It is desirable for the Plan to be a basic guideline document on ensuring the emergency preparedness at a site and to determine a unified approach to arrangement and sequence of actions on detection and classification of accidents at any facility situated at the site, protection of personnel, elimination of accidents; to establish responsibility between officials, emergency actions, and define a composition of forces and equipment meant for these objectives. The Plan should include:

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

Conditions of a site change continuously during decommissioning works. That is why the Plan should be repeatedly updated, and should take into account real and potential hazard of facilities at the site. Quality and applicability of the Plan is checked during drills with personnel evacuation that are integrated for the whole site.

Development of a unified Plan for the whole site allows some advantages enabling to improve the efficiency of emergency preparedness. Such approach enables to get a synergetic effect due to creation of emergency response infrastructure, which is common for the whole site. Vital common elements of infrastructure are as follows:

- Common protective building;
- Common center of medical assistance;
- Common fire-fighting unit;
- Integrated staff for elimination and management of accidents;
A decommissioning state for a single facility often does not imply per se the need for an external emergency plan. But as one or more facilities are still in operation in the nuclear site, offsite emergency provisions are likely to be dictated by operating facilities – which generally have a potential greater impact on the environment than shutdown/decommissioning facilities. The level of emergency preparedness can be softened during transition to a whole new level of safety as a result of decommissioning. For example, the complete removal of spent nuclear fuel from the site can allow to significantly down-grade or even eliminate the external emergency plan. However, the onsite emergency plan will remain a continuing requirement – and could even more stringent than during operation – as long as decommissioning work continues.

Compliance with the Plan’s requirements should be obligatory for all personnel of all facilities, as well as for personnel of contracting organizations performing works at facilities on site.

### 5.7. INDEPENDENT OWNERS/OPERATORS

It is a common case that facilities situated on the same site belong to different owners or are managed by different operators. If so, 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 inter-facility 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 an 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 INCLUDING LEARNING FROM EXPERIENCE AND RECORD KEEPING

The loss of information at any stage of a facility’s life, including decommissioning, deprives people 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 specific implications on timely delivery of the work as the conservative decision making means that conditions are often assumed to be far worse than are actually present; due to a lack of knowledge there is no way to confirm what the true condition is.

Knowledge management should aim to ensure that dependency on individual (human) memory (a.k.a. tacit knowledge) is reduced, and hence enhance the organization’s robustness against changes of personnel over time – an inevitable consequence of transitioning from operation to decommissioning. Knowledge Management should seek to preserve knowledge about plant design, construction, operation and maintenance, so that the knowledge can be transferred to the next generation of plant personnel [57]. In this regard, doing decommissioning at a multi-facility site offers the opportunity of transferring information to the adjacent facilities being at an earlier stage in the facility lifecycle, especially when they belong to the same owner/operator. At a multi-facility site the loss of knowledge can be more gradual than at a single unit site. Decommissioning a single-unit site would be more problematic as the storing and retrieving of useful knowledge may be separated by significant lapses of time. The loss of knowledge is inevitable in any case if specific provisions against it are not taken.

The IAEA has provided guidance on the establishment of decommissioning-oriented records and their preservation for long periods in two technical publication [68, 69]. Like for other IAEA publications on decommissioning, the focus is on single-unit projects. It can be expected that in multi-unit projects the records relevant to the one facility being decommissioning are extracted and selected from a broader database including other site facilities and are organized according to the specific issues of decommissioning. This process can entail challenges additional to the selection of records from an
operational database, where one and the same facility is involved. Moreover, the record keeping functions for the decommissioning facility may have to be clearly separated from those associated with remaining operational facilities.

A multi-facility site being gradually decommissioned also offers the opportunity of learning from experience and the “new” knowledge generated from the decommissioning activities can be shared with others onsite (and offsite).

5.9. HUMAN FACTORS

Over the past twenty years, the nuclear industry has progressively evolved 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 application, but much less with respect to decommissioning.

Decommissioning projects exhibit significant differences in the required mentality from the design or operation phases. 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 operational phase. The organization undertaking the new tasks will also change. Some of the staff will leave; others will have new jobs and responsibilities. New staff will also enter the organization, some of these 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, such as motivational, psychological and personality-driven, though contributing to a significant percentage of all incidents and mishaps, not to mention delays, must addressed and recognized by the decommissioning community itself: understanding these issues would enable decommissioning projects to take a proactive approach, and thus improve safety, predictability, efficiency, performance and organizational learning.

Motivational, psychological and personality-driven issues include the following:

Teamwork
Team work is essential in decommissioning in that (a) the working environment changes at all times 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 staff and contactors’ motivation, reactions and ultimately work performance.

Trust
The new teams, often short lived or ad hoc established, 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, often with strong requirements on economy, efficiency, documentation and flexibility require people to balance and redress goals; safety goals vs. efficiency goals, workers’ goals vs. 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 organisations 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 KSA (knowledge, skills and attitudes) will need to be taken into account, including the following:

- Decommissioning is basically demolition and waste generation. This simplification may lead to a perception of low priority and lack of interest, especially in a highly qualified team (researchers etc.);
- 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. It is a widely reported syndrome that a facility’s staff may feel a sense of attachment to “their” facility and are less motivated to dismantle it.

It should be noted that all above-mentioned factors have a special impact in the decommissioning at multi-facility sites. On one hand, the presence of multiple facilities onsite should favour the re-allocation and rotation of staff to different projects and activities. In this way, typical decommissioning concerns such as “working-yourself-out-of-a-job” should be alleviated. But on the other hand, change factors may be exacerbated by the need to re-assign staff to poorly known facilities and for the re-assigned staff to work within entirely new teams. See Annex II-14 on the advantages of sharing human resources.

Deregulation of electric utilities is a driving force pushing the energy costs lower and the plant capacity factors higher. For the maintenance and operation personnel this means shorter, smaller scope outages and more online maintenance – once again, less time and lower priorities for any shutdown unit onsite. Site priorities for the operating unit during outages and during plant operations by all departments force the shutdown unit 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 accept and understand that there are still requirements and responsibilities for the shutdown unit. Even though there is a decommissioning unit staff, 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 that the decommissioning team do not feel a sense of isolation and marginalization while priority is given to operating facilities. It has been conflictingly reported [63] that if there is another operating reactor at the site, it both increases decommissioning safety because the organizational culture is still strong, and facilities and staff are still available; but 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 indeed at multi-facility sites: the opposite transfer of staff is also possible, and the implications on 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

An asset management is utilized 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 should adopt a clear asset management programme to achieve real and lasting improvements with the objective of longer-term decisions supporting the management of the overall site [57].

Finally, 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 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 multi-attribute utility analysis.

Site reuse implies that new consents and permissions are needed from the regulators (some of them may have not been involved in the previous nuclear operations); it is the responsibility of the new operator or owner to obtain them. It is important to ensure that the presence of the original plant be not
an essential feature of permissions to operate other plants on the same or adjacent sites. This could apply if there is a change in control or ownership of the land which the original plant occupied. An example here 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, maybe 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 license 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 re-contaminate the delicensed areas. A special case would be where the owner or other organization desires 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 materials onsite [70].

A 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 re-usable infrastructure (buildings, electric grids etc.) should 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 provide a wealth of references and case studies, even from 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. Multi-facility decommissioning sites are challenging examples to be considered in this regard taking into account that dismantling activities will take place in parallel with other operations onsite. These can include parallel decommissioning projects, the ongoing operation of existing nuclear facility(ies), and the preparation of part of the site for construction of new facility(ies) to be commissioned in 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 multi-facility site than in a single-facility site. Basically, the stakeholders will view the decommissioning project as one activity among many others taking place or planned onsite: for example, the stakeholders will view decommissioning of one facility as part of continued use of the site (e.g. a new more powerful facility planned in replacement of the decommissioned one), change of site use (e.g. from nuclear to non-nuclear) or decline and extinction of all site activities. A wide spectrum of opinions will be offered by the stakeholders. Active communications with the stakeholders are necessary: mechanisms may include the establishment to a decommissioning-oriented information centre, a hotline, the circulation of public information (periodic bulletins, brochures, TV sessions), and/or the organization of regular events to share information about decommissioning progress.

It has to be also 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 cessation of site operations. This implies a more favourable social and economic impact to local communities from facility decommissioning.

Decommissioning at multi-facilities sites usually implies different deadlines for completing work at various facilities onsite. Thus while one facility can complete the process of decommissioning and begin the process of redevelopment, at another object the works have 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 co-ordinated 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 ensure that progress in one area does not negatively impact on another. Whilst these aspects are important on all sites, they are increasingly important on multi-facility sites where the range of interfaces is likely to be greater.

On a multi-facility site there is potentially a different level of operational focus within different areas; from a highly compliant nuclear safety culture within operating plants to one more focussed on industrial safety in decommissioning work. This directly relays through 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 supporting supply chain sub-contractors 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 should 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 multi-facility sites it is important that workers moving from one facility to another be trained for new specific functions.

6. FINANCIAL ASPECTS

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

For multi-facility sites the financial aspects are further challenged by the range of priorities that are required to be undertaken on the site. Whereas this Section focusses on decommissioning costing, consideration should also be taken to ensure that appropriate asset care is undertaken to ensure 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 standardised structure described in [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 OECD Nuclear Energy Agency and the European Commission. It is intended that all costs within the planned scope of a decommissioning project may be reflected in the ISDC, which may also be used as a point of departure for cost calculations relating to
risks outside the project scope. The publication provides general guidance on developing a cost estimate for decommissioning a nuclear facility, including detailed advice on using the standardised cost structure, with the aim of promoting greater harmonisation.

It should be noted that ISDC does not provide per se specific guidance on how to apportion costs in a multi-facility 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 on a given site:

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

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 numbers of staff are between 20 and 70: but for a multi-unit power plant site, each unit in safe enclosure would require a staff level of 20 or fewer by sharing common resources.

There will also be schedule constraints, particularly where there are requirements for specialised 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 [74, 75]. Three reactors at Indian Point: IP-1 shutdown, IP-2 and -3 still in operation. The estimate for IP-3 considered that:

- Savings will be realized in program 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 purposes of this cost estimate that IP-3 will not transfer spent fuel directly from its pool to the Interim Spent Fuel Storage Installation (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 remediations 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 per se 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 the 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 to) decommissioning is equally important. National provisions differ widely. For example, larger flexibility in using accumulated funds is expected when the operating organization keeps decommissioning funds under its control than when management of the funds is trusted to an independent body.

Funding of decommissioning activities at multi-facility sites may present some specific issues. For example, if these funds are managed by the operating organization, a “conflict of interests” may occur between the funding of decommissioning projects and of major refurbishment/upgrading of operating facilities on the same site. An especially controversial issue may arise from the use of decommissioning funds for facilities (e.g. waste stores) that can serve the purposes of both decommissioning and operating facilities onsite, 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 decommissioning 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 onsite 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 materials and wastes;
- Reduced regulatory uncertainty;
- Reduced plant footprint;
- Partial site de-licensing.

It is noted that most of the above bullet points will have specific implications for multi-facility sites in that the entire site is affected, not only a single facility under decommissioning.

In Ref. [78] the IAEA has encouraged the early planning and execution of activities – including expenditures – conducive to timely start and smooth progress of decommissioning.

To put forward decommissioning steps there is the opportunity of making advance use of the allocated decommissioning funds. To some extent national legislations allow this. In the US the licensee may use up to 23 percent of the amount (specified in 10 CFR 50.75) of the decommissioning trust funds for decommissioning activities before submitting a site-specific decommissioning cost estimate. Included in this 23 percent is an initial 3 percent that the licensee can use, even before permanent cessation of operation, for planning the decommissioning. The licensee may use the remaining 20 percent for actual decommissioning or readying the facility for long-term storage before it submits a site-specific decommissioning cost estimate [79].

In the context of a multi-facility site the opportunity of putting forward certain decommissioning expenses could also serve to ensure a timely start of, and keep momentum on, decommissioning projects that could otherwise be perceived lower-priority than other site activities.
6.3. LONG-TERM FUNDING

Uncertainties in the long-term funding of decommissioning can be due to factors (not mutually exclusive) such as:

- 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); and
- Loss of competent staff and contractors;
- Changes in government policy.

The impact that these factors may have on facilities at multi-unit sites can be variable. For example, a lack of funds may induce the site licensee to further postpone a decommissioning project and divert available funds to more profitable projects elsewhere or to less expensive decommissioning projects onsite. 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 decommissioning stage.

Conversely, the occurrence of factors impacting decommissioning priorities on a multi-facility site (including lack of funds) may force a revision of the overall site use strategy. For example, instead of dismantling all site facility and ultimately de-licensing 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 above-mentioned strategic changes 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. OPTIMISATION 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 should not be deemed to be comprehensive:

- The overall site programme is reviewed and activities prioritised 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 wastes into more secure interim storage, rather than fully processing the waste;
- Consideration of alternative private financing models to enable progress to be maintained.

It is noted that the general worldwide experience is that deferring of decommissioning activities has resulted in significant increases in lifecycle costs, and that interim storage options have resulted in challenging projects being required to make safe in the longer term.

It will be important to maintain appropriate oversight of any deferred tasks to ensure that any deterioration in safety is recognised and appropriate managerial options identified.
7. INTEGRATED PLANNING AND DECISION MAKING

Given the potentially complex interactions that may arise during decommissioning of multi-facility sites the importance of producing and maintaining an integrated site strategy has been highlighted in Section 3. It is also considered important to appropriately integrate overall site decision making, prioritisation and monitoring, to ensure decisions made in one area do not compromise the capacity to deliver the mission in another, and to ensure that cross-site opportunities for an efficient delivery are recognised and implemented. The more complex a site is the more important an integrated approach is likely to be.

7.2. PRIORITISATION

There are a range of techniques utilised for prioritising 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 Multi Attribute Decision Analysis (MADA) 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 much broader programme of work.

Potential criteria to differentiate between approaches include (i) Health, Safety, Security, and Environment (HSSE), (ii) Programmatic and (iii) 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 from a 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 Chalk River Laboratory site, Canada (a large site with dozens of different facilities) twelve (12) parameters were identified and used for the prioritization of decommissioning projects:

- Radiological contamination;
- Non-radiological contamination;
- Proximity to public;
- Proximity to surface water;
- Condition;
- Technical feasibility;
- Experience and knowledge;
- Complexity;
- Uncertainty;
- Conformance;
- Rough order of magnitude cost estimate;
- Annual maintenance costs.

The scoring scheme included a combination of weighted parameters that enabled 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, Socio-economic impacts, Finance and enabling the mission. It is not deemed necessary to quantitate
assess all factors for each decision, but to select those that are considered to be most appropriate and provide the key differentiation between options.

As the interactions between separate projects increase it is also necessary to undertake optioneering and decision making at a high level, where individual projects may overlap. An example would be 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 utilised to aggregate 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 aggregated decision making may be appropriate and it is recommended that careful consideration is taken to determine whether an individual project, cross project or site-wide optimisation approach is applied.

7.3. INTEGRATED OVERSIGHT

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

- Develops a spatial map of the overall site utilising detailed mapping approaches including geographic information system (GIS) 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 visualise how the overall site infrastructure demands change.

Cross-cutting the above is an integrated assessment of existing facility asset conditions, including the opportunities to re-use 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 Masterplanning approach is a relatively recent innovation, but is already informing strategic and tactical land management decisions highlighting:

- Lack of early consideration of what infrastructure requirements are required to laydown 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 focussed 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 site to minimise transport within the site and ease the transport of material away from the site.

8. CONCLUSIONS

Multi-facility sites exist in many Member States and include 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. These include, but are not limited to:

- A number of independent licensed operations;
- Individual facilities being at different stages of their operational lifecycle, and more facilities being planned or actually being constructed on site;
- A shared infrastructure;
- Limited financial, human and technical resources to carry 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 impacting decommissioning over and above the factors observed for a single facility. Site-relevant factors may induce cost savings and other favourable impacts, but may also induce 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 main conclusions and guidance may be drawn from this publication:

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

Detailed consideration of the shared infrastructure between facilities, and how the demands of the planned work may impact on it, and assurance that the infrastructure is maintained for as long as it will be required. A critical point is that the required infrastructure is maintained functional where decommissioning of one or more facilities is deferred.

Multi-facility sites are likely to have facilities in the operational, shut down, 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 the ongoing safe operations, 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 license needs to be considered during the decommissioning planning phase. The results of nuclear security, safety and risk assessments should be used to further develop decommissioning plans that minimize the risks during multi-facility decommissioning.

Selection of appropriate decommissioning and demolition techniques and the scheduling of activities should consider the potential impact on other facilities within the site; particularly with respect to noise, dust, contamination spread and vibration.

Additional demands could be requested of existing common site utilities and services during decommissioning of one or more of the facilities on a multi-facility site. Additional demands could refer to waste management due to the appearance of new waste streams or due to the generation of larger amounts of waste. Waste management planning should take all relevant waste routes and associated Waste Acceptance Criteria into consideration as part of the site decommissioning strategy.
A site-wide decommissioning strategy should 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 should 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 case of significant contamination, the best option might be to preserve the whole site 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 should be considered. Simultaneous and sequential decommissioning may have both advantages and disadvantages that need to be evaluated in regard to optimum site-wide decommissioning strategy and facility-specific decommissioning plans.

Clear segregation between systems that support ongoing operations and those which can be decommissioned is required, therefore accurate configuration control must be maintained. This planning should also consider the timeliness for removal of inventory from a facility (also known in the UK as Post Operational Clean Out); especially as deferral timescales 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, when feasible due to the relative time schedules for project completion, synergies may be obtained by having construction projects and operational activities collaborate 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 for multi-facility sites: 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 on a multi-facility site may enhance the re-utilization 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 re-utilization could entail legal, financial and licensing issues that need to be considered. Another potential savings of resources in a multi-facility site management is the reuse of components from the shutdown unit in other similar units onsite, 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 should reflect an integral site management model. Key resources need to be effectively empowered so that the decommissioning activities are effectively delivered whilst operations are also ongoing.
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Annex I

NATIONAL PROJECTS

The examples provided in this annex cover the organization of decommissioning and detailed technical aspects in both large and small facilities being decommissioned in a multi-facility site. The descriptions should be useful to provide practical guidance on how such decommissioning projects are planned and managed in various Member States. The examples given are not necessarily best practices. Rather, they reflect a wide variety of national and corporate legislation and policies, social and economic conditions, nuclear programmes and traditions. Although the information presented is not intended to be exhaustive, the reader is encouraged to evaluate the applicability of these annexes to a specific decommissioning project. These national annexes reflect the experience and views of their contributors and, although generally consistent with the main text, are not intended as specific guidance. These annexes have only been edited to the extent considered necessary for the reader’s assistance.

