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LESSONS LEARNED FROM THE DEFERRED DISMANTLING OF NUCLEAR FACILITIES

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IAEA NUCLEAR ENERGY SERIES No. NW-T-2.11

LESSONS LEARNED FROM THE DEFERRED DISMANTLING OF NUCLEAR FACILITIES

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2018

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1400 Vienna, Austria
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tel.: +43 1 2600 22417
email: sales.publications@iaea.org
www.iaea.org/books

Printed by the IAEA in Austria
September 2018
STI/PUB/1803

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Lessons learned from deferred dismantling of nuclear facilities / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2018. | Series: IAEA nuclear energy series, ISSN 1995–7807 ; no. NW-T-2.11 | Includes bibliographical references.
Identifiers: IAEAL 18-01184 | ISBN 978–92–0–100418–5 (paperback : alk. paper)
Subjects: LCSH: Nuclear power plants — Safety measures. | Nuclear facilities — Decommissioning. | Nuclear power plants — Decommissioning.
Classification: UDC 621.039.566 | STI/PUB/1803

FOREWORD

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

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

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

Over the long history of nuclear decommissioning, deferred dismantling has been applied in a number of decommissioning projects. This is due to factors such as unavailability of financial resources, lack of waste disposal sites and the existence of multiunit sites where units being gradually shut down will be dismantled only when all site units have reached the end of their operations. The deferred dismantling strategy makes use of a defined waiting period commonly called 'safe enclosure' or 'care and maintenance'. During this safe enclosure period, which often lasts several decades, the facility is placed into long term storage in which it is maintained in a safe condition pending eventual dismantling. Potential savings from the deferral of dismantling and associated waste management are balanced against factors such as potential safety, environmental and regulatory impacts.

The IAEA has dealt with deferred dismantling in several previous publications; however, those publications reflected limited experience of the actual implementation of safe enclosure strategies. To date, several installations have been kept in safe enclosure for decades, and a few have even reached the stage of final dismantling after the planned period of safe enclosure has elapsed. It is estimated that some 50% of nuclear power units currently shutdown are kept in safe enclosure. Technical information and lessons learned over long periods of deferred dismantling are available from these nuclear facilities.

This publication presents information on and best practices for deferred dismantling from a number of nuclear power reactors. It also provides guidance on the preparatory activities for reaching safe enclosure, and on requirements for the management of the safe enclosure state. This publication was drafted and reviewed by a number of international consultants. The IAEA officers responsible for this publication were M. Laraia and V. Michal of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

SUMMARY

A decommissioning strategy with deferred dismantling emphasizes that the deferral of dismantling (i.e. the waiting period) is the specific state into which the facility is transferred and kept for a defined period of time. In fact, safe enclosure conditions, that is, those conditions in which a facility can be maintained for a long time without presenting a risk to workers, the general public and the environment, can vary considerably between decommissioning projects. The meaning of safe enclosure can therefore be only very general, as it can be achieved in different ways. For example, at a multifacility site (e.g. a nuclear power plant with several units), surveillance of one shutdown unit while the other units are still in operation does not present a significant problem, and therefore the shutdown unit can be maintained in a state not very different from its operational state for several decades. On the other hand, nuclear power plants or research reactors where there is no neighbouring installation and no infrastructure at hand are best placed into a passive state of safe enclosure, in which only minimum surveillance and almost no maintenance is required. This publication therefore first expands on the ‘active’ and ‘passive’ options of safe enclosure.

The preparatory activities for placing a facility into safe enclosure are similar to those that have to be carried out during any transition phase between operation and decommissioning. However, preparing an installation for safe enclosure has specific features. Knowledge of the plant, its history and its contamination status needs to be handed over to the future dismantlers over a period of several decades. This publication describes a number of activities that are planned or have been implemented for safe enclosure. These include, in summary, the following aspects:

(a) The work needs to be directed towards safe enclosure. Besides the removal of the spent fuel and the operational waste, a new infrastructure needs to be installed in view of the safe enclosure objectives. In addition, parts of the facility that will not be maintained during safe enclosure can be demolished. Furthermore, there are approaches in which buildings on-site have been repurposed for storing operational radioactive waste, e.g. to make use of natural decay.
(b) The hazards pertaining to safe enclosure are discussed in detail. It is necessary to demonstrate that there will be no impacts leading to a significant dose to workers and the general public, and that it will be possible to maintain the facility in a safe state for the defined period.
(c) Planning for later dismantling needs to account for tools and infrastructure in the plant that may become obsolete over several decades and will have to be replaced after the period of safe enclosure.

The publication further expands on the management of a safe enclosure state. The following points are worth considering in order to achieve safe and cost effective management:

(a) As decontamination, dismantling and other activities may continue for a certain period of time until safe enclosure conditions are attained, the appropriate resources in terms of staffing and training need to be ensured at all times.
(b) Organization and administrative control should be maintained at a sufficient level throughout safe enclosure, including the management of the decommissioning fund.
(c) In addition to the radiological characterization of those parts of the facility that will be dismantled for safe enclosure, care needs to be taken that the dormant plant is well characterized and that characterization records are preserved during the entire enclosure period.
(d) Waste management can take advantage of radioactive decay. This implies that part of the radioactive waste can be stored within the safe enclosure. In this way, the costs of waste conditioning can be reduced and postponed.
(e) Surveillance of the plant to ensure security during safe enclosure is of great importance. This control can be carried out by personnel on-site or through remote surveillance, making sure that any anomaly in the plant conditions or intrusion is detected in a timely fashion and countermeasures are taken with no delay.

Finally, the publication provides guidance to interested parties. The main text is supported by an extensive list of references, national case studies and a number of lessons learned based on actual occurrences.

1. INTRODUCTION

1.1. BACKGROUND

A nuclear power plant (NPP) can operate for up to 60 years, if maintenance and periodic back fitting is performed on a regular basis. Nuclear facilities like laboratories can have a longer lifetime, but, depending on the experiments performed, the laboratory may be refurbished several times during that lifetime. Some purpose built nuclear facilities might have a much shorter lifetime, as their nuclear components might only be used for a limited number of tests.

At the end of its operational lifetime, a nuclear facility will undergo planned shutdown and be decommissioned, and the site returned to other uses. In principle, there are two strategies for achieving this objective: immediate dismantling and deferred dismantling [1–3]. Entombment is not considered a decommissioning strategy and is not an option in the case of planned permanent shutdown [4]. It may be considered a solution only under exceptional circumstances (e.g. following a severe accident).

The IAEA has established the following strategy as being applicable to all facilities [4]:

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

For a reactor, in all scenarios, all spent fuel needs to either be removed to the spent fuel pool or to on-site (dry or wet) independent spent fuel storage installations, or be transported to a storage or reprocessing facility. Wastes arising from routine operations, whether of an NPP or laboratory, are also to be removed and eventually disposed of. The dismantling of the facility typically starts following the removal of the fuel. Dismantling can be immediate and the area subsequently reused for new purposes; or deferred dismantling can be applied, for which there are active and passive options. Reference [2] states that:

> "The active option means that the facility will be available for entry at any time and staff is on-site at least during the normal work day. The passive option means that the facility is not normally accessible and that entry is only made periodically (once or twice a year) to assess conditions."