I-1. ARGONNE NATIONAL LABORATORY (ANL): HOW DECOMMISSIONING EXPERIENCE TURNED ANL INTO A WORLD-CLASS TRAINING CENTRE, USA

Experience Base

The Argonne Nuclear Engineering Division, through its D&D Projects Group, has been leading and supporting the decommissioning of nuclear facilities at Argonne and at various other locations within the United States and abroad for over 30 years. The knowledge gained and the lessons learned from this work was applied to subsequent projects and shared with others. Some hands-on decommissioning work was performed using Argonne’s in-house labour forces while other projects were performed with contractor work forces. Several projects required a coordinated work effort of both forces. Other efforts focused on analysis of strategies and general planning support. Following areas of expertise are available by D&D Projects Group:

- Project management and execution including cost, schedule, quality and technical baseline management;
- “Path forward” planning, development, preparation and review (Decommissioning plan, Radiation protection, Characterization plan, Health & Safety, Quality Assurance plan);
- Project readiness reviews and facility walk-downs;
- Project health physics and industrial safety oversight;
- NRC licensing activities;
- License termination process;
- Quality Assurance audits and assessments;
- Decommissioning training.

Operations and training

Operations is charged with cleaning up contaminated facilities at the Laboratory that are no longer needed. This work involves disassembling the components of the facility and then recycling or packaging them as waste, which is sent offsite for disposal. The facility is decontaminated and either released for reuse or demolished.

The role of the training element is to provide general D&D training courses or niche training to those with special needs. The courses are organized and planned by NE division personnel. Training is given by Argonne instructors, as well as instructors drawn from other DOE sites, DOE, NRC, and commercial firms.

They have presented over 50 courses since September 1997. Special courses have been presented for the IAEA, JAERI of Japan, CNEA of Argentina, NASA, and the US DOE-Princeton Plasma Physics Lab.
Decommissioning Projects

As mentioned above, Argonne D&D Operations began establishing their own experience/expertise by tackling home projects. These covered a wide variety of different decommissioning activities from small-scale projects such as smaller laboratory or lesser budgeted projects to large-scale projects with larger facility footprints and funding to implement such as reactor decommissioning. A selection of projects is given in the following:

- Decontamination and decommissioning of Experimental Boiling Water Reactor (EBWR) began in 1986 and was completed in February 1996 under DOE Argonne direction at a total cost of $19.5M;
- The decontamination and decommissioning (D&D) of the Argonne National Laboratory Chicago Pile-Five (CP-5) facility was initiated in 1991 and completed in July 2000;
- The decontamination and dismantlement of the JANUS Biological Reactor Facility at Argonne National Laboratory was completed in October 1997;
- The decontamination and decommissioning (D&D) of the Argonne Thermal Source Reactor (ATSR) at Argonne National Laboratory was completed in October 1998;
- The decommissioning of 61 plutonium gloveboxes in nine laboratories located in Building 212 Plutonium Gloveboxes of ANL started in 1992 and was completed in 1996;
- The decontamination and decommissioning of the Argonne National Laboratory 60-Inch Cyclotron Facility began in 1997 and was completed in 2001;
- The purpose of the Argonne National Laboratory Building 200 M-Wing Hot Cells Decontamination Project was to practically eliminate the radioactive emissions of Rn-220 to the environment and to restore the hot cells to an empty restricted use-condition (safe storage);
- The Experimental Breeder Reactor-II (EBR-II) was shutdown in late 1994 after 30 years of successful operation. The detailed Safe Storage Work Plan describing the final condition of the EBR-II was implemented in October 2000;
- The Argonne D&D group has been managing numerous smaller-scale D&D projects including decommissioning a 5,000 sq ft kennel facility, multiple glovebox facilities, and plutonium contaminated equipment.

Decommissioning Technologies

The Argonne National Laboratory D&D Program is an integrated effort focused on addressing all technical facets of the D&D problem. The extensive operations and project execution experience of the Argonne D&D staff, coupled with the Laboratory’s strong foundation in research and development, provides a uniquely integrated approach to identifying and overcoming the issues arising from a burgeoning D&D marketplace. Through its comprehensive field experience, Argonne has developed unique insight and understanding into the critical role technology plays in project execution and in overcoming barriers to success encountered by using new and innovative techniques for solving D&D problems. The Technology portion of the Argonne D&D Program comprises four major areas:

- Identification: Knowledge of and experience with the technologies and methodologies currently available for performing D&D is crucial to having a clear understanding of how best to perform D&D activities. This knowledge base is integral to determining the applications and limitations of current technologies, as well as effectively allocating limited research and development funding. By its proven abilities in information management and distribution through multiple mechanisms, ANL serves as a conduit through which this information flows.
- Development: If, through the identification process, there are needs that cannot be met with existing technologies or there are suitable technologies that could be used with certain modifications and improvements, Argonne’s extensive capabilities in scientific and technological problem solving can be brought to bear on the problem.
- Demonstration: The tightly regulated and monitored environment in which the nuclear industry operates presents unique challenges for the utilization of innovative or improved technologies. To be used in this highly regimented environment, it is critical that new and innovative technologies are processed through a robust, independent, and industry accepted and recognized
demonstration process. Argonne has a proven record in this area as manifested by its participation in the CP-5 Large Scale Demonstration Project.

- **Deployment:** In order to ensure that the most effective technologies are utilized by the D&D user community, a vigorous technology information-sharing system is critical. A thorough understanding of the limitations of D&D technologies in the marketplace is a crucial aspect of the deployment issue. Argonne’s experience in the entire spectrum of technology deployment is invaluable to ensure that innovative technologies are deployed in the most effective manner.

**CP-5 Large Scale Demonstration Project**

In 1996, Argonne teamed with 3M, Duke Engineering & Services, ICF Kaiser, Commonwealth Edison and Florida International University to form the Strategic Alliance for Environmental Restoration. Under the sponsorship of the U.S. Department of Energy (DOE), the mission of the Strategic Alliance is to select and demonstrate innovative D&D technologies.

The D&D needs of the DOE Complex were evaluated, and the problem areas appropriate to demonstration at CP-5 were grouped into four areas: characterization, decontamination, robotics/dismantlement, worker Health and Safety. Twenty-three technologies were demonstrated at the CP-5 Reactor as part of the DOE EM-50 funded Large Scale Demonstration Project (LSDP); a complete listing with vendor acknowledgments is provided below.

**Characterization**
- Field-Transportable Beta Counter-Spectrometer, developed by Argonne National Laboratory and Triangle Research Ltd.;
- GammaCam™ Radiation Imaging System, developed by AIL Systems, Inc.;
- In-Situ Object Characterization System (ISOCs), supplied by Canberra Industries, Inc.;
- Mobile Automated Characterization System (MACS), developed by Oak Ridge National Laboratory and the Savannah River Technology Center for the U.S. Department of Energy’s Robotics Technology Development Program;
- Pipe Crawler Radiological Surveying System, developed by Radiological Services, Inc.;
- Pipe Explorer System™, developed by Science & Engineering Associates, Inc.;
- Portable X-Ray Fluorescence Detector, supplied by TN Spectrace;
- Surface Contamination Monitor and Survey Information Management System, supplied by SRA, Inc.

**Decontamination**
- Advanced Recyclable Media System (ARMS™), provided by Surface Technology Systems, Inc.;
- Centrifugal Shot Blast, provided by Concrete Cleaning, Inc.;
- Empore™ Membrane Separation Cartridge, developed and provided by 3M;
- MOOSE® Remotely Operated Scabbler, supplied by Pentek, Inc.;
- Pegasus Coating Removal System (PCRS), developed by Pegasus International, Inc.;
- Rotary Peening with Captive Shot, provided by 3M Company and EDCO;
- Roto-Peen Scaler, supplied by Pentek, Inc.;
- Starboldt™ Flashlamp System, supplied by Polygon Industry.

**Robotics / Dismantlement**
- Dual Arm Work Platform, provided by a consortium of national laboratories and industry manufacturers. Individual components and subassemblies were purchased from or provided by Schilling Robotics Systems, Redzone Robotics, Inc., Oak Ridge National Laboratory, the Idaho National Environmental and Engineering Laboratory and Sandia National Laboratories;
- Remote Controlled Concrete Demolition System, manufactured by Holmhed Systems AB of Sweden and supplied by Duane Equipment Corp.;
- Rosie Mobile Robot Work System, supplied by RedZone Robotics, Inc.;
- Swing-Reduced Control and Remote Crane Operation Upgrades, supplied by Convolve, Inc. Installation and upgrades were funded by DOE’s Robotics Technology Development Program.
Worker Health and Safety

- FRHAM-TEX Anti Contamination Suit, supplied by FRHAM Safety Products;
- NuFab Anti Contamination Suit, supplied by the G/O Corporation.

I-2. DECOMMISSIONING OF AECL WHITESHELL LABORATORIES, CANADA

AECL Whiteshell Laboratories is a Nuclear Research and Test Establishment that has been in operation since the early 1960s. In the late 1990s, AECL began to consolidate research and development activities at CRL and began preparations for decommissioning WL. WL occupies 4400 ha of land and employed more than 1000 staff up to the mid-90s. Nuclear Research and Development programs carried out at WL during the more than 40 years of operating history included the 60 MW WR1 organic liquid-cooled research reactor, shielded facilities, materials science, post irradiation examination, reactor safety research, small reactor development, chemistry, biophysics and radiation applications. The Waste Management Area and inactive landfill are located approximately 3 km and 4 km respectively from the main site. In preparation for decommissioning, a comprehensive environmental assessment was successfully completed and the Canadian Nuclear Safety Commission (CNSC) subsequently issued a decommissioning licence for WL starting in 2003 – the first decommissioning licence issued for a Nuclear Research and Test Establishment in Canada.

The WL Decommissioning Project scope encompasses all the site buildings, facilities, land and infrastructure associated with the WL site. Initially, the Project is focused on decontaminating and modifying nuclear facilities, laboratories and the associated service systems and removing redundant buildings to reduce risk and operating costs. The design, construction and operation of enabling facilities are fully underway. Site utilities are being decommissioned and reconfigured to reduce site operating costs.

New waste handling and waste clearance facilities have been constructed, and two new waste storage facilities have been constructed – a large shielded modular above ground storage (SMAGS) for storage of low-level solid radioactive waste, and a soil storage compound for storage of low-level contaminated soil.

Decommissioning Progress

The B300 Radiochemical Laboratory was primary research laboratory. Comprising an area of approximately 17,000 m², the B300 complex housed over 170 labs, including a variety of radiological and non-radiological laboratories, approximately 400 offices, mechanical rooms and storage offices, and a high bay for large-scale engineering experiments. B300 also includes the Shielded Facilities (SF) and RD-14M Thermo-hydraulics Experimental Facility. B300 was constructed in seven stages and the strategy is to demolish the building, similarly, in stages.

Prior to the NLLP funding the Van de Graaff Accelerator and Neutron Generator in B300 were fully decommissioned. During the five-year initial NLLP funding, most of the equipment and services from the other areas in these three stages were removed, and the building is being decontaminated to an eventual free release state, ready for demolition. The active drain lines, redundant furnishings, services, and active ventilation devices (e.g., fume hoods, glove boxes) from these areas have been removed. Nuclear research equipment has been removed and dismantled (e.g. Thorium-Nitric Acid Solution Storage tank and piping).

With this work complete, the active ventilation system (e.g., ducting, fan system) is now being decommissioned. Work has started in one of the above three stages – this ventilation system is the least contaminated of all the B300 ventilation and is being used to gain experience prior to working on more contaminated systems.

Planning and design are also in progress for the remediation of soils in the crawlspace. This work focuses on the reduction of cost and liability at WL site. In particular, removal of the active ventilation system eliminates a potentially mobile source of contamination and eliminates the majority of the site heating demand, thus enabling early decommissioning of the costly central oil-fired heating system. The remaining non-redundant buildings are being converted to less expensive and much cleaner electrical heating systems.
The Shielded Facilities includes a 1200 m² Hot Cell Facility (HCF), and a 1300 m² Immobilized Fuel Test Facility (IFTF), together with associated systems and operating areas. Six of the twelve Hot Cells were previously partially decommissioned.

The other six Hot Cells have been decontaminated and are presently in a defined interim end-state as they share active drain and ventilation systems with operating Hot Cells.

Associated experimental equipment such as a Scanning Electron Microscope and Hot Cell 12 (which contained a Metallographic Microscope) were dismantled and removed.

The HCF storage blocks, which were used to store irradiated samples of reactor fuel and other radioactive samples prior to, and following, post irradiation examinations in the HCF, have been decontaminated and are presently in a defined interim end-state. Final decommissioning of the hot cells will follow the final decommissioning of the WR-1 Reactor (Figure I-1).

Fig. I-1. Dismantling of tank on top of stack, WR-1 reactor, Canada (courtesy of WL)

Seven canisters in the IFTF, constructed of reinforced concrete 2.06 m in diameter by 1.68 m high with an internal cavity of 0.65 m in diameter and 1.44 m deep that were previously used to conduct a wide range of experiments in support of the Canadian Nuclear Fuel Waste Management Program, were dismantled and removed. Decommissioning of the IFTF’s Warm Cells 14-18 is complete and included dismantling of the Warm Cells (main floor), and removal of the active ventilation and drain lines in the crawlspace below the cells.

The cells were decommissioned in stages, starting with all exterior services, then the manipulators, interior services and decontamination (including cutting the cell liner), p-trap removal, window removal, lead brick removal, liner removal, and finally the table frames. Thereafter, the active ventilation and drain lines beneath the Warm Cells, located in the crawlspace, were decommissioned. Cells 17 and 18 were the most contaminated, and lessons learned from Cells 14-16 were incorporated in their decommissioning.

Decommissioning activities in the SF, as with B300, has reduced the nuclear liabilities of the WL site, and provides valuable floor space for new waste handling and treatment facilities that are needed for decommissioning. The Warm Cells are smaller and have less shielding than the Hot Cells.
They were also used in support of the Canadian Nuclear Fuel Waste Management Program, where a wide range of experiments using radioactive materials was carried out.

Plans are underway for the decommissioning of two other nuclear buildings at WL – the active liquid waste treatment centre and the laundry and decontamination centre (B411). The functions of these two buildings are being reconfigured and consolidated in the SF and B300.

The ALWTC began operation in 1963, receiving Low Level Liquid Waste (LLLW) effluent from site operating nuclear facilities. The liquid effluents are transferred via underground lines connecting operational facilities to the ALWTC for temporary storage in holding tanks prior to sampling, treatment and controlled release. The facility includes an Intermediate-level Liquid Waste (ILLW) processing system, taken out of service in 2001, which concentrated liquid waste originating from the SF and the WMA. The concentrate was solidified and then transferred to the WMA for storage.

The laundry and decontamination centre have been in operation since 1966 providing laundry service for radioactively contaminated clothing, and decontamination services for maintaining research and development rigs, equipment and tools in a safe useable state.

Several other smaller buildings have also been decommissioned (some were removed for reuse, others were demolished while maximizing material that could be recycled). These buildings were the Internal Friction Laboratory buildings (B500 and B530), the Gas Dynamics Facilities (B307 trailer and grain bin, B312), the Drill Site Office trailer (B515), the Meteorology Trailer #2 trailer (B525), and the Engineering Development and Civil Storage buildings (B504, B509, B526).

I-3. BOHUNICE V1 NPP DECOMMISSIONING, SLOVAKIA

Objectives and Scope of Decommissioning

In 1999, the Slovak Republic committed to shutdown Units 1 & 2 of the Jaslovské Bohunice V1 NPP (V1 NPP, see Figure I-2) by the end of 2006 and 2008, respectively, adopting the Government Resolution No. 801/1999 dated 14 September 1999, in compliance with the Energy Policy of the Slovak Republic. Both units were shut down on schedule.

As of 20 July, 2011 the operation phase of V1 NPP officially finished and the power plant entered the decommissioning phase following the Decision of Regulator (ÚJD SR) “The licence for the 1st stage of V1 nuclear power plant decommissioning of Unit 1 and 2”.

The ‘Immediate dismantling option’ was selected and approved by the management of JAVYS, a.s., and MŽP SR (Ministry of Environment of the Slovak Republic) pursuant to The V1 NPP Conceptual Decommissioning Plan. The main features of this option are immediate and continuous dismantling of the equipment, the demolition of buildings down to the bottom of the foundation pit and the preparation of the area to make it available for further use.
The final site status will be brownfield / restricted use. This term means a real property, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or radioactive contamination. In potential redevelopment plans for the site (use for other industrial or nuclear purposes) will need to consider whether site remediation can achieve end points that are compatible with their intended reuse.

The decommissioning of Bohunice V1 NPP will be performed in two stages (with a final deadline in 2025) in addition to the pre-decommissioning activities which have been carried out prior to the decommissioning itself.

The pre-decommissioning activities included the total defueling of the reactors into the respective spent fuel pools and consequently into the onsite independent interim spent fuel storage facility, preparation of waste processing facilities, conditioning the historical wastes, plant physical and radiological characterization, modifications to electrical and mechanical systems and their tag-outs to allow start-up of the dismantling operations, access control and physical security. During this stage, technical studies, technical specifications and tender dossiers for contracting the Stage I projects were performed.

Stage I activities encompass the removal of non-active systems and demolishing of structures no longer needed. This includes the removal of systems from the turbine buildings; demolishing of structures such as buildings associated with the cooling function, partial dismantling of electrical outdoor equipment and switchgears, removal of systems and demolition of the diesel generator building, dismantling of some outdoor tanks and the preparation of buffer waste storage places onsite and primary circuit decontamination. During this stage, technical and procurement documentation is being prepared to contract the Stage II projects and some conditioning of the buildings for future use will also be performed.

Stage II activities cover the removal of the remaining Plant systems and demolishing of remaining structures within the decommissioning scope. This includes the removal of systems and components from the reactor building, the auxiliary building, and the cross side and lengthwise electrical buildings. Outdoor tanks and buried piping trenches and cables will also be dismantled/demolished. Building decontamination and demolition will be performed once the systems are dismantled. Site release from the regulatory control of UJD SR will be applied for after site restoration (or clean-up) and Final Site Survey as license termination activities.

The scope of the decommissioning considered is limited to the Bohunice V1 NPP structures, systems and components which are not shared with other facilities. Therefore, the Interim Spent Fuel Storage Facility, the Bohunice Radwaste Treatment Centre (BSC), the Auxiliary Boiler will be kept untouched. In addition, a new building for the temporary storage of special wastes not acceptable at NRR Mochovce called IS RAW will also remain untouched after V1 NPP decommissioning. A significant number of shared storage buildings and workshops are found on the plant site. Some of them will be used as buffer storages for the decommissioning materials.

Managing the historical wastes and the decommissioning wastes is a transversal package of activities which has been carefully programmed throughout the duration of the decommissioning process. This includes the treatment and conditioning of the wastes produced during the plant operation, namely solids, metals, sludges and sorbents. Upgrading of the existing radwaste treatment facility began and new projects have been defined for the treatment of sludges and sorbents and for the fragmentation and decontamination of existing and future V1 NPP decommissioning wastes. The enlargement of the Mochovce repository to provide it with enough capacity to handle disposal of low-level decommissioning waste and the construction of new Very Low-Level Waste facility are also considered here. Activities of the material free release are also considered important to minimize the volume of wastes to be sent to NRR Mochovce and thus significantly decrease their disposal cost. The time frame for the whole period of V1 NPP decommissioning is shown in the following Figure I-3:
Status at the Beginning of the 1st Stage of Decommissioning

After the final shutdown of reactors the radiological situation of the V1 has been characterised. The total activity recorded represents the value of 2.03E+17 Bq with respected 2.43E+08 kg total mass of equipment that is the sum of activation and contamination:

- Total inventory of activated reactor parts and adjacent civil structures was determined at the level of 2.03E+17 Bq as the combination of its physical and radiological parameters. This induced activity corresponds to the total mass of 1.39E+06 kg materials. Induced activity of reactor internals represents up to 99.7% of the mentioned total activity;
- Total inventory of contaminated equipment and civil structures was determined at the level of 1.18E+13 Bq. This contamination value corresponds to the total mass of 2.41E+08 kg materials.

Average concentration for contaminated civil structures is 0.2 Bq/g and average concentration for contaminated equipment is around 1 kBq/g. The first value indicates the feasibility of free release option for civil structures while sorting and decontamination will be necessary for contaminated equipment.

Main aspects of physical status at the beginning of the decommissioning was as follows:

- Spent nuclear fuel of Units 1 and 2 is removed from reactor building and transported to the interim spent nuclear fuel storage;
- Remaining quantity of operational radioactive waste is processed, except concentrates in the Auxiliary Building (approx. 660 m²), highly-contaminated or activated solid radioactive waste (approx. 40 tonnes), and possibly other historical solid radioactive waste;
- Primary circuit is filled with demineralized water at atmospheric conditions. Other operational media were removed.

Radioactive Waste Management Facilities at Bohunice site

The following technologies for treatment and conditioning of radioactive waste are in operation by JAVYS, a.s. at Bohunice site:

- Bituminisation facility is used for treatment of radioactive concentrates into drums. A new technological facility (discontinuous bituminisation line) for treatment of radioactive sorbents and sludge has been installed as a part of non-functional plant for resin and sludge calcinations.

- Purification station of radioactive water. Water contaminated chemically and radio-chemically is cleaned by evaporation in a boiler evaporator equipped with an external heater. The resulting condensate is cleaned by ion exchangers until the specific activity of radionuclides in condensate drops below the limit values.

Bohunice Radwaste Treatment Centre (BSC), which was commissioned in 1999 and licensed at the beginning of 2001. The facility includes:

- Incineration plant (incineration of combustible liquid and solid RAW);
- High pressure compacting facility (compacting of solid RAW, in particular metal waste);
− Concentration facility (final evaporation of concentrates on the evaporator);
− Facility for RAW conditioning by cementation to fibre-concrete containers;
− Sorting facility for sorting of solid RAW;
− Storage and transportation facility.

Decontamination facilities (chemical, electrochemical and ultrasonic technologies) for metallic wastes consisting of decontamination baths, storage tanks and the auxiliary systems.

The National Radioactive Waste Repository (NRR) at Mochovce is a near surface repository designed to dispose of RAW resulting from the operation and decommissioning of other nuclear facilities. It serves and will serve for disposal of low level and very low level RAW of all Slovak NPPs (i.e. V2 NPP and NPP Mochove) and decommissioning of nuclear facilities (i.e. A1 NPP and V1 NPP) and from research institutes, laboratories, hospitals and other institutions (the above-mentioned institutional radioactive waste).

All wastes meeting acceptance criteria for disposal at the NRR, independently of their activity level, are at present time packaged in fiber-concrete containers (FCC), with an effective volume of 3.1 m$^3$ and an “occupied” volume of 5 m$^3$. The existing disposal facility consists of two double-rows of reinforced concrete vaults. The dimensions of a vault are 17.4 x 5.4 x 5.5 m, with an effective volume of 510 m$^3$. Each row includes 20 vaults divided into five expansion units containing four vaults each. Each vault is able to house 90 FCC. The capacity of the two existing double-rows is thus amounts to 7200 FCC. Currently, FCCs are disposed of at the second double-row.

In addition there are variety of fragmentation, transportation and decontamination equipment available as well as a new metallic RAW melting facility (from 2019) and Interim storage as a waste and material buffer capacity before further processing.

**Status of the Systems and Buildings at the End of Decommissioning Stage I**

Decommissioning Stage I projects encompass the removal of non-active systems and demolishing of structures no longer needed for Stage II dismantling. These projects are included into “D” projects category. These include the removal of systems from the turbine building, demolishing of some structures and buildings associated with the cooling function, partial dismantling of electrical outdoor equipment and switchgear, removal of systems from and demolition of the diesel generator building, dismantling of some outdoor tanks and the preparation of buffer waste storage areas onsite.

A brief description of V1 NPP at the end of Decommissioning Stage I is summarised below:

− Unnecessary non-radioactive buildings with equipment of secondary circuit were decommissioned, including cooling towers, Figure I-4;
− Unusable technological equipment is dismantled in those buildings, which were included into the scope of Stage I;
− Demolition of the non-radioactive unnecessary buildings is completed;
− Some non-radiologically contaminated buildings (turbine hall, buildings with auxiliary electrical systems – longwise side and cross side electrical building) were not be demolished after dismantling a substantial part of their technological equipment and their decommissioning was shifted to the next period;
− Technological equipment in buildings with systems in operation (reactor building, auxiliary building and others) has remained untouched;
− Remaining part of non-radioactive buildings is not the subject of dismantling and demolition (technology and building part). This part is divided into group of buildings to be decommissioned in Stage II and group of remaining buildings;
− Non-contaminated waste (event. radioactive waste, if generated), is finally transported to dumps and repositories;
− Part of the site, in which buildings are to be removed (demolished) during the decommissioning Stage I, shall be subject to earthworks according to Site Clean-up Plan.
Expected Status at the End of Decommissioning Stage II

The aim of the Stage II (2015-2025) is the decommissioning of structures and buildings in the nuclear island, i.e. the reactor, steam generators, main reactor building, auxiliary operations building and remaining auxiliary buildings, which have not been decommissioned in the Stage I of the decommissioning process.

Main activities in the second stage of the decommissioning the V1 NPP are following:

- preparation and dismantling of reactors of Unit 1 and 2;
- preparation and dismantling of the primary circuit equipment (see e.g. Figure I-5 and I-6);
- dismantling of other equipment in the controlled area;
- contamination removal from technologies as well as from buildings and subsequent radiation monitoring of cleanliness of systems and buildings;
- demolition of original buildings down to their foundation slab;
- site restoration and its release from under the administration of the Atomic Act with subsequent release into environment for unrestricted industrial use.

The above-mentioned activities will be consistently managed and supported by activities, such as project management, technical support, supporting systems operation, radiation protection, maintenance, industrial and radiation safety and other.

From the technical point of view, the most challenging activities in the 2nd stage of decommissioning will include intended dismantling of reactors and dismantling of related equipment of the reactor coolant system, which apart from special radiation characteristics, may be considered to be technological challenge regarding their manipulation, since they are focused on dismantling of large components with weight exceeding 100 tonnes. Also, due to this, selection of the optimal alternative of the reactor dismantling was made after the special study has been drafted. This study defined detailed proposals of procedures/sequences for individual alternatives of dismantling, including their safety and economic characteristics.
Brownfield / restricted use will be the site final status at the end of the Stage II. This status will be achieved after successful completion of the final radiological survey. This survey, to be done at the end of the decommissioning, will release the site from regulatory control after demonstration of compliance with the authorized regulatory clearance levels for restricted use of V1 NPP site.

Demolition of civil buildings will be performed down to the bottom of the construction pit. The radiation monitoring will be performed in the area remaining after decommissioned buildings that will verify that the area can be released for restricted use. Consequently, the site will be backfilled with backfilling materials and backfilled and compacting and final landscaping will be performed. The site at this status will be prepared to handover to user.

I-4. BOHUNICE A1 NPP DECOMMISSIONING, SLOVAKIA

A1 NPP (Figure I-7) was in operation from 1972 and shut down in 1977 (after an accident), since 1980 it is in the decommissioning process. Reactor HWGCR (Heavy Water moderated Gas Cooled Reactor), fuel natural uranium, the total electric power of the three generators was 150 MWe.
In Czechoslovakia was not applicable legislation specifying the frames of the nuclear facilities decommissioning or technical conditions for implementation of such activities. Apart from legislative and administrative conditions and staffing required for these activities, specific technological facilities for management of radioactive waste (RAW) and spent nuclear fuel, including the repository for final disposal of RAW and related transport means were being gradually designed and constructed.

Governmental Resolution No. 266/1993 dated 14 April 1993, requested “to prepare a comprehensive proposal to place NPP Bohunice A1 into the radiologically safe condition”. According to the Atomic Act No. 541/2004 Coll., such activity is defined as “Decommissioning of Nuclear Installation” and allows implementation in stages.

Works executed by 1994 were focused primarily on elimination of consequences of the operational events. Subsequently, the pre-decommissioning activities were in progress by 1999. These activities included dismantling of several technological facilities, creation of areas required for installation of technological facilities intended for management of radioactive materials, decontamination of selected areas/premises, mainly in the main reactor building and transport of spent nuclear fuel used in the A1 NPP reactor outside the territory of the Slovak Republic.

**Decommissioning Process**

The objective of the Stage I of decommissioning was to secure a safe radiation state of the A1 NPP. Activities implemented in this stage addressed the following tasks: long-term storage and removal of spent nuclear fuel, processing of liquid RAW in external buildings, contaminated waters and technological facilities in the plant main reactor building. Preparation of future projects focusing on decontamination and removal of the primary circuit systems/equipment and also revision of priorities focused on extended monitoring of the heavy-water and gas circuit reactor [I-1].

The activities of Stage II are focused on removal of environmental loads from the A1 external buildings, removal and sorting of contaminated soil and concrete debris and monitoring and treatment of underground and leaking water, treatment and conditioning of historical RAW and RAW from the A1 NPP decommissioning, decommissioning of technological equipment and civil units of external buildings and buildings of A1 main reactor building and decommissioning of long-term storage for spent nuclear fuel. Within the second stage, the disposal facility for very low-level waste in nuclear facility of NRR Mochovce is also to be erected, within the scope of first module erection, designated for disposal of very low level waste from the A1 NPP decommissioning.

Activities of Stage III and IV will be focused on decommissioning of long-term storage for A1 NPP nuclear spent fuel, processing of sludge from long-term storage, casks of long-term storage of nuclear spent fuel and liquid RAW from the external tanks of storage place for liquid RAW,
decommissioning of mutually connected technological parts, (steam generators with accessories, turbo compressors, section valves).

The subject of the final Stage V of A1 NPP decommissioning is the nuclear reactor itself and connected equipment in reactor shaft, short-term storage, long-term storage pool for spent nuclear fuel and equipment situated in Reactor Hall, which were installed and used for the decommissioning process itself. From the previous stages, decommissioning of remaining steam generators with accessories will continue. From decommissioning of such equipment, certain quantity of RAW cannot be disposed of at the National Repository for low level waste and will be stored in the Interim Storage of RAW until the deep geological repository is erected.

Above described operation and decommissioning stages of A1 NPP are in Figure I-8.

A1 NPP decommissioning process is continual and regarding the concept of operation termination, it is a very complex and specific process. During its demanding implementation, safety is the main criterion of all activities, and therefore, in respect of nuclear safety and radiation protection, no substantial negative impact of such activities on the environment was recorded. Decommissioning works are implemented continually pursuant to strategic document approved by the Slovak Government “The proposal of national policy and national programme for spent fuel management and radioactive waste in the Slovak Republic” as an update of the strategic document “The Strategy of final stage of peaceful use of nuclear energy in the Slovak Republic” in accordance with procedure of EC 2011/70/Euratom with an objective to fully free release the plant site for its further industrial use.

I-5. DECOMMISSIONING OF MULTI-FACILITY CHERNOBYL NPP SITE, UKRAINE

According to “Memorandum of Understanding between the Governments of G7 countries, European Community and the Government of Ukraine on Chernobyl NPP shutdown” (MoU), dated 20 December 1995, Ukraine accepted obligations on the Chernobyl nuclear power plant shutdown before 2000 and its subsequent decommissioning.

Showing goodwill and demonstrating its commitments to the accepted obligations, Ukraine has consistently shutdown all three operating Chernobyl NPP’s Units for decommissioning before the design life-time expiration. Last operating Unit 3 was shutdown in December 15, 2000.

Integral Decommissioning Program for the Whole Site vs. Separate Programs for each Facility

Units 1 and 2 of ChNPP were built according to the same design and have the same structure, and common auxiliary premises. Radiation situation in similar premises of both units is approximately the same.

Therefore, the basic design solutions, content and sequence of decommissioning works performed at Units 1 and 2 are practically the same and will differ only in the time of their implementation. And approximately the same will be harmful impacts on workers, general public and environment and, accordingly, safety measures for the Units 1 and 2 decommissioning.
Unit 3 has been built in accordance with another design and structurally is different from Units 1 and 2. It has common building constructions, as well as a number of technological systems, common with the Unit 4, destroyed as a result of the accident (the "Shelter" project, to recover from the accident, is further addressed in Section I-6).

Radiation situation in the Unit 3 premises is significantly worse than in Units 1 and 2 premises. Consequently, the design solutions and measures to safety assurance, carried out at Unit 3, will differ from Units 1 and 2. All works should be coordinated with the work at the “Shelter” project.

In Ukraine it was decided to develop a unified decommissioning program for the entire Chernobyl NPP site. Site decommissioning activity planning and management allowed to develop an optimal, interrelated schedule of decommissioning works (including work at the “Shelter” project).

In terms of licensing activity Chernobyl NPP site is considered as a single Licensed nuclear installation. The State Nuclear Regulatory Committee of Ukraine has issued License to the State Specialized Enterprise “Chernobyl NPP” for ChNPP decommissioning in March 2002. Earlier, the License for Shelter object operation and transformation into ecologically safe system has been obtained in December 2001.

Currently all three units are at the same level of readiness for decommissioning, the list of activities and range of planned activities is the similar for them and differs only in terms of implementation.

This made possible to spread successful organizational and technical solutions and technologies for all installations located at the site. This approach allows to plan optimally sequential works and in some cases, to organize their parallel execution. Eventually this leads to cost savings and more efficient use of infrastructure and qualified personnel.

**Chernobyl NPP Units 1-3 Decommissioning Strategy**

The recent strategy of the Chernobyl NPP decommissioning has been continuously improved from the strategy set back in the Concept 1992 to the strategy proposed in the Decommissioning Programme 2008. During these years the following was analyzed and taken into account: results of various research and development works, international experience in decommissioning, IAEA recommendations, and comments of Regulatory Body of Ukraine.

“Deferred dismantling” strategy has been accepted for the ChNPP Units because of some objective reasons. However, the term “deferred dismantling” relates only to the reactor and some systems adjacent to it, which have a high level of radiation contamination and dismantling of which is not possible at the early stage due to the lack of necessary infrastructure (first of all, final disposal facilities for long-lived RAW) and high collective doses.

The low-contaminated “external” equipment of ChNPP that is not subject to preservation will be dismantled at the early stage – by 2025, i.e. by the start of “safe enclosure” stage. Chernobyl NPP Units 1, 2, 3 decommissioning strategy defines the following sequence of stages (see Figure I-9):

- Shutdown – current, final stage of the facility operation: the main task of the stage – release of power units from nuclear fuel, the stage completion date – 2015;
- Preparation for preservation (during 10-12 years, from 2015 to 2028);
- Safe enclosure (from 2028 to 2045);
- Dismantling (during 20 years, from 2045 to 2064).
The main objective of the final shutdown and preservation stage is to bring Chernobyl NPP Units into the state that excludes the possibility of their use for the purposes, for which they were constructed. It complies with the safe storage of radioactive substances and ionizing radiation sources located inside them during a definite period of time.

At the stage of safe enclosure a nuclear facility is in the preserved state corresponding to the safe storage of ionizing radiation sources located inside it. The main objective of the stage is considerable reduction of amount of radioactive substances at a nuclear facility due to natural decay of radionuclides. Duration of the stage will be not less than 20 years with expected start in 2028 and completion in 2045.

At the stage of final dismantling are ionizing radiation sources, which are located in a nuclear facility, removed from the facility and placed into the radioactive waste storage facilities. The expected stage implementation period will be from 2045 to 2064. Further activities will include remediation that will be carried out within the framework of the Exclusion Zone remediation program.

Final Status of ChNPP Decommissioning

It is not reasonable to proceed with decommissioning of the Chernobyl NPP up to “green field” unrestricted conditions, because the ChNPP is located within the Exclusion Zone area contaminated by radioactive substances as a result of 1986 accident. Power Unit 3 has common building structures with the Shelter Object. Considered has to be also non-availability of prospects for constructing new power and other national economy facilities on site.

The most preferable final status of the ChNPP decommissioning is such that can be conditionally specified as a “brown spot”. In this regard, taking into account the Chernobyl NPP location within 10-km Exclusion Zone, which is the most contaminated with long-lived radionuclides, and presence of a great number of building structures within the Exclusion Zone, the full dismantling of the building structures within the frame of the ChNPP decommissioning is considered to be unreasonable. Such task should be resolved within the frame of a unified program of the Exclusion Zone remediation.

Thus, the final state during the Chernobyl NPP decommissioning is dismantling of the equipment, which are not necessary for the SSE ChNPP activity, and cleaning/decontamination of building structures up to levels of restricted release from regulatory control.

Reuse of Chernobyl NPP Site

Since 1992 strategy is continuously evolving. Along with the strategy development various options for the final state is permanently reviewed. Normative documents of Ukraine established the main objective of decommissioning of non-accidental nuclear power plants – reuse of the nuclear power plant territory.