The common factor in the process of deferred dismantling is the transfer of the nuclear facility to a stable condition. Loose (also known as mobile) activity is removed (as far as is practicable) and conditioned, non-contaminated buildings are demolished and contaminated buildings are sealed by the establishment of safe enclosure. After a period of safe enclosure, final dismantling begins; the decommissioning process is complete after site release.

The decision regarding immediate dismantling or deferred dismantling depends on several internal and external factors. Regardless of a growing preference being given to immediate dismantling as a decommissioning strategy, it was recently estimated that some 40% of shutdown NPPs worldwide have adopted a strategy of safe enclosure [5]. Even for facilities that have aimed at immediate dismantling, a lead time of five to ten years is commonplace before active dismantling works begin.

Although it is never too early to start planning for decommissioning [6], the choice of dismantling strategy is often made in the last years of the operating lifetime of the facility. Factors that influence the selection of the decommissioning strategy are described in a number of IAEA publications [1–3]. Funding, for example, is an important input to that decision. What funds are available now or in the future governs the amount of work that can be performed and when it can be performed. Another important consideration is the availability of storage or disposal facilities for the wastes generated during the dismantling process.

There are several other issues that occur when a nuclear facility is permanently shut down. A major issue is the loss of the workforce, as many staff may leave the company to find a new job. This may lead to a loss of knowledge about the construction features and the history of the facility ('brain drain'). Another major issue is the gradual deterioration of, and the need to maintain, the structures, systems and components needed for ensuring safety and eventually for dismantling the facility.

1.2. OBJECTIVE

The objective of this publication is to provide information, experience and assistance on how to plan for a safe enclosure strategy and manage nuclear facilities after they have been transformed into safe enclosure facilities, and what needs to be considered in decommissioning plans. Technical aspects are mainly addressed in this publication. Safety and security considerations are briefly introduced with relevant IAEA references provided.

It is assumed that the decision to employ safe enclosure has already been made and the relative merits of this approach are not discussed. Even large facilities bound for immediate dismantling are likely to remain in an inactive state for several years before active dismantling is implemented (e.g. due to the need to finalize plans and obtain regulatory body authorizations); therefore most considerations discussed in this publication would also apply to those facilities. This publication also gives indications of what issues are likely to occur in the long term management of these safe enclosure facilities, and emphasizes the value of proper planning for their operation and maintenance.

This publication discusses the issues that have to be dealt with when preparing a facility for safe enclosure or safely maintaining it for a long time. It provides details of lessons learned from deferred decommissioning of nuclear facilities following planned shutdown; these lessons have been learned from experience at a variety of facilities, with a variety of hazards, configurations and decommissioning programmes. While some of the considerations addressed may apply to facilities involved in an operating incident or accident, the individual nature of their hazards and decommissioning challenges precludes their use as the intended target of this publication. This publication concerns only the preparation for, and the steady state part of, the safe enclosure phase; in the later part of that phase the on- and off-site requirements and arrangements will change as plans and infrastructure are prepared for the next phases, which are final dismantling, environmental remediation and site release. These arrangements are not described here.

This publication updates information and guidance contained in previous IAEA publications [1–3, 7], based on growing experience and lessons learned from the deferred dismantling projects of nuclear facilities following planned shutdown at the end of operational life. Time has provided a wealth of new information that was not available when the IAEA produced the above mentioned publications; there are now many facilities that have been kept under safe enclosure for 30 years and more.

1.3. SCOPE

Nuclear facilities include large commercial facilities such as NPPs or chemical nuclear facilities (reprocessing or fuel fabrication plants). Smaller facilities such as laboratories and industrial or medical facilities are also involved, although they are less likely to go through an extended period of safe enclosure. Special attention should be paid to smaller research facilities, as research teams have a tendency to focus on experimental results and not necessarily on detailed preparation for final shutdown and decommissioning. These facilities might be left improperly cleaned up and secured after the research ends. This concern is particularly acute for multifacility sites (e.g. research centres), where the focus can be placed on operating facilities and shutdown facilities can lag behind.

Entombment as a final decommissioning approach is conceptually very different from deferred dismantling, and its radiation protection principles are poorly defined as yet. Furthermore, experience of entombment is limited to very few countries. For these reasons, this publication does not address entombment. Recently, the IAEA position on entombment has changed. Entombment, in which all or part of the facility is encased in a structurally long lived material, is not considered a decommissioning strategy and is not considered an option in the case of planned permanent shutdown [4].

The information in this publication is intended to give a consolidated review of experience and practical guidance to those planning, managing and implementing the decommissioning of nuclear facilities. The publication may also be of use to those involved in the nuclear regulatory field when reviewing plans, carrying out inspection activities and confirming satisfactory completion of decommissioning. It may also be helpful to other stakeholders, such as local communities.

1.4. STRUCTURE

Following this introduction, this publication covers safe enclosure plant and site configuration in Section 2 and preparation for safe enclosure (PSE) in Section 3. Fire protection is addressed in Section 4, and approaches to managing safe enclosure are considered in Section 5. Section 6 deals with system functions and configuration. Safety management, organization and management, and regulatory considerations are addressed in Sections 7, 8 and 9, respectively. Principles of cost estimation for safe enclosure are considered in Section 10. Conduct of operations in the safe enclosure phase, and selected examples of safe enclosure projects are introduced in Sections 11 and 12. Conclusions are summarized in Section 13.

The Appendix includes an overview of possible ventilation systems for a safe enclosure. Annexes I, II and III provide experience from national projects, lessons learned, and meeting outcomes of the 2014 IAEA International Workshop on Lessons Learned from Planning and Implementation of the Deferred Dismantling Strategy for Dismantling.

2. SAFE ENCLOSURE PLANT AND SITE CONFIGURATION

This section describes the various definitions and types of safe enclosure and the options when a facility is put into a safe enclosure condition. For the purpose of this publication, the term ‘safe enclosure’ may be used to describe either the shutdown building or facility, or the stage or phase of decommissioning pending final dismantling.

2.1. TYPES AND DEFINITIONS OF SAFE ENCLOSURE

The concept of safe enclosure covers a variety of plant configuration and management options depending upon the regulatory approach of Member States and site specific considerations, but the general concept is consistent. In the case of an NPP, all spent fuel is typically moved from the reactor to the spent fuel pool following planned shutdown. In most cases, the fuel is either transported to a reprocessing plant or stored in dry casks or wet stores on-site. The least favourable option is where the fuel is stored in a spent fuel pool within the reactor building during safe enclosure. Depending upon the nature of the residual hazard, the intended period of safe enclosure and the local regulatory approach, personnel may remain on-site, continuously or periodically.