Currently ChNPP decommissioning Strategy determines the final state of the industrial site from radiological point of view as a “brown spot”.

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Fig. I-9. ChNPP decommissioning license, stages and final states (courtesy of ChNPP)
From a pragmatic point of view, taking into account the specificity of the Exclusion zone, the optimal solution for the final status of Chernobyl site decommissioning is industrially developed site integrated into the Nuclear Industrial Complex of Ukraine, using the developed infrastructure and performance of ChNPP staff.

In 2008 new development of the final state for ChNPP decommissioning appeared – industrially developed area, giving possibility to re-use the site (see Figure I-10).

![Fig. I-10. Evolution of the final status of Chernobyl NPP – from “green field” via “brown spot” to the industrially developed site (courtesy of ChNPP)](image)

Chernobyl NPP site, Exclusion zone and infrastructure in general are most convenient for creation of nuclear industries and technologies for radioactive waste and spent fuel processing and storage. In such way can be assured the constructive use of the territory, buildings, constructions and Chernobyl NPP personnel in the economic activity of the country, remediation and development of the depressive region affected by the Chernobyl accident and its transformation into the perspective and economically developed site.

I-6. STRATEGY OF CHERNOBYL NPP UNIT 4 (SHELTER) TRANSFORMATION INTO THE ECOLOGICALLY SAFE SYSTEM, UKRAINE

On April 26, 1986 in the Soviet Union the worst in the history of nuclear energy accident occurred at Chernobyl NPP’s Unit 4. As a result of the accident the reactor was completely destroyed (Figure I-11), contaminating vast area of about 200,000 square kilometres and producing a large amount of high-level radioactive waste in the premises of the destroyed Unit and at Chernobyl NPP site. Construction of the protective shelter above the emergency Unit was started since May 1986 in the severe radiation conditions.
Later in November 1986 the State Commission accepted for maintenance preserved Chernobyl NPP’s Unit 4 which obtained a double name: “Shelter” or “Sarcophagus” (Figure I-12).

“Shelter” or “Sarcophagus” represents the approach to limit contamination release following the beyond design accident at Unit 4 of Chernobyl NPP, which lost all functional properties of the power unit, and at which priority measures to reduce the accident consequences were performed and works are underway to ensure nuclear and radiation safety.

Within a very short time – just during six months – destroyed Unit 4 was transformed into the “Shelter” object (SO) which had no analogues in the entire world. This allowed within the shortest time to mitigate the negative impact of the destroyed unit on the environment, personnel and general public. Chernobyl NPP accident emergency mitigation stage was completed. Unprecedented in its scale man-made source of hazard was localized.

Simultaneously with the SO construction a large scope of works on decontamination of the area around the Shelter object, at the roof of adjacent facilities, inside the ChNPP premises was performed, that allowed to introduce undamaged Units 1-3 back into the operation.
Further actions on the “Shelter” object transformation are performing according to plan, with participation of the International Community. According to the Strategy of the Shelter object transformation, approved by the Interdepartmental Commission on comprehensive solution of Chernobyl NPP problems on March 12th, 2001, transformation of the Shelter object into ecologically safe system is achieved by three basic Stages implementation (Figure I-13).

**Fig. I-12. A general view of the Shelter object (courtesy of ChNPP)**

**Stage 1 – Stabilization**

A set of measures to improve durability, reliability and efficiency of existing or additionally created structures and systems (construction, control, dust suppression, emergency) needed for maintenance or improvement of the existing safety level at the facility was carried out during this stage (1998-2008). Objective of stabilization was to reduce a risk of responsible SO structures collapse prior to the New Safe Confinement (NSC) construction completion. Implementation of stabilization measures allowed to improve the safety level of the localizing SO building until 2023 (Figure I-14.). In future the problem of unstable SO structures will be resolved by dismantling or reinforcement of these constructions inside the localizing NSC.

**Fig. I-13. Strategy of the SO transformation into ecologically safe system (courtesy of ChNPP)**

**Phase 1:** Stabilization of existing object status  
**Phase 2:** Creation of the additional protective barriers  
**Phase 3:** Fuel Containing Materials and Long-Lived RAW retrieval from SO
Stage 2 – Creation of protective barriers (New Safe Confinement construction)

New Safe Confinement creation (2008-2018) to provide a possibility to achieve the following objectives:

- Ensuring of the personnel, public and environment protection against the influence of the nuclear and radiation hazard sources, associated with Shelter object existence;
- Creation of the necessary conditions for practical activities performance aimed on Shelter object transformation into an ecologically safe system, including for residues of nuclear fuel and fuel-containing materials retrieval, radioactive waste management and Shelter object unstable constructions dismantling/reinforcement.

The New Safe Confinement (Figure I-15) is a protective structure, which includes a complex of the technological equipment for retrieval of nuclear fuel containing materials from the destroyed Chernobyl Unit 4, radioactive waste management and other systems intended for the activity on this Unit transformation into ecologically safe system and personnel, public and environment safety assurance.
New Safe Confinement designing, construction and commissioning is performed by the International Consortium NOVARKA, consisting of two French companies “VINCI Construction Grands Projets” and “Bouygues Travaux Publics”. The construction involves specialists from contractors and subcontractors from 27 different countries around the world. However, the bulk of the work is done by 2000 Ukrainian workers, of whom more than 1000 are constantly present on the SO site.

NSC lifetime is 100 years. According to the design NSC includes (i) main building, consisting of arch structure, which span in north-south direction is 257.44 m, height 108.39 m, length 150 m; (ii) foundations, eastern and western end walls and necessary support systems; (iii) technological building, including decontamination, fragmentation and packaging facilities, sanitary locks, workshops and other technological facilities; (iv) auxiliary facilities.

To ensure NSC nuclear, radiation and industrial safety and for its effective operation with involvement of a minimum quantity of operational personnel it is stipulated to create NSC Integrated Management System. It will consist of the following systems:

- Radiation safety monitoring system;
- Seismicity monitoring system;
- Building constructions condition monitoring system;
- Operation support systems: ventilation system, water supply system; sewerage system (including liquid radioactive waste management), power supply system;
- Technological systems for radioactive waste and fuel containing materials management.

It is planned to create fire safety and nuclear security systems and to mount communication and television networks. To ensure dismantling of unstable structures it is planned to install crane equipment. Main functions of the NSC are to limit the radiation impact on population, personnel and environment within the established boundaries, both during normal operation of the Shelter object and in case of normal operation disturbances, emergencies and accidents, including accidents in process of unstable structures dismantling and future Fuel Containing materials (FCM) and Radioactive Waste Management.

NSC shall also limit the spread of ionizing radiation and radioactive substances, presenting inside the Shelter object and provide technological support, i.e. creation of conditions for the unstable structures dismantling and future Fuel Containing materials (FCM) and Radioactive Waste Management.

NSC construction will allow to achieve the following:

- Improve the Radiation Safety level; integrity of NSC construction restricts radiation impact on the population, personnel and environment within the period of operation 100 years;
- Reduce the accidental collapse probability due to dismantling of unstable structures;
- Reduce the impact of emergency collapse due to the protecting and load-bearing structures and monitoring systems inside the NSC;
- Improve SO nuclear safety due to elimination of atmospheric moisture penetration in FCM congestions that significantly reduces the risk of a self-sustaining chain reaction occurrence;
- Ensure implementation of the Strategy of Shelter object transformation into environmentally safe system due to NSC structures durability, feasibility of existing Shelter object unstable structures dismantling and fuel containing materials retrieval.

The NSC slid into the place in November 2016 and thus the successful enclosure of the heavily damaged Unit 4 at Chernobyl was formally completed (Fig. I-16). Installation of technological equipment is being performed. The NSC commissioning started in 2018.
Stage 3 – SO Transformation into the Ecologically Safe System

Within the third stage according to the “Strategy” it is planned to remove FCM from SO (if there is no other proposed alternative options for transforming FCM to the controlled state), to transform them into controlled state by providing of controlled storage within the protective barriers and/or disposal in geological RAW disposal facilities. Thus all FCM should be sorted according to activity level, compacted and transferred in safe condition before the storage (High - level and nuclear-hazardous RAW). FCM accounting should be in accordance with current legislation.

After FCM retrieval from the Shelter object it will be possible to go to the standard procedures of the final stage of its life cycle – decommissioning (Fig. I-17). At the stage of the Shelter object decommissioning long-term risks to people and to the environment should be completely eliminated. Choice of directions for SO transformation into ecologically safe state will be determined by the design of Shelter decommissioning in accordance with the available technical and financial resources.

Fig. I-16. The New Safe Confinement on the place (courtesy of ChNPP)

Fig. I-17. Tentative schedule of SO transformation strategy implementation (courtesy of ChNPP)
I-7. DEVELOPMENT OF INTEGRATED APPROACH TO DECOMMISSIONING AT SELLAFIELD, UK

The Sellafield Nuclear Site (hereafter Sellafield, Figure I-18) is located on the coast of West Cumbria in the UK. Sellafield Ltd is the site licensee of Sellafield, with the UK Government’s Nuclear Decommissioning Authority (NDA) owning the site. The nuclear licensed site at Sellafield covers approximately 2 square miles and comprises three types of nuclear reactor (a total of seven reactors) with three different generations of reprocessing facilities and all of the supporting infrastructure for ongoing nuclear operations.

These facilities range in age from those built in the 1940s right through to modern facilities built in the 2000s. Due to the complexity of operations on the site, the facilities are in a range of different sections of the facility lifecycle from construction, operations, decommissioning, surveillance and maintenance. The purpose of this case study is to provide an insight into the development of the integration approach for the decommissioning of the Sellafield site.

![Aerial View of Sellafield Site](courtesy of Sellafield Ltd.)

**Fig. I-18. Aerial View of Sellafield Site (courtesy of Sellafield Ltd.)**

**Context**

The context is shown in Figure I-19. This explains the strategic context within which Sellafield operates.
Sellafield Decommissioning Strategy

For the site, the Sellafield Decommissioning Strategy is intended to provide the strategic direction for the full lifetime of the sites decommissioning mission, presently expected to extend out to 2120. It also provides high level guidance on planning near term delivery of the decommissioning activities forming the scope of the current Remediation Operating Unit.

To provide a strong focus for the Strategy the following overarching objective has been defined – The Decommissioning Strategy and its implementation plan will provide the best means to achieve sustained delivery of rapid aggregated risk reduction across the full lifetime of the decommissioning mission.

It recognises that delivering the greatest aggregated risk reduction at any time can be achieved by various means. The Strategy introduces the concept of risk groupings that can be managed within a framework of principles and rules to deliver sustained aggregated risk reduction. The significant projects and facilities categorised into the four specific risk groups that differentiate between: continued safe and secure storage of the nuclear inventory; risks posed by facilities with significant nuclear inventory present; risks posed by aged and deteriorating facilities; projects that contribute to sustaining aggregated risk reduction.

The Strategy informs the preparation of the Decommissioning Integrated Strategic Plan that will present the current programme for meeting near term decommissioning strategic objectives. The Strategy includes Rules and Instructions for the formulation of the Decommissioning Integrated Strategic Plan. The Plan provides the justification and basis for its construction and describes any constraints that have affected decision making on apportionment of resource against the risk groupings.

The Decommissioning Integrated Strategic Plan has been prepared using a ‘top down’ approach to enable programme integration and provide a composite view of risks to delivery for the overall site Mission.

It is understood that whilst there will be further opportunities for optimisation of the current output; this output is credible and deliverable. This approach has enabled learning, including that from previous Sellafield Plan builds, to be incorporated. The Decommissioning Integrated Strategic Plan addresses the following:

- Demonstrating sustained risk reduction;
- Integrating all decommissioning activities delivering rapid aggregated risk reduction;
- Credibility of individual plans and hence the Integrated output;
- Recognition of inherent uncertainty associated with individual plans;
- Deliverability influences at Site and Division level;
- Maintaining of a live plan.

The Decommissioning Integrated Strategic Plan has the following features:

- Logic links for leading risk reduction activities to their key preceding enabler activities (e.g. provision of waste management capability);
- Accounting for competing demand from donor facilities by prioritising waste processing capacity based on the risk posed and the alternative routes (or options/contingencies) available for risk reduction for each facility;
- Is consistent in that common facilities have been given common assumptions. A common rate of ramp-up of scope and therefore resource deployment (based on past performance) was used to identify the optimum sequencing of the enabling activities;
- Master Production Schedules (or equivalent) have been built for each Programme Area to optimise to the most rapid credible schedule. The aggregated plan is assessed to determine potential clashes and resources are prioritised to resolve any clash. The logic links have been used to identify the impact of one programme on another where shared use of resources is required;
- Throughput assessment for the downstream waste treatment facilities has been used to ensure that the overall capacity for retrievals is credible;
- Has credibility because the key dates and assumptions have been robustly challenged to address optimism bias;
- The deliverability assessment considered the decommissioning requirements in the context of those from the rest of Site.

The Decommissioning Integrated Strategic Plan introduced the concept of the “Logic Aligned Master Programme” which is a visual graphical representation of the interactions between the start of risk reduction activities and the associated enablers.

These interactions are shown on a series of wiring diagrams that illustrate these interactions in a spatial sense to show the movement of materials between the different facilities.

The Logic Aligned Master Programme shows the risk reduction activities as they occur in relation to time and the links between these risk reduction activities and their associated enablers.

The Division Logic Aligned Master Programme is very complex due to the number of interactions, so has therefore been given colours assigned to the different programme areas and to recognise critical enablers that support multiple areas. An example of a small section of the Logic Aligned Master Programme to show the layout is shown in Figure I-20.
The Logic Aligned Master Programme shows all of the primary risk reduction activities and enablers across the Division and has been created to feed into the Sellafield Plan build process.

**Future Work**

Further work is grouped into two specific topic areas: continuous improvement and development of the legacy ponds and silos programmes; development of the Sellafield Decommissioning Strategy for the phase beyond these retrievals.

To improve and develop the legacy ponds and silos programmes there is effective portfolio and programme management in place to identify and respond to changes, in order that the plan remains integrated, credible and deliverable. A Business and Programme Integration Department within the Division has been established which strengthens this aspect of the planning process e.g. modelling local tactical plans to understand their cross programme impact. The key is to have effective reporting, live strategic planning and rapid decision-making (change control) processes on a Divisional basis. The Decommissioning Integrated Strategic Plan is live plan and will be used to govern any changes to the strategy that are required as new information emerges.

The work on the development of the Sellafield Decommissioning Strategy is looking at how potential options for different facility end-states and interim states (sensible hold points) could be best used to both drive the near-term decommissioning activity and to ensure that appropriate decision points are introduced into the future plan. An enhanced enterprise approach is also being developed to ensure the best use of existing capabilities, and to establish and implement the best value approach to introduction of additional capability to support the planned decommissioning activities across the site. Decision calendars have also been produced to provide clarity on the logic and timing of key decisions associated with decommissioning the site.

**Conclusions**

The implementation of this approach is to drive co-ordination of activities as well as establish and provide a best value approach to delivery of the overall site decommissioning mission. The creation of a Decommissioning Integrated Strategic Plan has also provided a vehicle for explaining the overall approach being taken to external stakeholders, such as the UK regulators (Office for Nuclear Regulation and Environment Agency).
I-7. MANAGEMENT OF DECOMMISSIONING ON THE NECSA SITE, SOUTH AFRICA

Necsa is a multi-facility site that was established more than fifty years ago with construction of the SAFARI research reactor, the first research reactor in Africa. The Pelindaba site subsequently developed to house research, fuel cycle, isotope production, chemicals production and waste management facilities. Facilities were established with overlapping life cycles and coexist on the same site with or without interdependencies.

Although some research facilities were decommissioned earlier, the focus on decommissioning became apparent with the early shutdown of Necsa’s uranium enrichment and fuel cycle facilities since the late nineteen eighties and early nineteen nineties. The need for decommissioning of specific facilities came at the time of establishment of an independent regulatory body and regulatory framework which re-emphasized amongst others, the need for a systematic approach, the justification of activities, a safety case and quality assurance.

The management of the decommissioning on a multi-facility site requires a site-specific approach and strategy. This is mainly due to the existence of a multiple facilities with varied nature of activities undertaken, their interfaces and their interdependencies which are likely to complicate the management of decommissioning. The complexity of management of decommissioning on a multi-facility site is intensified where some facilities are entering the decommissioning phase while others are still operational or even new facilities are being built.

The management model for decommissioning on the Necsa site included the establishment of a site-wide decommissioning management system, specification of functional groups that are responsible for decommissioning management including the execution of decommissioning projects, and a project evaluation and approval process. The management model, the key components and interfaces are indicated in the Figure I-21 below:

![Decommissioning Management Model](image-url)

**Fig. I-21. Decommissioning Management Model (courtesy of NECSA)**

**Site-wide Decommissioning Management System**

The decommissioning management system or a decommissioning management process for Necsa is incorporated into the site and facility specific licenses or authorizations. This documented system covers the management and quality assurance arrangements to ensure that decommissioning good practice is followed for existing and planned facilities. Specific objectives, outputs, processes and responsible functionaries are defined for decommissioning planning and projects which are verifiable at all stages of a facility’s life cycle. The objective of the decommissioning policy, principles and objectives is to also reflect the requirements of all relevant stakeholders including the Governmental Department as the decommissioning liability owner and the Regulatory Authority.
The documented system includes the following general aspects/arrangements:

- Multi-facility site decommissioning organization and assignment of responsibilities where different operators and support functionaries (Safety, Health, Environmental and Quality Assurance-SHEQ) co-exist;
- Facility life cycle decommissioning requirements such as the decommissioning planning process covering the full life cycle of a facility;
- Specific approaches and requirements to management of interfaces that occur during decommissioning of facilities on a multi-facility site;
- Arrangements to ensure proper collation and retention of facility specific information and records (facility history) over the lifecycle of facilities;
- Process for selecting and justification of facility specific decommissioning strategies, objectives and end-points as bases for the decommissioning plan;
- Content of decommissioning plans at the various facility stages;
- Decommissioning project management including project approval, execution and close out requirements;
- Reporting, close-out and de-licensing arrangements.