The two safe enclosure strategies, active and passive, are detailed in Ref. [2]. These are two extremes and there may be elements of both within a facility in a safe enclosure phase. Common to both strategies is the management of a site that poses a low risk to humans and the environment, and may be maintained in such a state for several decades. In general, a passive approach is implicitly associated with a lower level of residual hazard and requires little in the way of active management arrangements, for example ventilation or power supplies, and for this reason may be managed remotely from a central hub location or from another site managed by the same operator. The security aspects for a single unit, passively managed safe enclosure are expected to be more substantial than those on an actively managed site. An example of such a passive facility is the Nuclear Power Demonstration prototype reactor facility in Canada (see Section 12.5).

A decision to continue to manage a safe enclosure as an active facility may be taken based on the need to maintain a higher level of control of the residual hazard, or in the case of a relatively short safe enclosure period such as 10–20 years. The decision to maintain a safe enclosure as an active facility may simply be made because the facility is part of a much larger plant and therefore it is simpler to use the current workforce associated with the larger site. These sites may, however, need more frequent plant walkdowns and may still have operational requirements.

The United States (US) Department of Energy (DOE) uses the term ‘deactivation’ to refer to the process of placing a radiological or chemically hazardous facility into a safe and stable condition for interim storage prior to decommissioning and dismantling [8]. Deactivation is followed by a period of post-deactivation surveillance and maintenance.

The categorization of decommissioning strategies adopted by the United States Nuclear Regulatory Commission (NRC) is in wide use in the United States of America (USA) and elsewhere [9].

For NPPs governed by the US NRC, the period of deferred decommissioning is termed safe storage (SAFSTOR). Different sublevels of SAFSTOR are recognized, which vary in the type of activity and monitoring required:

(a) Hot/cold standby — the plant is kept in operating condition but is not actively delivering power; monitoring and maintenance is similar to that during a long outage. This may be a first step to allow the planning of further shutdown and decommissioning.
(b) Custodial SAFSTOR — systems such as radiation monitoring and ventilation are kept in operation, along with continuous site security and maintenance. Minimal initial decontamination is carried out.
(c) Passive SAFSTOR — requires a more thorough initial cleanup but allows only intermittent inspection of the site and shutdown of active systems such as radiation monitoring.
(d) Hardened SAFSTOR — prevents intrusion on contaminated parts of the plant by substantial barriers.

All varieties of SAFSTOR require positive action to decontaminate the site at the end of the storage period. In general, SAFSTOR alternatives include the shipment of spent fuel off-site prior to amending an operating licence to a possession only licence. However, the operator of Humboldt Bay Unit 3 found at the time of final shutdown that there were no facilities in the USA to receive spent fuel from that reactor. Therefore, spent fuel storage at Humboldt Bay is considered to fall within the definition of custodial SAFSTOR [10].

A strategy named ‘cold and dark’ was established at the Savannah River Site and elsewhere within the US DOE complex [11]. Cold and dark in US practice generally refers to individual buildings within a site and ensures a facility is isolated from all external sources of energy. This includes both identifying potential sources of stored energy and isolating electrical and mechanical devices that might pose a hazard to employees. For a building to be declared cold and dark, the following conditions need to be met:

(a) All electrical and mechanical systems that enter or leave the building have been identified, de-energized or depressurized, and physically disconnected;
(b) ‘Split’ systems have had their contents recovered and the piping entering the building may have been physically disconnected;
(c) All stored electrical energy devices that are part of the building distribution system (i.e. large capacitors, batteries) have been removed or discharged;
(d) Any stored mechanical energy devices (i.e. roll-up door springs, air receivers, gas cylinders) have been removed, verified to be discharged or left in place with a warning tag or label.

See also Annex II–4 for a cold and dark case.

There are many other safe enclosure terms, such as ‘cocooning’ and ‘mothballing’, which were used instead of safe enclosure in the literature in the 1980s and 1990s (e.g. Ref. [12]) but their use is now less common. These terms are not interchangeable and need to be used with caution to avoid confusion.

2.2. THE LIFETIME OF A SAFE ENCLOSURE

The duration of safe enclosure is dependent on numerous factors. The facility type, the number of buildings, whether the site has multiple units or is complex, whether the safe enclosure partially or fully encloses the site, the structural conditions of the buildings, the location of the site, the safety case, funding and waste route availability are some of the key factors that influence the duration of the safe enclosure period.

Decay of radionuclides present in the safe enclosure can be a contributor to the decision on the duration of the safe enclosure period. For water moderated reactors, the driving nuclide for the radiation dose profile is generally ^{60}Co. In some cases, there have been fuel leakages or other events during operations (including post-accident scenarios) that have resulted in other nuclides contributing to the dose to the workforce performing safe enclosure and the final decommissioning activities. As decay times for alpha emitting nuclides are generally longer than for beta/gamma emitting nuclides, a longer period of safe enclosure might be considered or immediate dismantling may be chosen. For graphite moderated or heavy water reactors, the contamination and activation by ^{14}C is of importance but will not dictate the duration of safe enclosure because the decay time of ^{14}C is very long. The activated impurities in graphite are the main contributors to the dose. Other components in the facility such as activated steel structures or embedded rebar need to be considered.

Generally, the most significant dose reduction is achieved during the first 15 years after the shutdown of the reactor. Transport of spent fuel outside the reactor may take three or more years. The defuelling period is followed by the transition phase to safe enclosure. The outcome of this approach is that some 12 years after the establishment of safe enclosure, most of the dose reduction has already been achieved.

The safe enclosure period needs to include a strategy for and the implementation of an ageing management programme. This programme identifies the likely mechanisms of degradation of in-service systems and structures that remain on-site during safe enclosure. Measures need to be put in place to mitigate these as necessary to maintain envelope and structural integrity. Additionally, some relatively short lived building components, for example the roof or wall cladding, may periodically need replacement. If both these sources of cost are fully factored into the safe enclosure management budget, deterioration is less likely to be a factor limiting the safe enclosure lifetime. However, extending the safe enclosure period beyond the original design lifetime or after the occurrence of severe events (e.g. extreme storms or earthquakes), which demand additional, unexpected investments in repair, may force the responsible organization to reconsider the continuation of safe enclosure. This is particularly true for non-reactor facilities where individual, smaller, conventionally constructed buildings are more prone to environmental damage than the sturdy, massive reactor buildings. As a result, in certain cases it may be desirable to accelerate preparations for final dismantling of the affected structures.

Another contributing factor to the lifetime of the safe enclosure is the availability of funding for final dismantling. The decommissioning fund established may grow by various means, including gaining interest on accumulated funds. The value of the fund needs to take account of inflation occurring over time. The decommissioning estimate ought to be checked periodically, e.g. every five to ten years, to determine if funding is still in line with the expected costs of final dismantling.

Another influence on the decision regarding the facility lifespan may be due to the availability of a waste repository. For example, if a waste disposal repository is not available there may be little incentive to dismantle the facility and store the waste in an existing or newly constructed facility on-site. In this case there can be a very limited gain in costs by starting the final dismantling, as the decommissioning waste needs to be kept under surveillance on-site and therefore the site infrastructure needs to remain available. There can be other factors, however, that drive the decommissioning strategy towards final dismantling and waste storage on-site (public opinion, high local unemployment, regulator expectations, etc.).

2.3. SYSTEMS IN SAFE ENCLOSURE

A facility in safe enclosure will typically still have systems to support surveillance and maintenance activities, including a ventilation system, electrical supply, fire detection equipment, etc., as well as a security system. Individual systems may be those that were used during the operational life of the facility, but it is more likely that these systems would be reduced to minimize the maintenance burden, or a new, smaller system would be substituted to support the safe enclosure phase. A safe enclosure strategy may be defined as passive or active; however, individual systems may also be active or passive regardless of the intended designation of the facility as a whole. Specific considerations relating to managing the systems at a safe enclosure facility are provided in Section 6.

2.3.1. Passive systems

2.3.1.1. Ventilation

Where the safety assessment does not require ventilation for the control of radioactive material or humidity, the ventilation system may be switched off, taken out of service or even removed prior to the start of the safe enclosure period. A passive ventilation system may utilize a differential pressure regulator or a breathing vent where air can enter the safe enclosure via valves if the outside pressure is higher than the inside pressure; conversely when the inside pressure is higher than the outside, air will leave the safe enclosure. An example of a reactor with a shutdown ventilation system is shown in Fig. 1.

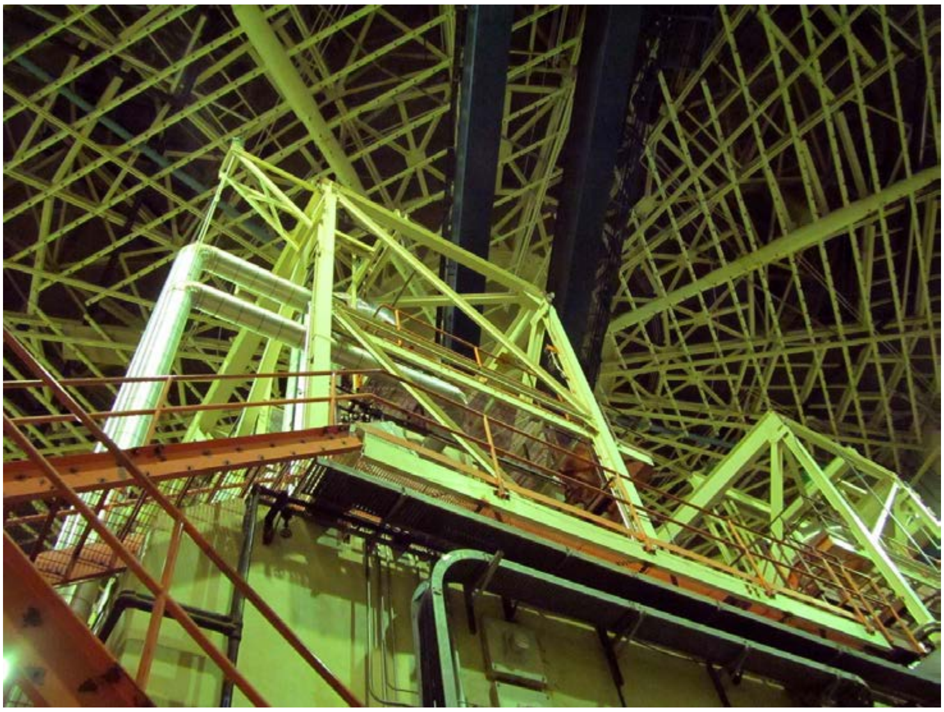

FIG. 1. Gentilly-1, Canada, in a cold and quiet state within the safe enclosure; all ventilation has been shut down and a dehumidifier installed to maintain the safe enclosure and systems properly (photograph courtesy of Atomic Energy of Canada Limited (AECL)).

A filtration system may be required to prevent radioactive materials from leaving the buildings. A wind catcher system can be used to force air through the facility to regulate the humidity in the reactor safe enclosure; this is possible in low residual contamination facilities. In all cases, care needs to be taken when entering a passive safe enclosure, as oxygen levels might be low in some areas and airborne contamination can be present. In some cases, the ventilation system is switched on a few hours before people have to enter the safe enclosure for periodical inspections.

2.3.1.2. Electrical supply

If an electrical supply is only necessary for limited surveillance and maintenance activities, the high voltage power lines could be removed and a suitable power supply provided. In the absence of an installed power supply, an alternative power supply will be utilized to meet safe enclosure requirements. System conditions should be assessed to ensure that they will function as expected throughout the duration of safe enclosure.

2.3.1.3. Conventional water system

Where a water supply is not necessary for surveillance and maintenance, a portable water supply may be sufficient. If water supplies are only necessary for the welfare of personnel, water may be brought to the site and wastes removed from the site by road during periods of planned works on a passive safe enclosure facility. Storm water systems may need to be reconfigured to meet safe enclosure requirements.

2.3.1.4. Aqueous wastes

If very low levels of loose contamination exist that may result in low volumes of low activity liquors being produced, as may be achievable with passive safe enclosure, it may be appropriate to transfer this liquor to a holding tank for disposal from site by road rather than discharging to the environment. More information on this item can be found in Section 6.2.

2.3.1.5. Security and site access

A safe enclosure facility will always need a security and site access system. When the safe enclosure is located on a multifacility site, this may be provided by other site staff. For a single site safe enclosure with a passive intent, the security arrangements may be provided remotely. The presence of personnel for a significant proportion of the time enables surveillance arrangements to be simpler. Where the safe enclosure is not associated with another facility, the cost of a continuous or semi-continuous site presence can be a significant contribution to the overall safe enclosure budget, particularly where local regulations preclude lone working.

2.3.1.6. Fire detection and fighting

Passive fire detection and fighting systems may be appropriate where significant effort has reduced the fire loading material in the building enough to justify the removal of active fire detection and firefighting systems. Such justification would be subject to appropriate safety assessment. Combustibles around the structure (e.g. vegetation and storage sheds or similar structural attachments) also need to be removed, and vegetation needs to be maintained on a regular basis. Deactivated electrical transformers that pose a fire hazard to the main structure need to be removed or drained of their combustible oils. Oil lines and oil carters in pumps and valves have to be drained. The turbine oil carter needs to be drained as this may be the largest volume of oil on-site. Storage of flammable or combustible liquids needs to be eliminated. Storage containers, including above ground and underground tanks, need to be emptied and secured either by purging or removing the container, or by filling with sand or concrete. More information on this item can be found in Section 4.

2.3.2. Active systems

2.3.2.1. Ventilation

An active ventilation system may be permanently or periodically operated where required by safety assessment. The cost of maintenance of these systems over the period of safe enclosure, as well as the wastes requiring disposal, should be recognized when this strategy is selected. Ventilation may, however, be required where loose contamination is present or for other reasons, for example the control of humidity within a building.