Ncsa’s lifecycle decommissioning and licensing requirements, as well as the prescribed responsibilities are summarized in the following Table I-1:

<table>
<thead>
<tr>
<th>Lifecycle stage</th>
<th>Decommissioning action</th>
<th>Licensing requirements for decommissioning action</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designing of new facilities</td>
<td>Facility designs to incorporate features to facilitate future decommissioning considering interfaces with other facilities on site.</td>
<td>Submit to the Regulatory Body a part of the facility safety case as required for phased authorization</td>
<td>Project Manager / Design Authority</td>
</tr>
<tr>
<td></td>
<td>Initial decommissioning plan as part of the safety case of the new facility</td>
<td>Submit to the Regulatory Body a part of the facility safety case as required for phased authorization</td>
<td>Facility Manager / Decommissioning Manager / Licensing Specialist</td>
</tr>
<tr>
<td>Operational facilities</td>
<td>Initial decommissioning plan and updated initial decommissioning plan (Updated every 3 years)</td>
<td>Submit to Regulatory Body for acceptance</td>
<td>Facility Manager / Decommissioning Manager</td>
</tr>
<tr>
<td>Pre-termination of Operation</td>
<td>Final decommissioning plan</td>
<td>Submit to Regulatory Body for acceptance</td>
<td>Facility Manager / Decommissioning Manager / Decommissioning Specialists / RP and Licensing Specialists / Waste Management Specialists</td>
</tr>
<tr>
<td>Termination of operation and post-termination of operation</td>
<td>Decommissioning plans for specific decommissioning projects (Decommissioning projects are subject to the internal project approval process)</td>
<td>Submit decommissioning plan including a safety assessment to the Regulatory Body as basis for decommission project authorization</td>
<td>Facility Manager / Decommissioning Manager / Decommissioning Specialists / RP and Licensing Specialists / Waste Management Specialists</td>
</tr>
<tr>
<td></td>
<td>Surveillance and Maintenance plan supported by safety assessment to the Regulatory Body as bases for Surveillance and Maintenance</td>
<td>Submit Surveillance and Maintenance plan supported by safety assessment to the Regulatory Body as bases for Surveillance and Maintenance</td>
<td>Decommissioning Manager / Decommissioning Specialists / RP and Licensing Specialists</td>
</tr>
<tr>
<td>Lifecycle stage</td>
<td>Decommissioning action</td>
<td>Licensing requirements for decommissioning action</td>
<td>Responsibility</td>
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<tr>
<td>----------------</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>authorization</td>
<td></td>
</tr>
<tr>
<td>Clearance Surveillance</td>
<td>Submit Clearance Surveillance Plan including clearance criteria to the Regulatory Body as basis for authorization of clearance surveillance methodology and criteria</td>
<td>Decommissioning Manager / Decommissioning Specialists / RP and Licensing Specialists</td>
<td></td>
</tr>
<tr>
<td>Clearance (delicensing)</td>
<td>Submit Clearance Surveillance Report to the Regulatory Body as basis for delicensing</td>
<td>Decommissioning Manager / RP and Licensing Specialists</td>
<td></td>
</tr>
</tbody>
</table>

Responsibility for Decommissioning

Necsa has established a dedicated organizational group with a site-wide responsibility for decommissioning. The responsibilities of this group include the establishment of a site-wide decommissioning policy, strategy and programme, to assess decommissioning cost and to ensure that decommissioning funds are or will be available at the appropriate time. The decommissioning group is also responsible for the coordination and execution of decommissioning projects on the site with the appropriate inputs and involvement of operators of the facility to be decommissioned as well as of the operators of other facilities that may be impacted by a specific decommissioning project.

The operators of facilities are responsible for decommissioning planning with involvement of the decommissioning group, shut down and execution of at least the initial phases of decommissioning aimed at the removal of the bulk of the radioactive and other hazardous material inventories. The operators of facilities are also responsible for obtaining authorization for shut down and initial decommissioning activities. At a predetermined point the facility, within clearly defined boundaries, is transferred to the group responsible for decommissioning.

A layout of how decommissioning activities are integrated with the life cycle of a nuclear facility is presented below (see Figure I-22): note that in the case of a multi-facility site that each facility or a group of facilities have separate life cycles that are not necessarily aligned and therefore with multiple starting and transition points.
Facility life cycle

**Facility Establishment**

**Facility Operation**

**Decommissioning**

**Decommissioning activity**
- Decommissioning considered during design / construction and initial planning.
- On going decommissioning planning
- Final decommissioning planning
- Decommissioning projects

**Desired state**
- Promotion of decom. good practice attributes and establishment of decom. planning framework.
- Decommissioning plan that is updated and commensurate with the operational stage of the facility and in accordance with the overall site decommissioning plan. Cost of decommissioning assessed and funds made available for decommissioning projects.
- Shut down and final decommissioning plan
- Authorized decommissioning projects or implemented surveillance and maintenance plans. Passively safe end-state or released facilities.

**Responsibility**
- Operators
- Operators and Decommissioning group
- Operators
- Decommissioning group

**Fig. I-22 Integration of decommissioning-related activities with lifecycle of nuclear facilities**

The main advantages of a single organizational structure that is responsible for decommissioning on a multi-facility site relate to improved efficiency and consistency in terms of the following:

- Decommissioning prioritization;
- Decommissioning planning including resource planning;
- Decommissioning project authorization or licensing;
- Execution of decommissioning projects;
- Waste and material management;
- Operation of facilities in support of decommissioning e.g. decontamination and waste processing facilities;
- Surveillance and maintenance and close-out of decommissioning projects.

The establishment of a workforce that specializes in decommissioning also alleviates the “short term” perception and human resource related problems associated with the transition from operation to decommissioning.

**Site-wide Decommissioning Project Evaluation and Approval Process.**

Decommissioning projects on the Necsa site vary in intensity and scope and are evaluated on project specific bases to determine the appropriate SHEQ and approval requirements. Decommissioning projects are, after its conceptual design phase, reviewed by a corporate specialist function that is independent from the decommissioning group to determine the project specific requirements including internal and external interfaces/requirements. The Necsa project approval process is accepted by the regulatory authority and forms part of process based licensing system. The project approval process caters for all projects on the site including decommissioning projects and provides for a corporate project evaluation function e.g. safety and auditing.

The main advantages of a site-wide project evaluation and approval process are the following:

- Consistent specification of approval and other SHEQ requirements for projects on the Necsa site that are aligned with site and regulatory requirements and conditions;
– Consistent application of the requirements of the site-wide decommissioning management system;
– Provides an opportunity for the specification of decommissioning requirements in all projects including projects to modify existing facilities and projects to establish new facilities.

I-8. APPROACH TO DECOMMISSIONING OF MULTI-FACILITY SITES, RUSSIAN FEDERATION

Nuclear power and nuclear industry in Russian Federation were operated under planned economy and state ownership so RW management and decommissioning activities used predefined plan and state funds. The challenges facing nuclear industry were mainly associated with [I-2]:

– More than 150 shut-down nuclear and radiation hazardous facilities, including NPP units and uranium production reactors;
– Engineered barrier systems for nuclear facilities and NPPs operated for more than 50-60 years and required urgent overhaul;
– The legacy sites include open water reservoirs for liquid radioactive waste (Karachay, the Techa Cascade of water reservoirs) and tailings as well as former Navy bases;
– The problematic old research reactors and laboratories which were commissioned in 40s-60s;
– Accumulated SNF needed processing;
– Needs in new disposal facilities for different RW classes.

Legislative framework

The main principles of the implementation of the decommissioning activities in Russian Federation described in the Decommissioning Concept 2008 [I-3]. In accordance with Concept the principles of implementing activities for the decommissioning of nuclear facilities are:

– Bring it into the state that excludes its potential nuclear hazard in the regulatory period after it has been shutdown (removal of nuclear materials and spent fuel);
– Bring it into the radiation safely condition during the optimal period, considering social and economic factors;
– The maximum and cost-effective release of materials and equipment;
– Implementation of technological processes and operations which will minimize volume of radioactive waste and possibility of decommissioning staff exposure;
– Final disposal of radioactive waste;
– Advanced planning and implementation of decommissioning works up to the removal of site from the state regulatory bodies.

By the mid-2000s, the situation in the sphere of nuclear legacy was as follows:

– More than 175 nuclear and radiation hazardous facilities subordinated to various federal executive bodies, including the Federal Atomic Energy Agency (four nuclear power plants, 10 industrial uranium graphite reactors and more than 110 nuclear and radiation hazardous facilities for other purposes) were shutdown, but not decommissioned;
– Number of near surface radwaste storage facilities no’s ensuring reliable isolation of RW from the environment was not ensured, new radioactive waste disposal sites were required;
– Large volumes of radioactive waste (Techa cascade of reservoirs, basins-settling tanks and tailing dumps of organizations of the nuclear fuel cycle) not isolated from the environment;
– More than 18.5 thousand tons of spent nuclear fuel (SNF) have been accumulated. Indicators of spent fuel storage at NPPs with RBMK and EGP-6 reactors, near-station radwaste storage facilities were close to critical levels;
– Sources of ionizing radiation were used by more than 15,900 organizations, often lacking adequate protection from terrorist danger;
– Not available due regulatory, legal and technological solutions to the problem of rehabilitation of facilities created by nuclear explosive technologies (peaceful nuclear explosions);
– Not fully implemented some of the requirements ratified by Russian Federation international acts in the field of nuclear and radiation safety;
– The engineering systems of a number of nuclear and radiation hazardous facilities, which were operated for 50-60 years, required urgent reconstruction and modernization.

For the comprehensive solution of the accumulated problems, in accordance with the instruction of the President of the Russian Federation of March 16, 2006, the federal target program “Ensuring Nuclear and Radiation Safety for 2008 and for the Period until 2015” had been established. For optimisation of management were all nuclear facilities and NPPs converted into the joint stock companies. Also new requirements in RW, SNF management and decommissioning were established and following tasks completed:

– Over 25,000 spent fuel assemblies (RBMK-1000, AMB, research reactors and nuclear-powered ships) were reprocessed or delivered to storage facilities;
– Establishment of a State RW Management System including creation of the National Operator (NO RWM) and State RW Management Company (RosRAO);
– Creation of new RW disposal facilities;
– Different stages of decommissioning are performed for over 200 facilities, 53 of which have already been decommissioned;
– 4,259,000 m² of contaminated lands already remediated;
– Establishment of centres for decommissioning excellence (NPPs, PUGR, SNF et. al.)

Federal Target Program “Nuclear and Radiation Safety in 2016-2020 and for the period up to 2030” was approved by the Government in 2015. The main responsibility for its implementation is on the State Corporation “Rosatom” that covers decommissioning of:

– Nuclear icebreakers “Sibir”, “Arctic” and “Russia”;
– Decommissioning of buildings and constructions (14 objects) of “Mayak” Association;
– Decommissioning of Graphite reactors of “Mayak” Association, Siberian Chemical Combine and Mining-Chemical Combine;
– Decommissioning of HEU reprocessing plant, Siberian Chemical Combine;
– Decommissioning of Plutonium processing facility, Radiochemical Plant, Mining-Chemical Combine;
– Decommissioning of research laboratories, pilot installations and repository of nuclear materials, A.A. Bochvar High-Technology Scientific Research Institute for Inorganic Materials (VNIINM);
– Decommissioning of radiochemical plant, Khlopin Institute;
– Decommissioning of burial sites and U production facility buildings, Angarsk Electro-Chemical Combine;
– Decommissioning of building 242, Mashinostroitelnaya Zavod (Elemash);
– Decommissioning of SNF Dry Storage, Physico-Energy Institute (PhEI);
– Decommissioning of Units 1, 2, Beloyarsk NPP;
– Decommissioning of Heavy-Water RR, ITEPh;
– Decommissioning of buildings of “Luch” Plant.

Decommissioning

The process of decommissioning includes following key tasks [I-4]:

– The final shutdown of nuclear facility;
– Unloading and removal of SNF and NM from the facility (transfer into a nuclear safe state);
– Removal of working media, carrying out regular decontamination of equipment and premises;
– Radiation and engineering survey;
– Development of the decommissioning concept including a feasibility study and selecting the best option;
– Development of decommissioning program;
– Development of a ToR for decommissioning project, safety assessment report;
– Licensing and implementation.

The typical decommissioning process as “Immediate Dismantling”:
– Creation of RW management infrastructure;
– Decontamination and dismantling of equipment, decontamination of the surfaces, dismantling of building structures;
– Processing of accumulated and decommissioning radioactive waste, containerization, storage and disposal;
– Rehabilitation of contaminated areas;
– Removal of facility and site from the regulatory control.

The typical decommissioning process as “Safe Enclosure”:
– Localization and conservation of highly contaminated equipment;
– Long-term exposure of localized equipment;
– Creation of RW management infrastructure (if necessary);
– Decontamination and dismantling of lightly contaminated or clean equipment, disassembly and dismantling of auxiliary buildings and structures;
– Processing of accumulated radioactive waste;
– Decontamination and dismantling of equipment, decontamination of the surfaces, dismantling of building structures;
– Processing of accumulated and decommissioning radioactive waste, containerization, storage and disposal;
– Rehabilitation of contaminated areas;
– Removal of facility and site from the regulatory control.

Alternative decommissioning process to establish disposal site for special RW:
– Creation of RW management infrastructure (if necessary);
– Decontamination and dismantling of equipment, decontamination of the surfaces, dismantling of building structures (with the exception of the reactor shaft);
– Creation of a system of additional protective engineering barriers with the purpose of reliable localization of radionuclides in the location for the entire period of potential danger;
– Processing of accumulated and decommissioning radioactive waste, containerization, storage and disposal;
– Rehabilitation of contaminated areas;
– Withdrawal of the object from regulatory control, registration as a “storage site / conservation / disposal site for special RW”;
– Monitoring of groundwater, surface air, dose rate on the surface, and so on.

Legacy Sites

Nuclear Legacy in Russian Federation came from the initial period of development of nuclear industry since the mid of 40s and it includes [I-5]:

– Nuclear Defence Production and Tests sites;
– Radiological Accidents (Kyshtym 1957 and Chernobyl 1986);
– Spent Nuclear Fuel – about 12,000 tons are kept with a total activity of about 8.2 billion Ci.;
– Research laboratories and pilot facilities;
– 650 Mio m³ of liquid and solid RW with total activity about 2.0 billion Ci accumulated on different nuclear sites;
– Uranium mining and enrichment facilities;
– The most part of the contaminated areas (94%) are on the “Mayak” Combine nearby areas.
Research reactors

About 55 research reactors, critical and sub-critical assemblies of the total number of 103 were shutdown or are under decommissioning. Spent nuclear fuel from research reactors was accumulated mainly at the sites of former and recent research and educational institutes as well as from some defence facilities. The SNF interim storage facilities are filled up to 80%.

Nuclear Power Plants

There are in total 10 nuclear power plants in RF with 35 units of following types:

- 18 units with VVER type reactors (of which 12 VVER-1000, 1 VVER-1200 and 5 VVER-440 or smaller power modifications);
- 15 channel reactors (11 reactors RBMK-1000 and 4 EGP-6 reactors);
- 2 fast neutron reactors with sodium cooling (BN-600 and BN-800).

According to the Russian regulatory documents (OPB-88/97), the decommissioning project should be submitted for approval to the supervisory authorities 5 years before the end of the project lifetime of the power unit, regardless of whether its service life will be extended (Figure I-23). Pre-decommissioning and Decommissioning Programs were developed and approved for:

- Beloyarsk NPP, Units 1-3;
- Leningrad NPP, Units 1-4;
- Bilibino NPP, Units 1-4;
- Smolensk NPP, Units 1, 2
- Novovoronezh NPP, Units 1-5;
- Balakovo NPP, Units 1-3;
- Kola NPP, Units 1-4;
- Kalinin NPP, Units 1, 2;
- Kursk NPP, Units 1-4.

The funding sources to cover decommissioning costs are subsidies from the federal budget, trust funds of the federal budget and the budgets of the Russian Federation and special reserve fund created by the operator to finance nuclear facility decommissioning.

Fig. I-23. NPP unit decommissioning concept [I-6]
REFERENCES TO ANNEX I


[I-6] ZIMIN, V., IAEA Regional Workshop on Lessons Learned from Decommissioning of Nuclear Facilities, 2015 … to be clarified via Sergey Mikheykin
Annex II

LESSONS LEARNED

The following examples of lessons learned comprise an outline of the problems encountered at the nuclear facilities being decommissioned within a multi-facility site. The situations are typical of the challenges that can arise when planning or implementing the decontamination and dismantling of facility surrounded by facilities at different stages in their lifecycle. Although the information is not intended to be exhaustive, the reader is encouraged to evaluate the applicability of the lessons learned to a specific project of his/her interest. The Table II-1 below groups individual episodes below in categories.

<table>
<thead>
<tr>
<th>Issues</th>
<th>Annexes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadvertently impacting service lines (piping, electrical cables) belonging to, or shared with, another facility</td>
<td>II-1, II-4, II-11, II-16.1</td>
</tr>
<tr>
<td>Coordination between multiple entities during decommissioning work</td>
<td>II-2, II-7, II-12, II-15, II-16.1</td>
</tr>
<tr>
<td>Transfer of solid waste and containers between facilities</td>
<td>II-6</td>
</tr>
<tr>
<td>Conflicting licenses between two adjacent facilities under decommissioning</td>
<td>II-8</td>
</tr>
<tr>
<td>Lack of retention of Operator knowledge and/or inadequate record keeping</td>
<td>II-3, II-5, II-9</td>
</tr>
<tr>
<td>Potential impact of decommissioning works on nearby areas/facilities</td>
<td>II-10, II-13, II-16.3</td>
</tr>
<tr>
<td>Training and utilisation of human resources during decommissioning at multi-unit sites</td>
<td>II-14, II-16.2</td>
</tr>
<tr>
<td>Benefits/dis-benefits of centralised waste consolidation, buffer and interim storage</td>
<td>II-16.3, II-16.4</td>
</tr>
<tr>
<td>Shortfalls in pre-planning and strategic planning</td>
<td>II-16.1, II-17</td>
</tr>
<tr>
<td>Inadequate engagement with Regulators</td>
<td>II-16.2</td>
</tr>
</tbody>
</table>

II-1. UNEXPECTED CONDITIONS OF ABANDONED PIPING, USA

Problem encountered: Prior to the demolition of a facility adjacent to a large process building, the utilities connecting the two facilities were to be isolated and air gapped. Multiple utilities travelled between the two facilities including one 4” (10 cm) line identified by labels as “air” at one location on the pipe and “water” in another location on the pipe. During an extensive effort to identify an isolation point, it was discovered the line had previously been air gapped and plugged with grout inside the process building. There was no evidence of the original piping it was once connected to. Once the line was verified isolated, a cut was made between the two buildings to create an air gap. After making the cut, the workers noticed the pipe contained small beads of mercury. It was later discovered that the inside of the pipe also had radiological contamination. The outside of the pipe at the cut location had been checked prior to the cutting and no radiological contamination was found. The discovery of mercury and radiological contamination inside the pipe was an unexpected condition [II-1].