2.3.2.2. Electrical supply

If an installed power supply is necessary, the system only needs to be sufficient to manage the safe enclosure period and not final dismantling, unless the safe enclosure period is relatively short (10–20 years) and a system assessment has been completed to prove the integrity of the system. This may mean reducing the size of the existing system or installing an overlay. It is unlikely that high voltage will be present on single facility safe enclosure sites.

2.3.2.3. Conventional water system

Maintaining a conventional water system, whether for plant operation or personnel welfare, introduces a significant maintenance burden, e.g. to ensure continued compliance with *Legionella* regulations. As with the electrical system, the system should be sufficient to manage only the safe enclosure period.

2.3.2.4. Aqueous wastes

Where aqueous wastes are generated during the safe enclosure period and there is no provision to remove them from the site by road, an aqueous waste disposal system will need to be maintained. The extant operational life of the plant may be reconfigured during the preparations for safe enclosure to ensure the continued operability of the plant for the deferral period. More information on this item is found in Section 6.2.

2.3.2.5. Security and site access

An active security and access system is more likely to be associated with a remotely managed safe enclosure. While the cost of maintaining the hardware is more expensive than a passive system, the labour costs are typically substantially lower, thereby making this the preferred configuration where a positive safety assessment can be made.

2.3.2.6. Fire detection and fighting

Where there is significant fire loading within a facility, or a safety assessment requires it, a fire detection system needs to be maintained. A wireless detection system is demonstrably cheaper than a wired system and involves less operational activity, but detection coverage and reliability needs to be assured. More information on this item can be found in Section 4.

2.4. DEMOLITION OF BUILDINGS

For all types of safe enclosure described above, the number of structures and the volume of the enclosed structure needs to be kept to a minimum. Buildings which are to remain during the safe enclosure phase may have their height or footprint reduced; at some facilities all non-contaminated buildings are demolished (Figs 2 and 3) with regulatory approval, including barrier walls associated with turbine cooling water systems, thereby reducing maintenance activities and costs.

The approach taken to demolishing buildings will depend upon the length of the safe enclosure phase; if the phase is short, for example, 20 years, it may be justified to maintain a building whose structure may be of use

FIG. 2. Bradwell NPP, UK: Auxiliary turbine hall demolition (courtesy of the UK Nuclear Decommissioning Authority).

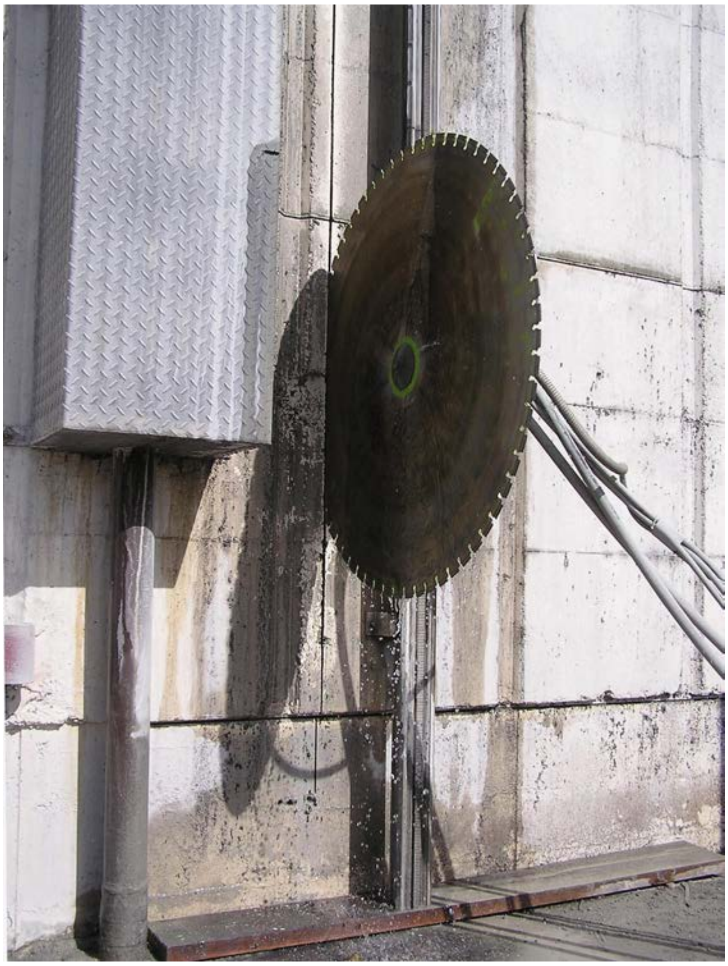

FIG. 3. Caorso NPP, Italy: Demolition of cooling tower during the pre-decommissioning phase (courtesy of the Nuclear Plant Management Company in Italy (SOGIN)).

during the final dismantling. It is not recommended, however, that the services to these buildings are maintained, as their standard is likely to have moved on, even over the short period of safe enclosure. Here it would be beneficial to install new services at the beginning of final dismantling.

Demolition of buildings can be used to release them from regulatory control on parts of the nuclear site. At most nuclear sites there are areas and buildings that are practically unaffected by nuclear operations. It can make sense then to reuse or redevelop those parts of the site for new purposes. A number of delicensing projects have been conducted at NPPs in the United Kingdom (UK) while implementing decommissioning strategies. A detailed example is given in Ref. [13].

When an area is released from the nuclear licence, space still might be needed for the temporary storage of equipment and materials, and a building may be needed for storage of conditioned waste awaiting off-site transport. Therefore, sufficient land needs to remain under the nuclear licence to accommodate these activities.

Certain buildings used for operational purposes may be retained under new functions relevant to safe enclosure and future dismantling, e.g. waste stores. The shutdown emergency core cooling system building at Garigliano NPP, Italy (Fig. 4), was converted to a waste store. Another example is at Douglas Point NPP, Canada, where the old control room was converted to office space (Fig. 5).

Where support buildings cannot be repurposed in this way, and where they have extensive window glass, consideration needs to be given to the buildings' early removal, since glass is prone to fail, which would compromise the building envelope.

A further consideration regards the visual impact of the site. In some Member States, the decommissioning licence establishes specific visual impact requirements for the safe enclosure period which may include the

FIG. 4. Garigliano NPP, Italy: Former emergency core cooling system building converted to waste store (courtesy of SOGIN).

FIG. 5. Douglas Point NPP: Old control room area converted to office space (courtesy of AECL).

planting of vegetation to soften the look of the structures. Remaining structures should not give the appearance of abandonment, even if they are safely maintained: any visual indication of abandonment may not be acceptable to the regulatory body and may attract unwanted attention from the local stakeholders. Reference [14] highlights a decommissioning case where reduction of the height of the reactor buildings to reduce their visual impact is scheduled to take place as a separate, stand-alone project. Figure 6 shows activities aimed at lowering the reactor building height at Berkeley NPP, UK.

FIG. 6. Berkeley NPP, UK: Lowering of reactor buildings (courtesy of Magnox Ltd).

2.5. SINGLE VS. MULTIFACILITY SITES

Safe enclosure sites can consist of multifacility sites where there are operational and shutdown facilities, or single purpose sites. Managing a safe enclosure on a multifacility site has both advantages and disadvantages with respect to the safe enclosure. Advantages include localized support staff, maintained distribution services and other general support. Single purpose facilities are generally shutdown and all support is brought into the site from external sources. However, decommissioning of one facility at a multifacility site may be a low priority over the other operating facilities on-site.

2.5.1. Single facility sites

Some facilities were built and operated as stand-alone facilities. In some cases, years before shutdown, the decision is made to build a new plant on the site or on a location nearby, to replace the old facility. If this is the case, the issues surrounding responses to alarms and maintenance of the safe enclosure apply as described for multifacility sites in Section 2.5.2.

If no operating facility is nearby or on-site, alarm response and maintenance will be performed by a designated group. This can be achieved by transferring personnel to another company and giving that company responsibility for taking care of the safe enclosure. The operating organization often reduces staff to a minimum after final shutdown. The staff members in charge of the safe enclosure are often recruited from former plant personnel. These people have a broad knowledge of the facility, including the operation of equipment that is still in use and how to operate the newly installed equipment. As the workforce at a safe enclosure is generally small in order to reduce costs, these people might need easy access to any alarms coming from the safe enclosure. This is the case for both passive and active safe enclosures. In the case of a passive safe enclosure, alarms might be limited to signals coming from fire detection equipment. For an active safe enclosure, this transfer is much more complicated as the number of alarm points and alarms can be much higher. For instance, the ventilation system might need daily attention. Some safe enclosures have developed a building control system. Relevant signals are collected on computers that can be accessed by safe enclosure personnel who are not on-site. The use of the Internet is a very good tool to establish these functions. At some safe enclosures, staff members are allowed to control some of the operational systems from any place with an Internet connection, including their home. At other safe enclosures, these connections are used only as a warning system. This means that personnel will have to go to the site in the case of an alarm being triggered. In general, the need for staff on-site at a safe enclosure is minimal. However, when using electronic systems for remote management of the safe enclosure, a security system needs to be in place to avoid cyberattacks.

2.5.2. Multifacility sites

Multifacility sites are in operation in several Member States. In some cases, if one or more facilities at these sites reach a state of safe enclosure, the operations staff may be redistributed to the facilities that are still in operation. The experience of such staff can be effectively used when technical problems occur with the safe enclosure. In general, the sharing of resources is a great opportunity at multifacility sites, and can include staff, equipment, consumables and funds. Alarms coming from the safe enclosure can be transferred to the control room of the operating facility. Personnel for the maintenance and operation of the facility in a safe enclosure condition need to be available. Timely response to alarms at the safe enclosure needs to be ensured, despite other priorities being given to the facilities that are in operation. Long standing alarms coming from a safe enclosure might be judged as less important by operating 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 facility in operation is understandable, care should be taken that maintenance on the safe enclosure is prioritized as no less important and is 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 safe enclosure. During PSE, the maintenance crew can be assigned to the safe enclosure for specific maintenance work in the future. This crew can be composed of workers from the former operational facility.

On a multifacility site, services are generally centralized and distributed through the site. For this reason, it is important that systems are isolated outside of the building boundary points of the safe enclosure to prevent unplanned events in the safe enclosure, e.g. a water main break.

Figure 7 shows the Bohunice site in Slovakia, where reactors under decommissioning (A1, V1) coexist with operational reactors (V2) and other facilities.

Reference [15] describes a case where one NPP (Indian Point 1) is situated at the same site where two more reactor units (Indian Point 2 and 3) are in operation and had applied for a licence extension (Fig. 8).

FIG. 7. Jaslovské Bohunice nuclear site in Slovakia, with A1 and V1 NPPs in decommissioning phase and V2 NPP in operation (courtesy of JAVYS, a.s.).

FIG. 8. Indian Point Units 2 and 3 (courtesy of the US NRC).

3. PREPARATION FOR SAFE ENCLOSURE

The extent of safe shutdown activities, which are preparatory to safe enclosure, may have a direct impact on the duration, safety and cost of the safe enclosure period. An optimal balance between partial and extensive shutdown activities needs to be achieved. The impact of these early decisions will affect the safe enclosure costs. The detail of activities prior to safe enclosure depends on the safe enclosure end state, i.e. on the safe enclosure configuration expected to last for a defined period of time; on any activities planned to be carried out during the safe enclosure phase; and ultimately on the expected state of the safe enclosure just prior to final dismantling. Shutdown activities should be well documented in a ‘turnover manual’ that may include information on required maintenance activities, document management, configuration updates, operational information, known hazards, operations manuals and other useful information that may be required for safe enclosure and future activities. The IAEA has addressed the operation to decommissioning transition in several publications [16–18]. Using different terminology, the US DOE has also addressed the subject in Refs [19, 20].

3.1. RADIOLOGICAL AND NON-RADIOLOGICAL HAZARD INVENTORY FOR SAFE ENCLOSURE

During the final shutdown of the nuclear facility, the transition to safe enclosure begins. During this period, among other activities, spent fuel is transferred out of the facility, waste is removed and the safe enclosure structure is installed. During PSE, a hazard inventory of the facility needs to be updated or completed. The hazard inventory will consist of radiological and non-radiological hazards present in the facility. This information should be put into a database, e.g. in the form of a geographic information system. The information is required as a baseline at the time of turnover to safe enclosure and could be a combination of measurements, historical records, operational logs, interviews, videos, pictures, drawings, material samples and other documents than can be used for option studies and preparation of decommissioning plans. Today’s state of the art technology allows the use of 3-D modelling and 3-D simulations for hazardous activities, non-routine entries, characterization and other required data. Figure 9 shows an example of graphics developed in preparation for the A1 NPP decommissioning project in Slovakia. Incidents, spills and leakages, which may have occurred during plant operations, could affect the safe enclosure and future decommissioning process. Recording this information may minimize surprises such as the unexpected discovery of contaminated concrete (at some facilities contaminated floors and walls were over-painted in order to fix contamination) [21]. This information should ideally be stored in an electronic database; the data can then be migrated to new systems as electronic systems become redundant during the safe enclosure period [22, 23]. A comprehensive review of pre-decommissioning radiological characterization is given in Ref. [24].

Radiological and other hazardous substance records should ideally be updated on a regular basis. To verify the validity of the records, it is important that sampling, measurements and inventories are carried out at a predefined frequency.

A comprehensive identification of hazards during the PSE phase, and a related safety analysis, for the High Flux Australian Reactor (HIFAR) are given in Ref. [25]. The safe enclosure phase for HIFAR, including hazards and safety analyses, is described in more detail in Ref. [26].