Analysis: Due to the necessity to identify an isolation point, a great amount of effort was spent looking at existing drawings and performing field walk-downs. The discovery of the isolation point only occurred after performing a hand-over-hand walk-down in a congested overhead pipe gallery. The configuration of the 4” line led the project team to believe this was an abandoned airline. Additionally since only grout had been used to fill the open end of the line rather than mechanical device, there was no reason to believe it contained a hazardous material. It is still not known what the function of the pipe was or why it contained droplets of mercury and radiological contamination.
Looking back at the conditions leading up to the event, the following should have been taken into account:

1. The pipe had two different labels indicating the pipe’s function. Labelling may have occurred a number of years after installation as part of a new requirement or corrective action. The labelling may not have been performed correctly.
2. Since the pipe had already been air gapped and no piping remained at the disconnect point, the system function could not be verified back to an active distribution header.
3. Due to these two existing facility conditions, the facility’s operating history should have been considered in determining the controls necessary to execute the work.

In addition to an impact on the project schedule, the failure to plan for the unexpected condition resulted in additional costs being expended to analyse the incident, perform surveys of the pipe and surrounding areas, order bioassays of impacted personnel, and a rework of the work package.

**Lesson learned:** When working on abandoned piping in process buildings, anticipate encountering unexpected conditions inside the piping until otherwise verified. The impacts of inaccurately checking conditions may be more significant in piping connecting two separate facilities.

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II-2. COORDINATE WITH MULTIPLE ENTITIES PERFORMING VARIOUS WORK ACTIVITIES ON THE DOE-OWNED PADUCAH SITE SO THAT ALL DIRECT AND INDIRECT HAZARDS ARE EVALUATED AND CONTROLLED, USA

**Problem encountered:** On August 20, 2007, two electricians wearing powered air purifying respirators made a permit required confined space entry in a manhole, as indicated on the “Personnel/Atmospheric Testing Log” to complete the removal of asbestos insulation from electrical cable. An electric spot cooler was used to reduce the interior manhole temperature and supply a constant flow of outside air. Unrelated work by another organization was being performed about 75 to 100 feet due south of the manhole (25 to 33 m). The unrelated work involved two diesel powered generators for welding and an air compressor. The confined space work team was not aware that the unrelated work was going to be performed at the same time and did not immediately recognize a potential for migration of exhaust gases into the confined space.

**Analysis:** There was no prior coordination between the two work crews to ensure that there were no direct or indirect interferences based on the work that each was performing and it was not immediately recognized, by either work crew, that there was an unexpected change in condition that could potentially create a hazardous situation.

**Lessons learned:** During the planning, preparation, mobilization, execution, and restoration activities it is important to understand the work that may be performed by other organizations and contractors in the vicinity so that all potential hazards can be properly evaluated and controlled to ensure that work objectives can be met successfully. In particular, the following actions should be considered:

1. Work activities must be coordinated with the other groups working in the area around the confined space to ensure that unrelated activities did not impact the workers in the confined space.
2. In the event work activities have not been coordinated prior to starting work each day, the field supervisor should stop the work for which he is responsible and contact the supervisor of the unrelated work.
3. Consider potential sources of vapours and gases (i.e. exhausts, tanks, processes, etc.) that could enter into the confined space and expose entrants to unsafe levels of hazardous materials or that could displace oxygen levels creating a hazardous condition.
4. Perform a walk around (recommend 150 feet – 50 m – radius) of the surrounding work area before each entry to ensure no additional sources of hazards are being generated and be aware of changing conditions while the work is in progress.
5. Entrants and attendants should be reminded to stop work and assess the impact and controls anytime there is a change in condition or work area that could potentially create a new unrecognized hazard.

II-3. FERMI 1 NPP RESUMING DECOMMISSIONING AFTER A LONG PERIOD OF SAFE ENCLOSURE, USA

The Enrico Fermi Atomic Power Plant, Unit 1 (Fermi 1) is located in Michigan, USA. The site boundary is completely contained within the Fermi 2 site boundary, adjacent to Lake Erie. Fermi 1 was a fast breeder reactor power plant cooled by sodium and operated at essentially atmospheric pressure. The reactor plant was designed for a maximum capacity of 430 Megawatt (MWt); however, the maximum reactor power with the first core loading (Core A) was 200 MWt. The primary system was filled with sodium in December of 1960 and criticality was achieved in August 1963. In 1972, the core was approaching the burn-up limit. In November 1972, the Power Reactor Development Company made the decision to decommission Fermi 1. The fuel and blanket subassemblies were shipped offsite in 1973. The non-radioactive secondary sodium system was drained and the sodium sent to Fike Chemical Company. The radioactive primary sodium was stored in storage tanks and in 55 gallon (200 L) drums until the sodium was shipped offsite in 1984. The first phase of decommissioning of the Fermi 1 plant was originally completed in December 1975, then the reactor remained in a safe storage condition for over 20 years.

There is no spent fuel onsite. Bulk sodium has been removed from the site, and the reactor vessel has been grouted and is being removed. The facility transitioned from active decommissioning in 2011 and returned to safe storage in early 2012 [II-3 – II-5].

Problems Encountered: The following selection of personnel issues refers to a decommissioning phase in the late 1990s (25 years after final shutdown) when management started to determine the condition of Fermi 1 systems and structures and launch some short-term actions in preparation to another safe storage phase.

Over the long time when Fermi 1 had been idle, some staff and labour personnel left or were temporarily re-assigned. This limited the capability to complete work, in addition to the knowledge loss and additional training costs incurred due to retirements and replacements. Also, since Fermi 1 was not making the company any money, the company focus was to use available personnel to support plant outages at Fermi 2 whenever possible. This resulted in further loss of personnel for Fermi 1 decommissioning project.

While being located on the same site of the operating Fermi 2 NPP had some benefits, it also had some drawbacks. The benefits included access to equipment (e.g. crane, tool crib etc.), personnel (e.g. radiation protection, environmental etc.) and pre-approved programmes (e.g. safety tag outs, radiation protection procedures etc.). Some of the drawbacks were locked into unwanted Fermi 2 programmes (e.g. purchasing), heightened nuclear security (i.e. added difficulty to get material and personnel onsite), and to have to always keep in mind how Fermi 1 related actions would impact Fermi 2. Since there was no fuel onsite at Fermi 1, the heightened nuclear security would not be required if Fermi 1 were not on the same site as an operating NPP.

When decommissioning work was resumed after 25 years, there were few personnel available familiar with the plant and how systems were left. For instance, they found sodium in inert gas lines where it was not expected due to lack of knowledge of how the plant was laid up.

Finally there was the underlying desire for people to do not want to work themselves out of a job. There were several personnel that viewed Fermi 1 as a place to retire from, and for a few of them, it was actually so.

Lessons Learned: Long period of safe enclosure in general results in loss of knowledge, demotivation of personnel, and a general perception of low priority. Operation of another nuclear facility at the same site might bring some benefits to resolve this issue.
Problem encountered: An undocumented and undetected buried electrical cable was encountered during hand excavation for a new water line. During preparation of the excavation permit for the work a search for as-built drawings was performed. Utility scans completed before excavation indicated that buried utilities were present in the areas. However, the encountered electrical power cable was not detected during the utility scans. The excavation permit and work package specified hand digging of the trenches because buried utilities were known to exist in the work area. Instructions in the excavation permit specified “When anything unusual or unexpected is identified in an excavation, STOP and carefully hand dig until the discovery can be properly evaluated.

During hand digging of the water line trench, an undocumented (not on an as-built drawing or identified by utility scans) buried electrical cable was encountered. The workers stopped work and contacted the Responsible Manager (RM). The trench was inspected by the RM, Work Supervisor, and Electrical subject-matter expert. An electrician was also brought in to investigate the cable. The electrician checked the undocumented cable with a proximity voltage tester and determined that the cable was not energized. Next, the workers investigated the routing of the cable and determined that it ran into an electrical conduit which was connected to a fuse box. The fuse inside of the box was turned in a manner so that the connection was de-energized. Work was then paused and management was notified.

A work package was issued to perform a facility outage. The main power feed to the trailer complex was isolated, utilizing the hazardous energy control procedures, and the undocumented cable was removed. The other electrical utilities (in use and abandoned) located at the trailer complex were also documented during the outage [II-6].

Analysis: Temporary office trailers and associated utilities were installed in the work area to support a previously (about 10 years prior) completed construction project. After the construction project was completed, the temporary trailers were removed. However, some of the associated electrical cables (without marking/locator tape) were not removed. As-built drawings did not show all of the remaining, abandoned electrical cables. In addition, utility scans did not identify the undocumented buried cable. As explained in several existing DOE Lessons Learned (SWPF-LL-134, 2003-NV-NTSBN-001, L-2001-OR-BJCPORTS-1101, 2001-RL-HNF-0022) no single utility location instrument can detect all types of buried utilities or all buried utilities in areas congested with utilities or other interferences (near buildings, fences, other utilities, etc.).

In addition, proximity voltage testers shall not be used to verify an electrically safe work control boundary. Even if the tester determines that a cable is not energized, the tester cannot ensure that the cable will remain de-energized during the work.

Lessons learned: Excavation in areas congested with buried utilities or in areas where previous activities likely required buried utilities presents a risk to discover undocumented or undetected utilities. Extra caution should always be taken when excavating these areas. Specific actions to consider include:

- Perform walk-downs of work areas to identify physical conditions that may indicate the presence of anomalies (i.e., disconnect box with no associated power line, exposed cables not previously identified, indications of disturbed soil, etc.);
- Research as-built drawings and previous site activities and uses to identify buried utilities and potential locations for abandoned utilities;
- Use hand digging in areas congested with known utilities or in areas where the site history indicates that abandoned or undocumented buried utilities are likely to be encountered. If possible, isolate the main electrical feed into the trailer/facility complex prior to performing the work;
- Use utility scans to determine location of buried utilities and remember that not one type of utility locator can detect all types of utilities, especially in areas with other interferences (buildings, fences, other utilities, etc.). Do not rely on utility scans to be the single line of defence;
– Do not use proximity voltage testers to determine or verify an electrically safe work condition. Even if the tester determines that a cable is not energized, the tester cannot ensure that the cable will remain de-energized during the work. Utilize hazardous energy control procedures (lock and tag) when performing investigations;
– Require as-built drawings to be issued for utility installations, removals, and modifications;
– Include the removal of utilities during demobilization activities. If utilities are not removed ensure as-built drawings are issued showing location of abandoned utilities;
– Notify Management when electrical anomalies or unexpected conditions not covered in a work package are encountered;
– When taking over responsibility for facilities and trailer complexes, ensure pre-existing surveys include locating as-built drawings for the utilities.

II-5. LEGACY CONTAMINATION FOUND AT 420-2D DECOMMISSIONED PAD: EMPHASIZES BEING COGNIZANT OF TRACEABILITY OF ACTIONS FOR IMPACT ON FUTURE ACTIVITIES (ARRA), USA

**Problem encountered:** In preparation for the project for the D-Area Concrete/Soil Removal Action at the Savannah River Site (SRS), Radiological Protection personnel were probing the building pads that were to be rubblized and placed in the heater pit. During the probe of the 420-2D (Zone E) slab, 6,000-8,000 dpm beta-gamma (100-130 Bq) was detected in an ~5 feet X 5 feet area on the southwest corner of the pad with a centre small area ~2 inches x 4 inches (~50 cm²) probing 14,000 dpm (230 Bq) beta-gamma.

The pad is located within a posted Controlled Area, but there was no posting or labelling of the pad indicating the presence of the contamination. Health Physics Technology personnel were contacted and performed an isotopic analysis, finding $^{137}$Cs as the predominant isotope.

The 420-2D building was decommissioned during fiscal year 2005 and left posted as a Fixed Contamination Area (CA) due to several spots of fixed contamination on the slab. Due to its close proximity to the 420-D facility, the slab was later covered during fiscal year 2006 with crusher run to support the crane operations necessary to support the decommissioning activities for that facility. At this time, the area was still posted as a Controlled Area/Underground Radiological Material Area (URMA). When 420-D decommissioning was completed, the crusher run was left in place, and the 420-2D slab was still covered. The area still remained posted as a Controlled Area/URMA.

When the legacy contamination was found during the survey, it was a re-discovery of the fixed contamination that existed on the pad following decommissioning and prior to its being covered with the crusher run. Reviews of other work associated with the area from the 2006 to 2010 time frame did not reveal the exact timing or any documents related to the removal of the URMA postings [II-7].

**Lessons learned:** Personnel performing decommissioning-related activities need to be cognizant of the traceability of their actions for future area closure related activities. Personnel performing area closure activities need to also be cognizant that existing visible conditions and postings (or lack thereof) do not necessarily provide all of the information necessary to address potential hazards during activities that disturb the soil or ground covering. Reviews of previous work should be conducted to ensure adequate understanding for potential hazards that may be found as the soil or other ground covering is disturbed and removed.

II-6. LIQUIDS AND PRESSURIZED AEROSOL CANS IN LEGACY WASTE CONTAINERS, USA

**Problem encountered:** As part of a risk reduction effort by Bechtel Jacobs Company (BJC), specific transuranic (TRU) waste containers were to be relocated from one facility to multiple facilities. While reviewing container waste data, an RTR printout was discovered that indicates specific 55 gallons (200 l) drums may contain liquid volumes greater than 0.5%, pressurized aerosol cans, and other prohibited items. The current Safety Basis (SB) analysis did not adequately address the impacts of these items inside the drums [II-8].
Analysis: The Design Analysis Calculation (DAC) for waste storage facilities was written in 1996 by the prior prime contractor in support of the Safety Analysis Report (SAR) for the facilities. At the time the DAC was written, the developers of the analysis considered that hazardous liquids and flammables inside the legacy TRU waste containers would be of concern in an extreme fire event. However, consideration was not given during the analysis to the reactions of free liquids, aerosol cans and gas cylinders inside the containers and the postulated exposures that could result from their reactions during a severe fire event. The presence of these prohibited items had been discovered during Real Time Radiography (RTR) testing during the late 1980s to early 1990s timeframe. Printout reports from the RTR testing had been filed with some of the original container data packages, but were not included during the development of the DAC. This fact led to the inadequate analysis when the DAC was developed in 1996. The facilities had continued to operate under the 1996 DAC analysis and corresponding safety basis until the RTR test reports were discovered during a transportation DSA review that was being performed in May 2003 to support relocating the drums from building 7842.

Lessons learned: As an industry, such as the handling and storage of hazardous wastes, evolves, so does the knowledge and standards by which that industry is regulated and controlled. Previous concepts and assumptions regarding safety factors and possible impacts on worker safety, the public or the environment must be re-evaluated to determine whether those concepts and assumptions remain valid, especially in case of transportation and re-location to other facilities.

II-7. SHIELD BLOCK SPACER FALLS ONTO OPERATOR’S FOOT AT ORNL MELTON VALLEY’S 7841 SCRAP YARD, USA

Problem encountered: On October 13, 2005 at the ORNL Melton Valley Completion Project's (MVCP) 7841 Scrap Yard Facility, a subcontractor was re-wrapping spacer plate keys that serve to provide specific spacing between shield blocks, used as shielding for underground cells at the Molten Salt Reactor Experiment (MSRE). The activity involved moving the shield plates from the scrap yard and placing them in a Sealand container at MSRE. The blocks were being removed from the scrap yard to aid the MVCP Decontamination and Decommissioning (D&D) Project in clean-up of the 7841 Scrap Yard Facility.

Note: The work was being accomplished for the ORNL Melton Valley MSRE Facility. The work was physically being accomplished for MSRE by a subcontractor. The subcontractor's normal work alignment is through BJC's Waste Management Organization. The work was taking place in the ORNL Melton Valley 7841 Scrap Yard Facility.

The work package contained the required information for performance of the work activity, i.e., job walk down, pre-job briefing, job instructions, Blocking/Bracing Plan, AHA, etc. During pre-job planning discussions, the possibility of the plates sliding was addressed. It was concluded the weight of the plates (~250 lbs. each, 120 kg) resting on the 6” X 6” (15 x 15 cm) wooden blocks would prevent the plates from sliding.

On October 5, 2005 all notifications were made by the subcontractor for the scheduled work in the MVCP's 7841 Scrap Yard. The work package had been previously reviewed by the MVCP's 7841 Scrap Yard Facility Manager and authorized. A pre-job briefing was conducted on the work package. Daily pre-job briefings included the use of the Safety Task Analysis Risk Reduction Talk Card (STARRT Card) as a tool for review of potential hazards. Due to ergonomic factors it was determined to leave the shield plates in their current stacked configuration for the re-wrapping. Each stack was to be raised to allow the placement of heavy plastic to be used for the re-wrap. Once the top layer was wrapped, it was to be moved to allow access to the next set of shielding plates. The process was to continue until all three sets had been re-wrapped. On October 5, 2005 the subcontractor contacted the 7841 Scrap Yard’s Facility Manager and the Health Physics (HP) Lead for the scrap yard as required prior to the start of work. Due to rain and other factors no field work was performed on this task between October 5, 2005 and October 13, 2005. On October 12, 2005, the subcontractor’s Transportation Specialist called the 7841 Scrap Yard’s Facility Manager requesting a HP shipping survey. The survey was needed for the shield blocks that were previously wrapped and staged outside of the 7841 Scrap Yard Facility fence. No mention was made relative to the subcontractor restarting work on the remaining shield blocks or
lifting beams. On October 13, 2005 the subcontractor contacted the HP Lead for the scrap yard to let him know they would be working that day. The HP Lead allowed access to the 7841 facility. Based on communication with the HP Lead during the October 5, 2005 work performance the subcontractor assumed that the 7841 Facility Manager had been notified by the HP Lead. The subcontractor did not contact the Facility Manager responsible for the 7841 Scrap Yard. As a result, the subcontractor was in the 7841 Scrap Yard Facility performing work without Facility Manager knowledge or authorization. The MSRE was carrying the work scope on their plan of the week schedule but was not informed that the subcontractor was to recommence work on October 13, 2005. The MSRE Facility Manager was not notified that this work scope was to restart on October 13, 2005.