A specific project aimed at the characterization of a reactor being prepared for safe enclosure is given in Ref. [27]. A comprehensive Electric Power Research Institute study on the characterization of reference US NPPs in view of a SAFSTOR strategy is given in Ref. [28].

More details on this topic are given in Annexes II–11, II–12, II–15 and II–17.

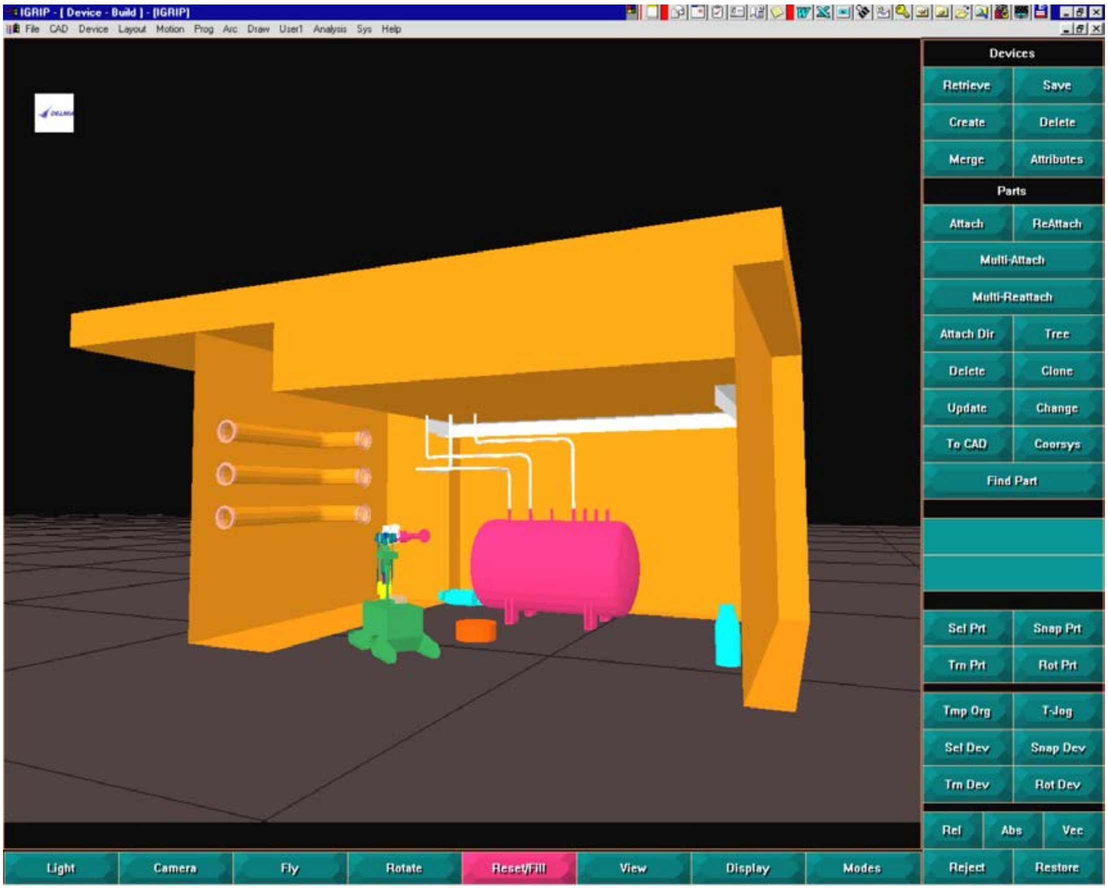

FIG. 9. Interactive Graphics Robot Instruction Program graphics developed in preparation for A1 NPP decommissioning, Slovakia (courtesy of Nuclear Power Plant Research Institute Trnava).

3.1.1. Hazardous materials

As the facility or site is being shut down, consideration will be given to hazardous materials that were deployed during the operation. The preferable option is to remove as many non-fixed hazardous materials as possible during shutdown and PSE. However, if the material cannot be removed, a programme needs to be initiated to safely maintain these items within the safe enclosure structures.

These materials need to be stored in suitable containers and properly disposed of as soon as possible. Reference [29] offers a comprehensive description of hazardous materials to be dealt with during decommissioning of nuclear facilities, including commercial management or disposal strategies for these materials.

Some of the compounds listed below may be subject to changes in regulations over time that may require removal from the site prior to establishing the safe enclosure. Some materials are considered mixed waste, e.g. contaminated polychlorinated biphenyl that it is more difficult to find a disposal path for.

3.1.1.1. Asbestos

Asbestos is especially likely to be present in facilities constructed before the mid-1970s. Asbestos was used as thermal insulation on piping, walls and ceilings and in many building products, and continues to be used today in some building materials. Facilities have used asbestos or asbestos-containing products to protect electrical cables from fire. Some facilities have removed as much asbestos as possible during their operational lifetime, but a large inventory of asbestos remains in a number of facilities currently under decommissioning. Radioactively contaminated asbestos needs to be treated as mixed waste. There is a tendency at some facilities to remove as much asbestos as possible during PSE, as asbestos may deteriorate fast and release airborne fibres (Fig. 10). However, the removal of asbestos is complex and regulated, and the method of removal is crucial. The spreading of asbestos particles during removal needs to be avoided at all times. Therefore, special tents need to be installed surrounding the asbestos containing materials to be removed. The operators performing this work need special training and protective clothing. After removal, very careful checks need to be performed in order to declare an area free from asbestos. This is a costly process that can generate a lot of waste and needs to be planned for. Preparing, using and removing the infrastructure for the removal of asbestos is complicated and expensive. This work could be done during PSE or during the safe enclosure period only if the facility will be completely cleared of asbestos. During safe enclosure and final dismantling, asbestos might be found in unexpected places, and further removal work may be necessary. This makes the process even more costly. It is reasonable to remove accessible bulk asbestos materials prior to safe enclosure; however, unless there is a statutory obligation or safety drivers, full asbestos removal is generally more economical to do at the beginning of final dismantling. An asbestos management programme needs to be maintained throughout the safe enclosure period, which may require active management, e.g. heating of facilities to prevent deterioration of conditions.

FIG. 10. Asbestos removal from components at Trino NPP, Italy (courtesy of SOGIN).

Easily removable asbestos used as insulation could be removed during PSE to avoid further problems (corrosion, water accumulation, etc.). Asbestos removal remains a critical activity, as a recent case from Hanford, USA, proves [30]. A project involving asbestos abatement is described in Ref. [31].

3.1.1.2. Lead

The use of lead in nuclear facilities is widespread. It is used as a shielding material in the form of bricks, sheets, wool or shot. The physical form of the lead shielding material is dependent on the nature of its use. In addition, lead based paints and primers as well as lead sheathed cables were routinely used during the construction of many facilities. Lead is a toxic metal, and needs to be treated as chemical waste. In the case of radioactive contamination, trying to remove the lead might lead to a 'push in' of the contamination into the weak structure of the lead. This makes it a costly product to dispose of, as it will be categorized as mixed waste. However, there are well established lead decontamination processes. Reference [32] is one arbitrarily selected decontamination method. In fact, there are several commercial processes to recycle lead. The experience of the French Alternative Energies and Atomic Energy Commission (CEA), France, is quoted in Ref. [33]. Studsvik, Sweden, also melts low level lead comprising bricks, transport casks, radiation shielding, etc. [34].