The top stack was raised using a fork truck and a sheet of heavy plastic was spread under the shield plates and on top of the wood cribbing. The shield plates were placed back on top of the cribbing. Three subcontractor employees, one on each end and one on the side of the plate pulled on the plastic in order to tighten prior to taping. The shield plate slid on the cribbing causing the plate and cribbing to tilt and the plate to fall approximately one and a half foot to the ground. The employee injured was unable to move his left foot clear of the falling plate. The employee was wearing steel toed boots at the time of the injury. The employee was diagnosed with 3 metatarsal bone fractures and was referred to an orthopaedic specialist.

At the time of the accident the subcontractor notified their BJC Subcontract Coordinator (SCC) who notified the appropriate personnel in the BJC Waste Management Organization. The subcontractor removed their employee from the site to obtain medical treatment. The Facility Manager for the 7841 Scrap Yard and the Facility Manager for MSRE were notified of the incident. The Waste Management Organization notified their appropriate Waste Management DOE Facility Representative and the MSRE Facility Manager notified the MSRE DOE Facility Representative. The MVCP 7841 Scrap Yard Facility Manager did not directly notify their DOE Facility Representative.

The subcontractor operator was taken immediately to East Tennessee Technology Park (ETTP) Medical for treatment where he was x-rayed and a preliminary report indicated the foot was broken in three (3) places. He was not taken off-site for immediate treatment. An initial critique of the incident and work scope was conducted to determine if any additional safety and health issues needed to be implemented in the existing activity hazard analysis and work package.

A follow-up critique was held between BJC and the subcontractor and several instances of failed communication were noted. Communication requirements were reemphasized before work was allowed to continue within the 7841 Scrap Yard Facility footprint [II-9].

Lessons learned: The organization charged to perform a scope of work should ensure that the Facility Manager responsible for the facility where the work is to take place has authorized facility access and the work scope prior to initiating physical work activities. If multiple facilities are involved, as in this case, the Facility Managers for the facilities involved are responsible to communicate with each other and ensure there is a clear understanding of the work scope, its impact for both facilities, the work performance schedule, the work performing organization, its work supervisors and personnel responsible for the satisfactory completion of the work scope and each Facility Manager's individual responsibilities relative to the work (start to finish). The work scope and schedule should be discussed in both facilities' Plan of the Day (POD) meetings prior to the initial start of the work scope and prior to any restart after a break in work performance. Work progress should be checked periodically until completion. There should be a clear understanding that the Facility Manager responsible for the facility where the work is to take place is the individual that authorizes access and approves work within that facility.
II-8. DECOMMISSIONING OF RESEARCH REACTORS RITMO AND RANA, ITALY

Problem Encountered: The two zero-power reactors Ritmo and Rana were situated at the Casaccia Research Centre, near Rome. Ritmo and Rana were adjacent pool-type reactors separated by a gate. Either facility/site (the pool) was separately licensed (see Figure II-1). The two reactors were dismantled in 1984-5 (Ritmo first, and Rana a few months later). Contamination/activation detected during dismantling was almost nil in either reactor. At that time, Italian legislation gave no indications on the procedure to follow for decommissioning and license termination of nuclear installations. In lack of specific guidance, the Ritmo pool was surveyed at the end of dismantling and its license was terminated—before the Rana works were completed. The Rana pool had still some remaining water, which later leaked out to the adjacent—already de-licensed—pool.

Analysis: It was readily ascertained that the leaked water was not contaminated and no radiological contamination resulted from this incident.

Lesson learned: The license of a decommissioned facility should only be terminated if assurance is provided that neighbouring facilities under decommissioning will not re-contaminate the decommissioned part of the site.

Fig. II-1. The two adjacent pool type reactors, Rana and Ritmo, Italy

II-9. REUSE AND REDEVELOPMENT COMPLICATED BY DRAINS LEGACY, UK

Problem Encountered: A complex nuclear research site with hundreds of buildings utilized a network of drainage systems, developed over decades, to connect the buildings to a central liquid effluent treatment plant. The drains included:

- Local Soakaways;
- Networked industrial effluent systems which were nominally non-radioactive;
- Old generation active drains with no secondary containment;
- Modern active drains with secondary containment;
- Rainwater drains.

Problems included:
– Generations of successive drains and delay tanks had been installed with no decommissioning of old systems;
– Drains were sometime collapsed or leaking;
– Inactive drains had been used for active effluents by mistake;
– Not all drains were recorded on site drawings;
– Some drains had been decommissioned but there were no records kept;
– Some drains had been grouted in-situ with inadequate survey records to justify the drain being left;
– Rainwater was ingressing into drains creating additional effluent.

**Analysis:** A programme of drains decommissioning was established to enable site redevelopment. The remaining buildings requiring drainage were isolated with dedicated systems. The remaining network of drains was decommissioned in a manner to regain confidence in the eventual land quality. It included:

– Drains detection and mapping;
– Use of a geographical information system to record and map progress;
– Flushing of drains;
– Contamination monitoring using a pipe crawling robotic probe;
– Removal of collapsed sections;
– Grouting in-situ of all cleaned drains to avoid unnecessary excavations.

**Lessons Learned:** Progressive decommissioning of redundant systems during the phase of site operations is beneficial to reuse and redevelopment of the site. Record keeping is very important in order to justify the final land quality status. Drains may be suitable for reuse (the rainwater drainage system was reused on this site) or may have to be decommissioned. Decommissioning may not require excavation and removal if grouting in-situ can be justified.

**II-10. DECOMMISSIONING AND DISMANTLING OF THE MOATA REACTOR, AUSTRALIA**

**Problem encountered.** The MOATA ARGONAUT type reactor was constructed at ANSTO (Australia) in 1961. It was built as a 10 kW reactor, but modified in 1972 to 100 kW. It had graphite moderator / reflector (12 t) and was cooled by light water. The shielding consisted of high density and low-density concrete. Preliminary dismantling started in July 2009, while the biological shield was dismantled in 2010. A specific problem was that MOATA was housed in the same building as an adjacent Tandem Accelerator. The challenge was the accelerator sensitivity to $^{14}\text{C}$ ($1 \times 10^{14}$). This posed a serious risk to the future of carbon dating program and research at the ANSTO research centre [II-10, II-11].

**Analysis:** The following measures were taken to confine any dust produced by MOATA dismantling, see Figure II-2:

– Localised tent and extract;
– Fully enclosed and tented work:
  - Double skinned,
  - Air inflow through tent skin.
– Extract filtration:
  - Primary dust,
  - Secondary HEPA extract filtration.

**Lessons Learned:** The presence of adjacent facilities may imply extra precautions during dismantling.
II-11. ABANDONED SYSTEMS ENERGY STATUS, IDAHO NUCLEAR TECHNOLOGY AND ENGINEERING CENTER (INTEC), USA

**Problem Encountered:** On March 2, 2009, Utility Operations personnel noted abnormal cycling of the Idaho Nuclear Technology and Engineering Center (INTEC) fire water service pumps and notified the INTEC Plant Shift Manager (PSM). Upon extensive investigation they located a leaking water line in building CPP-621. This particular line was a two foot section of two inch line that protruded from the building slab and was capped on the end. This line had apparently frozen and ruptured the capped end inside the building. They isolated the line by closing a valve below the rupture point. Upon further investigation, D&D personnel determined this water line was part of a legacy raw water system that resided in some older buildings at this site and was supplied from the fire water system. This line also likely supplied the buildings original potable water system. In recent years a concerted effort had been undertaken to separate the potable water systems from the fire water systems, yet some buildings still have the original pipe stubs connected to the fire water system as is the case in this event. The D&D organization participated in a facility turnover walkthrough with the previous owner and during the walkthrough the line was identified by the previous owner as inactive. The turnover checklist generated by the previous owner in conjunction with D&D did not list this line or the raw water service as an active system. During the work package planning stage, the search for active utility systems did not reveal this line as an active system on any active drawings. The planning walk-down for this work package did not identify this line as being connected to an active system. D&D personnel assumed that this line was inactive based on the lack of supporting evidence to the contrary [II-12].

**Analysis:** Demolition of facilities, and in particular older facilities, requires in-depth planning and engineering to ensure all systems are identified, isolated, and air gapped as necessary. It is critical that the up-front planning includes searches of databases for not only active but also inactive drawings. When active systems are unintentionally encountered during demolition or excavation it seems they can always be located on a print somewhere, after the fact. Physical appearance can reinforce misconceptions about
the configuration of a particular system as was the case in this event. The pipe stubbed out of the floor with a cap in place and an open valve below the cap reinforced the assumption that this line was inactive as indicated by the absence of it on the building utility prints. This line did appear on an inactive Aluminum Nitrate Filtration System print that was found after the event and was designated as a raw water line. The raw water was used to back flush the filters on the old filtration system. This building and its associated utility systems was built in the mid-1950s. The Aluminum Nitrate Filtration System was removed over 20 years ago so the availability of personnel with historical knowledge is limited. The key to ensuring that all systems have been identified is the reconciliation of all discrepancies between the actual facility configuration and the building drawings, both active and inactive. Also, inactive or abandoned systems may still contain hazardous energy, materials that are not compatible with the environment, or may still be physically connected to active systems.

Lessons Learned: Abandoned/not in-service systems should not be considered as isolated until a positive zero energy check is completed.

II-12. SAFETY BASIS CHANGES REQUIRE ADEQUATE ANALYSIS AND REVIEW, IDAHO NATIONAL LABORATORY (INL), USA

Problem Encountered: On January 20, 2014, a positive unreviewed safety question determination was declared revealing an inadequacy in the documented safety analysis for remote-handled transuranic (RH TRU) waste operations in the New Waste Calcining Facility (NWCF) at the Idaho National Laboratory (INL).

The issue was self-identified from questions that arose related to the assumptions in the source term (ST) calculation for the NWCF high-efficiency particulate air (HEPA) filter degradation accident scenario. This scenario addresses the consequences of a release from the HEPA filters in the ventilation system for the entire facility. The ST calculation currently in the NWCF safety analysis report (SAR) is for the tank farm facility (TFF) liquid waste processing operations that are no longer performed in the facility. The ST calculation does not include RH TRU waste repackaging operations currently performed at NWCF. The material at risk (MAR) associated with the TFF waste consists of high concentrations of gamma emitters and low concentrations of alpha emitters. Whereas, the MAR associated with the RH TRU waste consists of high concentrations of alpha emitters and low concentrations of gamma emitters. Adding the RH TRU waste ST to the accumulated TFF ST on the HEPA filters will result in a higher consequence from the HEPA filter degradation accident scenario [II-13].

Analysis: As is typical with many older facilities, the NWCF safety basis has evolved over time. The TFF consists of underground tanks that collected liquid wastes from the reprocessing of nuclear fuel. This waste was transferred to the NWCF where it was treated using a fluidized bed process that converted the liquid waste to highly radioactive granular solids. The characteristics of TFF waste were considered in the ST calculations for consequence analyses in the NWCF SAR. Calcining operations in the NWCF were stopped in 2000, however the ST for the TFF waste was still considered the bounding MAR for evaporation activities that continued to be performed in the facility. It was determined that RH TRU waste repackaging would be added to the scope of work performed at the NWCF. At this time, it was also determined that there would be two nuclear facility managers (NFMs) at the NWCF. One NFM would be responsible for the RH TRU activities and the other NFM would be responsible for all other activities at the facility. The NWCF SAR was revised in 2006-2007 to include RH TRU repackaging operations that are now performed in the NWCF. However, this revision did not update HEPA filter degradation accident scenario to include the ST for RH TRU waste repackaging.

Due to the time that has lapsed since the SAR revision in 2007 and the relocation and retirement of individuals directly involved with the revision, the investigation into the cause of this oversight could not identify why the NWCF HEPA filter degradation accident scenario was not updated to include the ST for RH TRU waste repackaging. It is possible that those involved in the SAR revision at the time erroneously assumed that the TFF ST would be bounding for RH TRU repackaging. It is also possible that re-analysis of the ST was inadvertently missed due to the large number of changes to the SAR, the shared responsibility between two NFMs, and multiple safety analysts involved in making the changes.
In addition to adding the RH TRU waste repackaging scope, the annual SAR update and two other scope changes were also included in the SAR revision. The safety analysts involved with the change were also in transition at the time. The safety analysts for RH TRU may have erroneously assumed that the HEPA filter degradation scenario was only for other operations performed in the NWCF. It is noted that DOE-STD-5506-2007, "Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities" issued at about the same time period that the SAR was being revised, specifies the accidents that should be analyzed for a TRU waste facility in Table 3.3-1. DOE-STD-5506, Table 3.3-1 does not specify a HEPA filter failure event as one of the events recommended for analysis for a TRU waste facility.

**Lessons Learned:** Nuclear facility safety basis documents should be carefully reviewed when implementing new work scope, especially in shared facilities where there are multiple nuclear facility managers and nuclear safety analysts, when there is a significant change or addition to the isotopic profile, and/or when implementing more than one change in scope.

**II-13. ASSESSING CHANGING CONDITIONS DUE TO HAZWOPER REMEDIATION ACTIVITIES**

**Problem Encountered:** On November 4, 2010, during remediation activities in the East Yard of the Old Salvage Yard (OSY), funded by the American Recovery and Reinvestment Act (ARRA), a small piece of metal (approximately 1"x2"x1/2" - 2.5cm x 5.0cm x 0.75cm) was discharged during shearing operations. The metal travelled approximately 200 feet (70 m) across the yard and made contact with the back of a metal chair which was occupied by a subcontractor. Upon striking the back of the chair, the metal dropped to the ground. There were no injuries to the subcontractor and no visible damage to the chair [II-14].

**Analysis:** The OSY is a HAZWOPER site and multiple activities have occurred to remediate the Site. As the OSY remediation activities have progressed, several very large and/or very dense/hard objects have been discovered that require shearing to meet the waste acceptance criteria of the intended disposal facility. These objects were either too large or dense/hard for the smaller shears that have been operating in the OSY. Accordingly, these objects were segregated for campaigning when a large shear could be brought onsite. The large shear was being used to size reduce these materials when the incident occurred. A 150 feet (50 m) radius around the operation of the large shear was being used as a standoff distance. Small shears and grapples have been used for metal size reduction in the OSY until use of the big shear was required. For over 90% of these small operations, “natural” barriers and shields were in place in that there were initially 5 huge piles and approximately 1200 stacked boxes that acted as shields, and as work progressed, additional smaller piles emerged and also acted as shields and barriers for the surrounding size reduction operations. As piles started shrinking due to the disposition of the metals offsite, more open space resulted, and when large shear operations began, the number and size of barriers was minimal. A centralized location for big shear operations that had a natural embankment on one side was chosen, and when available, some large tanks and other large items were strategically positioned around the big shear operations to act as a shield or barrier for any potentially ejected metal. Although the standoff distance was pro-actively increased to 150 feet and barriers and shielding used when available, an adequate job hazards analysis/assessment of the risks associated with using the big shear without the "natural" pile and box barricades that had previously been in place was not completed. Since metal had never travelled greater than 50 feet (15 m) when using the small shear, personnel failed to adequately analyze the potential impacts associated with using a big shear without the "natural" barricades that approximately 90% of the small shear operations had the advantage of. Small shear operations were allowed to resume on November 8, 2010. The location, number and use of spotters for the small shears remained the same. The JHA for small shears indicated that spotters will control the area. This practice of using spotters to control the work zone for small shear operations was reinstalled with reinforced discipline.

The JHA for large shear operations was red-lined to implement controls for a 300 feet (100 m) stand-off distance and for a grapple operator to be allowed within the zone to bring metal to the Shear Operator, with the stipulation that the demo cage of the grapple will be facing toward the shear during shearing activities. The number of spotters was retained the same for large shear operations, but spotters were
relocated at least 300 feet away with the primary purposes of controlling the established 300 feet boundary and assisting the Shear Operator in ensuring that the shear stays within the safe designated operating location and does not encroach into potentially dangerous or unauthorized zones. Shear materials were relocated to the shear itself to maintain the 300 feet boundary.

The Facility Manager committed to sharing the Lessons Learned from inadequate review and assessment of the changing conditions in the OSY and the associated failure to evaluate how such changes might impact ongoing and future work. Although the intent of the ongoing remediation activities was to reduce and eliminate the scrap metal in the OSY and was being successfully achieved, it was not adequately acknowledged that the large piles and stacks of boxes were playing a vital role as barriers/shields for the small shear operations. Since elimination of the piles and boxes was the goal of the remediation activities and since the piles and boxes had never been credited as controls, no evaluation was made with regards to how their elimination could impact future operations, such as large shear operations.

Facility Managers and Project Managers should evaluate their ongoing and long-term HAZWOPER remediation activities as changes occur in order to determine if adequate controls remain in place or if additional controls are needed. Successful completion of these activities can result in changing conditions and may render previously implemented controls as inadequate. Assessing how completion of an activity may impact other ongoing or planned activities on a regular basis will allow an opportunity for determination and implementation of any additional controls needed to ensure safe and successful completion of the additional activities.

**Lessons Learned.** Certain remediation activities have a potential to cause hazards to nearby environments and facilities. Adequate hazard assessments should be conducted in this regard.

II-14. SHARING OF INDEPENDENT OVERSIGHT RESOURCES AMONG SITES, PADUCAH AND PORTSMOUTH FACILITIES, USA

**Problem Encountered:** In order to maintain approval to ship waste to the Nevada National Security Site (NNSS), each Site is required by the NNSS Waste Acceptance Criteria (NNSSWAC) to have an annual Independent Assessment of their NNSS Waste Certification Program. This assessment verifies compliance with the NNSSWAC program requirements and must encompass the entire waste certification program and supporting elements. In previous years, the required annual Independent Assessment has been performed by a contractor (3 auditors) with vast knowledge of the NNSSWAC requirements and previous Nevada Auditor experience. This is not only expensive but hard to find the skill mix needed to perform an adequate assessment.

In 2011 Paducah evaluated the program requirements to develop alternate options to third party contractor audits. Exchanging resources with another DOE site with an active NNSS program was determined to be a viable alternative. Based on follow-on discussions between the Paducah and Portsmouth Waste Certification Officials, the two contractors agreed to exchange resources to conduct Independent Audits on each other’s NNSS Programs. A memorandum of agreement between Portsmouth and Paducah was developed and the process for the assessment sharing was started. After the agreement, the contract, and all other applicable documentation were signed by each Site and the arrangements were made for the actual assessments.

Paducah assembled a team to perform the Portsmouth assessment in the areas of Quality Assurance, Waste Characterization and Traceability. The team consisted of a QA Specialist, Waste Engineer and Waste Certification Official (Lead Auditor). Paducah developed a checklist and Audit Plan and submitted it to Portsmouth for approval. Portsmouth provided Paducah with the implementing procedures of their NNSS Waste Certification program to be reviewed prior to the assessment. Paducah’s team went to Portsmouth to perform the on-site portion of the assessment on November 27-28, 2012. A Draft Assessment report was completed and provided to Portsmouth on 12-20-12 for review and factual accuracy. The final report was signed and sent to Portsmouth on 1-3-13.

Portsmouth assembled a team to perform the Paducah assessment in the areas of Quality Assurance, Waste Characterization and Traceability. The team consisted of a QA Specialist (Lead Auditor), Waste Engineer and Waste Certification Official. Portsmouth developed a checklist and Audit Plan and submitted it to Paducah for approval. Paducah provided Portsmouth with the implementing procedures of their NNSS Waste Certification program to be reviewed prior to the assessment. Portsmouth’s team
went to Paducah to perform the on-site portion of the assessment on December 18-19, 2012. A Draft Assessment report was completed and provided to Paducah on 1-15-13 for review and factual accuracy. Paducah received the final report on 1-29-13.
The NNSS Waste Certification Program Independent Assessment sharing between Portsmouth and Paducah was not only a cost savings for both sites, but provided a program improvement learning experience for both teams. Each site’s audit team members were very knowledgeable in their respective areas of expertise. The ability to see how another site implements NNSS requirements was invaluable and will promote process improvements and streamlining at both sites [II-15].

**Analysis:** Utilization of resources currently engaged in implementation of an NNSS Program increases the quality of the audit. Exchanging resources with another site significantly reduces the costs of the audit team and resources to manage site access of visiting personnel. Observing operations at another site provides workers with exposure to alternate programs and processes that may result in identification of improvement opportunities that can be implemented when they return to their home site. When pursuing resource exchanges with other contractors a Memorandum of Agreement is required at a minimum and should be started as early as possible with timely communication updates and coordination with the DOE office.

**Lessons Learned:** To share resources between facilities and sites provides cost savings and performance improvement opportunities

II-15. DISCUSSION OF LESSONS TO BE LEARNED WHEN TRANSFERRING AREAS BETWEEN CONTRACTORS, IDAHO OPERATIONS OFFICE AND IDAHO NATIONAL LAB

**Problem Encountered:** For a few years decommissioning work was carried out by a DOE-EM (DOE Office of Environmental Management) contractor in a defined and separately controlled decommissioning area located within an operating facility managed by an NE (DOE Office of Nuclear Energy) contractor. Both DOE-EM and DOE-NE are prime contractors to DOE-ID (Idaho National Engineering and Environmental Laboratory). The scope of the work included decontamination, demolition and complete removal of highly contaminate reactors, confinement buildings and support structures. After completion of decommissioning work, the area was vacated and turned over to the Facility operated by NE.
Subsequently, some radiologically contaminated debris or soil has been found in areas within or near the previously managed D&D area [II-16].

**Analysis:** Inter-contractor issues emerged regarding adequacy of radiological cleanup, surveys and coordination of turnover of the work-site from the decommissioning contractor to the Facility contractor. Some of the inadequacies included:

- The Interface Agreement for decommissioning work did not contain any details about turnover of the decommissioning area back to the facility operating contractor;
- Coordination between contractors was limited to the following:
  - Informal agreement was reached with the contractor assuming responsibility perform detailed radiological surveys with vacating contractor observing,
  - Receiving contractor performed limited radiological surveys prior to assuming responsibility for the area,
  - A formal turnover meeting was held but the receiving contractor did not attend.
- Surveys performed by the contractor assuming responsibility, beginning about a month following transfer, discovered a number of radioactive particles and contaminated debris in and around the transferred area;
- Difficulty obtaining support from the vacating contractor following the transfer due to project completion and no remaining funding.

**Lessons learned:**
More detailed information should be specified in the Interface Agreement on transferring responsibility back to the facility operating contractor;

Formal transfer agreement between contractors should take place, including a process similar to a readiness review;

Assuming contractor needs to be more fully engaged in verification of conditions prior to assuming control.

II-16. LESSONS LEARNED FROM V1 NPP DECOMMISSIONING PROJECT, SLOVAKIA

II-16.1. Planning and Projects Preparation

Lack of detailed characterization of nuclear facility

Issue: Missing Comprehensive Decommissioning database for planning of decontamination processes, dismantling procedures and tools, radiological protection, materials management (radioactive, non-radioactive and hazardous) and decommissioning planning (e.g., planning costs, decide on decommissioning methods, dismantling works planning, manpower, decontamination efforts, waste stream determination, waste management, dose assessment, free release of materials, cost estimation, and other decommissioning activities).

Lessons learned: Site characterisation (Physical and Radiological) is a basic precondition for decommissioning. Analysis of the project based on the plant inventory / characterisation is necessary to issue successful dismantling strategy, a consistent plan and a well-structured project. Initial characterization has to include estimation of the radioactive, hazardous and other waste amount. Keep conservative approach and take into account atypical occurrence of contaminants and hot spots (local emitters, asbestos, oil, other organic compounds) that might have significant impact on the cost of treatment and disposal. Existence of other nuclear facilities at the same site has to be considered in this regard.

Lack of knowledge of precise location of existing utilities

Issue: Missing as-built drawings or precise location of existing utilities (piping, electrical cables) belonging to, or shared with, another facility and the risk of possible damage during execution of works. During civil works can be also find unexpected obstacles in the ground.

Lessons learned: This issue has to be considered during preparation of tender documents and management procedures for notification and solution of unexpected obstacles. During preparation provide review of local documents as carefully as possible performing of excavation, visual inspection and walk-downs, possibly use hand digging. Prior to performing the works switch-off (if possible) electrical power supply in affected areas.

Coordination and interfaces with others decommissioning projects or entities at the site

Issue: The Suppliers declare experience in the complexity of multi-project environment and interfaces, in terms of input data, parallel works, requirements, priorities and boundary condition. However, coordination is often difficult because many constraints and outputs from other contracts were delayed or advancing in parallel.

Lessons learned: Keep interfaces between contracts/projects under managerial control. Analyse projects’ impacts and interfaces with other projects and activities as soon as possible. Plan implementation of the most interfering projects as early as possible because impact to the time, rework, delay, claims/contract amendments.

Knowledge of the plant facilities and equipment

Issue: The learning curve of the implementation of a multi-project development had a considerable influence on the project implementation.

Lessons learned: When selecting suppliers, put emphasis on deep knowledge of legislation, procedures and working conditions on the site and design of nuclear facilities. For foreign suppliers is important to have an experienced local subcontractor to support successful implementation of the project and the overall project team performance. These workers should have had more responsibilities and should have been more involved in critical tasks where this knowledge is used in the benefit of the project. To
understand the learning curve and accept it as necessary parameter of working in an efficient project environment.

**Common systems shared within a multi-facility site**

**Issue:** Because of the final shutdown of V1 NPP and the following preparation for decommissioning, the Nuclear Regulatory Authority required the segregation of V1 NPP from other nuclear installations and erection of a new independent area nuclear security and protection system. It complies with all legislative requirements to enable the decommissioning of the V1 NPP without any negative influence on other nuclear installations in operation.

The common systems in multi-facility site have to be adopted to a new situation, e.g. heating and steam distribution system functions, demineralised water, compressed air, compressed nitrogen, decontaminating solutions, wastewater etc.

**Lessons learned:** To design and implement a new comprehensive plant nuclear security and protection system. To design and implement an optimal configuration of the operating systems of the NPP, satisfying the following conditions:

- The supplying media to the operating consumers (including waste processing) will continue operation after the final shutdown without any perturbations;
- The number of the equipment in operation will be minimised;
- The operating systems configuration and conditions will facilitate the shutdown and decommissioning process;
- To cope with the new operational conditions during shutdown and transition period;
- To provide maximal flexibility with regard to the process of decommissioning;
- To continue the remaining nuclear facility(ies) in operation without any disturbances;
- Any entity, as building, turbine hall and so on, shall be able to be entirely dismantled without any impact on the other entities of V1 area.

**II-16.2. Licensing activities and contract management**

**Smooth Authority approval process**

**Issue:** Inappropriate quality of licensing documents submitted for approval in accordance with the legislative requirements and standards might have significant impact on delays.

**Lessons learned:** Develop appropriate communication procedures to assure that all regulatory bodies and stakeholders are promptly informed of any important information or decision.

Keep effective communications and regular meetings with authorities – on monthly or quarterly basis.

Firmly adhere to “no surprises” policy as the most important commitment in any licensing process.

Close follow up the process of legislation amendment, close contacts with authorities. Flexible approach to accommodating changes decreases the costs.

Put comprehensive emphasis on the high technical level of licensing documentation.

**Experienced and skilled Project Managers**

**Issue:** Experienced and skilled Project Managers have significant impact to the contract performance.

**Lessons learned:** The Project Manager plays key role during preparation and implementation of the project concerned. Therefore, it is necessary to pay adequate attention to continuous education, training and motivation.

**II-16.3. Dismantling and demolition**

**Not enough space for execution of decommissioning activities**

**Issue:** Treatment of dismantled material in the place of removal might be difficult due to the space constraints, coordination of mass flow, radiation exposure, etc. It is important to precisely specify the interfaces of material flows and rigorous inspection by the customer. The efficiency of waste metals management significantly increases the separate treatment of ferrous and non-ferrous metals.
Lessons learned: Treatment of dismantled material in separate treatment workshop(s). External treatment after dismantling (warm workshop) contributes to the continuous and rapid dismantling (no bottlenecks), avoidance of contamination spreading, minimization of personnel radiation exposure and the project costs.

Central or separate concrete crushing station
Issue: During preparation of demolition projects was in place intention to erect one Central crushing station for large amount of concrete materials. Result of assessment in terms of schedule, mass flow, logistic, priorities and interfaces between contracts did not recommend this option to be adopted.
Lessons learned: Provision crushing concrete and construction waste by mobile crushing station in each project separately might minimize the costs, improve interfaces between separate contractors, decrease demand on coordination, and minimize possible delays.

Vibrations and dust – impact on other nuclear facilities in operation
Issue: Given the proximity of the V2 NPP and Interim Spent Fuel Storage in Bohunice, it was necessary to provide a temporary portable seismic reading device at the boundaries of site during demolition cooling towers. The device continuously monitored the vibrations during implementation of cooling towers demolition. The Contractor monitored vibration values continuously and ensured that measures were taken to be under the limit for vibrations. Within demolition of cooling towers the seismic sensors allocated in the Interim Spent Fuel Storage cannot record any seismic event exceeding the level of the limits. The same applied for the seismic sensors in adjacent V2 NPP.
For the implementation of demolition, the Contractor was required to take all measures which assist in any way possible to the elimination of the highest rate of dust production at the site.
Lessons learned: In case that the measured values of vibrations approached the stated limit, the Employer required to immediately stop the works, consider the situation occurred and take such measures to be below vibrations limit. The proposed measures have been approved by the Employer. Minimising the dust spreading can be achieved during demolition by so-called water jet method (water screen), which is standardly used in combination with a suitably selected method of demolition, or eventually in combination with additional (auxiliary) measures for decreasing dust arisings (catching screens, fencing etc.). If other methods (measures) are selected, the Contractor is required to prepare an assessment that would prove the best solution to the problem in view of nature of the site.

II-16.4. Waste treatment

Flow of material and temporary storages
Issue: Buffer storages and calculation of their capacity play essential role in smooth decommissioning process.
Lessons learned: Buffer places are necessary to avoid bottlenecks – early planning of that. For the release of materials from the controlled area is essential to establish the buffer storages. Significant attention should be paid to planning and logistics of the flow of radioactive waste and the associated costs and resources. Necessity appears to standardize packaging slots as a basis for further treatment of the material from decommissioning.

Interim Storage of radioactive waste
Issue: The great advantage of the decommissioning process was the availability of processing and storage capacity of JAVYS before the decommissioning, but very important was also to introduce a new interim RAW storage facility for the storage of solid RAW coming from the decommissioning of nuclear installations in the Jaslovské Bohunice site. This waste are such that can be released into the environment (decay function of the facility), RAW intended for further processing that can be disposed in the Mochovce Disposal facility (buffer function of the facility) and wastes that require safe long-term storage (storage function of the facility).
Lessons learned: Establishment of an interim storage in due time before decommissioning. Use of decay storage, capacity for dismounting large components and also for the high activated components placement.

II-17. REMOVAL OF SPENT NUCLEAR FUEL FROM CHNPP UNITS 1-3

The Chernobyl NPP has wide experience in overcoming issues that might significantly complicate implementation of ChNPP Units Decommissioning Program. Usually, programs for decommissioning of nuclear sites last for long period – up to 15 years in case of immediate dismantling and more than 50 years in case of deferred dismantling strategy. The strategic planning system under the conditions of uncertainties and “flexible” plan from the long-term perspective should be available at enterprises, which are responsible for the decommissioning, to identify problems at early stages and response in due time. The Chernobyl NPP has a positive experience in implementing strategic planning that considerably improved implementation of ChNPP Units Decommissioning Program.

This Annex includes considerations on issues resolved in relation to delayed construction and commissioning of the Interim Spent Fuel Storage Facility (ISF-2) that was expected to be commissioned in 2005. However, the ISF-2 construction was interrupted due to incompliance of the storage facility design with the national technical and safety standards. This resulted in the ISF-2 project interruption and as a consequence was impossible to remove spent fuel from Units 1-3 what would increase the total duration of ChNPP Units preparation for decommissioning – introduction into the safe enclosure mode. Problems with the new storage facility would have also a negative impact on the ChNPP decommissioning strategy. The new situation was unacceptable for Ukraine because of the following reasons:

- Beginning of Units 1-3 decommissioning would be postponed for 11 years;
- A risk that the ISF-2 commissioning will be delayed remains;
- Large expenses were necessary for the safety support.

The whole strategy of works was changed promptly to resolve this problem. The decision to transfer spent nuclear fuel from the Units 1-3 into the existing (old) “wet-type” ISF-1 has been made. Significant work on improvement of safety and licensing of this storage facility was performed to implement this option. The result was that the State Nuclear Regulatory Authority of Ukraine issued the permission to use ISF-1 for receiving of Units 1-3 spent fuel. This work allowed avoiding considerable time and financial losses due to delay of ISF-2 commissioning and minimized impact on the whole process of ChNPP decommissioning. Recently the ChNPP Units 1-3 decommissioning does not depend on new ISF-2 commissioning dates.

This allows completely released the Units 1-3 from spent nuclear fuel in 2015. Without such strategic decision the release of ChNPP Units 1-3 from spent fuel would not be possible before 2020. In such way were financial losses and radiological risks and ChNPP Units 1-3 minimized and planned decommissioning dates kept. Following lessons learned can be offered based on this case study:

- The enterprise responsible for decommissioning on multi-facility site should have a strategic planning function;
- Creation of several planning horizons (current / short-term: within a year; perspective – mid-term: up to 5 years; strategic / long-term: more than 5 years). It allows early detection of problems and their solutions;
- Development of flexible plans that include alternative scenarios in case of unexpected issues.
REFERENCES TO ANNEX II

[II-1] US DEPARTMENT OF ENERGY, Lessons Learned Data Base #: Y-2012-OR-BWY12-1103, 12/19/2012
[II-6] US DEPARTMENT OF ENERGY, Lessons Learned Data Base #: RCCC-08-002, 2/6/2008
[II-16] US DEPARTMENT OF ENERGY, Operating Experience Committee, Conference Call Archive, 10 April 2012
GLOSSARY

*Definitions are extracted from the IAEA Safety Glossary*¹ and other IAEA publications²³

**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.

**Decommissioning phase**
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) is the strategy in which parts of a facility containing radioactive contaminants are either processed or placed in such a condition that they can be safely stored and maintained until they can subsequently be decontaminated and/or dismantled to levels that permit the facility to be released for unrestricted use or with restrictions imposed by the regulatory body.

**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 materials 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**
This term refers to a logical and preferably optimized used in 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.

**License**
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 license is termed a **licensee**.
The licensee 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 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 [65].

**(Nuclear) facility**
A facility and its associated land, buildings and equipment in which radioactive materials are 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”.

**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, inter alia, private individuals, governmental bodies, consignors or carriers, licensees, hospitals, self-employed persons, etc. Operator is sometimes used to refer to operating personnel. If used in this way, particular care should be taken to ensure that there is no possibility of confusion.

**Operator** 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 quality assurance.

**Redevelopment**
Planning, development, re-planning, redesign, clearance, reconstruction or rehabilitation of all or parts of a project area.
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 has ceased; or the reuse for the original purpose but under new circumstances.

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.

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 clean-up 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).

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 syzygistic 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 of 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.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>BWR</td>
<td>Boiling Water Reactor</td>
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<tr>
<td>CEA</td>
<td>Commission of Atomic Energy (France)</td>
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<td>DOE</td>
<td>US Department of Energy</td>
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<td>INPP</td>
<td>Ignalina NPP, Lithuania</td>
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<td>ISDC</td>
<td>International Structure for Decommissioning Costing</td>
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<td>ISFSI</td>
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<td>MARSSIM</td>
<td>Multi-Agency Radiation Survey and Site Investigation Manual</td>
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<td>MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Thermal Megawatts</td>
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<td>NDA</td>
<td>Nuclear Decommissioning Authority (UK)</td>
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<td>NPP</td>
<td>Nuclear Power Plant</td>
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<tr>
<td>PDMS</td>
<td>Post Defueling Monitored Storage</td>
</tr>
<tr>
<td>PWR</td>
<td>Pressurized Water Reactor</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SAFSTOR</td>
<td>US term for SAFe STORage, a decommissioning option equivalent to Safe Enclosure</td>
</tr>
<tr>
<td>SAR</td>
<td>Safety Analysis Report</td>
</tr>
<tr>
<td>SSCs</td>
<td>Structures, Systems and Components</td>
</tr>
<tr>
<td></td>
<td>A general term encompassing all of the elements (items) of a facility or activity which contribute to protection and safety, except human factors. Structures are the passive elements: buildings, vessels, shielding, etc. A system comprises several components, assembled in such a way as to perform a specific (active) function. A component is a discrete element of a system. Examples of components are wires, transistors, integrated circuits, motors, relays, pipes, fittings, pumps, tanks and valves.</td>
</tr>
<tr>
<td>SE</td>
<td>Safe Enclosure</td>
</tr>
<tr>
<td>WWR</td>
<td>Water-cooled Water-moderated Reactor (A Russian-type research reactor, also spelled VVR)</td>
</tr>
</tbody>
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Consultancy meetings
Vienna, Austria: 18-22 May 2015, 2-6 October 2017, 21-25 May 2018