Its high density is another reason that lead can be hard to handle and remove. Although it can be used as a very effective shielding material in disposal casks, not all countries allow the use of lead in waste containers. This is due to the environmental rules in some countries, which do not allow heavy metals to be stored in final repositories.

If lead is present in the safe enclosure, it needs to be listed and marked, and dealt with at the latest during final dismantling. The same considerations as described for asbestos apply.

3.1.1.3. Graphite

Some facilities used graphite during their operating life. Graphite was found in electrodes or electrical conductors and was used as a neutron moderator in gas cooled reactors (Fig. 11), high-power channel-type reactors, thermal columns of research reactors, and biological shielding structures. Reactor graphite may generally remain in place awaiting final dismantling and future treatment or disposal in adequate repositories. Graphite in blocks is practically non-flammable and can be left in situ without fire hazard; on the other hand, there are no provisions for graphite disposal in many countries. However, flammability due to the Wigner effect needs to be assessed as

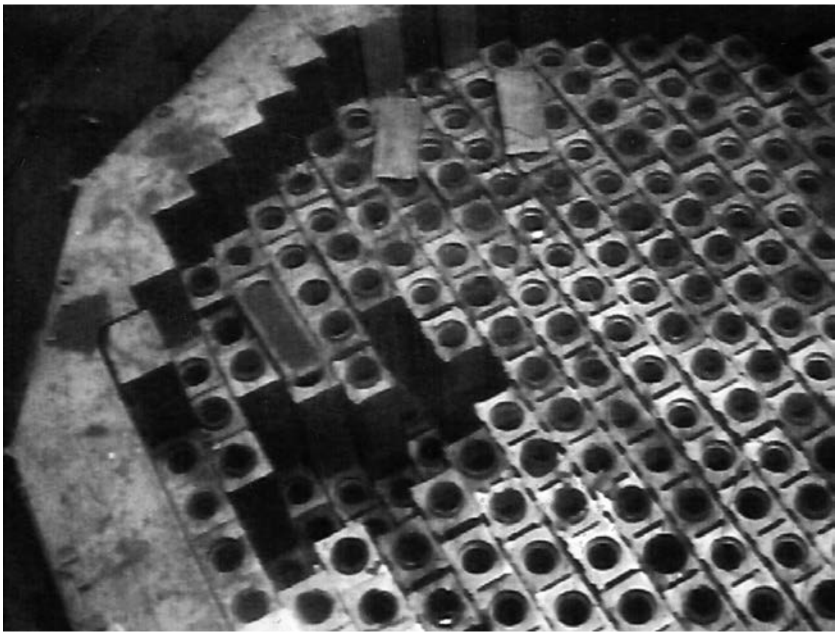

FIG. 11. Advanced gas cooled reactor core at Windscale, UK, showing graphite blocks (courtesy of Sellafield, Ltd).

it can be a problem, especially for research reactors. A noteworthy decommissioning work at the Vandellòs gas cooled reactor in Spain during the PSE period was the dismantling of the graphite silos that were formerly used for the graphite sleeves of the nuclear fuel (Fig. 12). At the Vandellòs reactor, graphite blocks have been confined in dedicated vaults for the entire period of safe enclosure.

3.1.1.4. Chemicals

As in any industrial facility, chemicals have been used in nuclear facilities for different purposes. Chemicals present hazards to human health and the environment such as corrosion and explosion. Caution needs to be applied to chemicals that may have become unstable over time. Some compounds may accumulate in the body with serious health implications. Therefore, chemicals should be identified and removed during final shutdown operations and before safe enclosure is fully established.

3.1.1.5. Organics

Organic compounds are chemicals that contain carbon and are found in all living things. Volatile organic compounds (VOCs) are organic compounds that easily become vapours or gases (gasoline, benzene, formaldehyde, polychlorinated biphenyl, freons, solvents such as toluene and xylene, perchloroethylene (a.k.a. tetrachloroethylene), zinc bromide, aerosols, sprays, degreasers, etc.). Along with carbon, they contain elements such as hydrogen, oxygen, fluorine, chlorine, bromine, sulphur or nitrogen. VOCs are released from burning fuel, such as gasoline, wood, coal or natural gas. They are also released from solvents, paints, glues and other products that are used and stored. All VOC related hazards should be taken into account while establishing safe enclosure and related hazards should be minimized by removing these products.

3.2. GENERAL AREA CLEANUP

General cleanup refers to minimizing the remaining loose materials left in the facility after operational shutdown. Removal of superfluous items such as desks, chairs, tools, maintenance equipment and other loose materials not required for safe enclosure activities or that may impact on safe enclosure activities is highly desirable. Implementation of a reduce, reuse and recycle principle needs to be considered for all waste paths. Contaminated

FIG. 12. Dismantling of graphite silos at Vandellòs-1 NPP, Spain (courtesy of the National Company for Radioactive Waste in Spain (ENRESA)).

items or hazardous materials may fall into this category as new technology and demands develop, e.g. lead and contaminated steel recycling back into the nuclear industry. Some equipment in a facility could be reused, recycled or sold. Decisions to pursue this approach could be cost beneficial, taking into account the salvage costs of clean materials. While these types of items may have resale or scrap value, the primary driver is to improve the overall safety of the facility and remove items that present tripping and bumping hazards for surveillance workers, become contaminated over time, or lose their current value [35]. Furthermore, where assets are removed, it is important to ensure that the area is restored to a safe state for the surveillance workers. As the cost of waste disposal becomes higher and higher with time, a recycling policy deserves careful consideration.

A thorough housekeeping tour should be conducted as a final step after the shutdown of the facility and before turnover to safe enclosure. The purpose of this tour is to identify and clean up the remaining items left behind that may impact on facility and worker safety.

Figure 13 shows a (typical) messy working environment at a research reactor that needs to be cleaned up before decommissioning.

The principal objectives of the housekeeping campaign are to minimize hazards, reuse serviceable equipment, facilitate surveillance and maintenance, reduce future issues for the decommissioning contractor, reduce fire loading and address safety issues [35].

3.3. DECONTAMINATION

The decontamination of a facility's internally or externally contaminated surfaces with a view to achieving a safe enclosure state requires decisions concerning appropriate decontamination methods, such as flushing of systems, aggressive or soft decontamination processes. A trade-off between different methods requires consideration of such factors as waste generation including secondary waste, collection, packaging and disposal costs, and dose control.

Unless there is a requirement to achieve unrestricted release of decontaminated materials or components, which is unlikely at the safe enclosure stage, decontamination objectives during PSE will generally refer to the reduction of area dose rates or surface contamination in preparation for specific activities. This includes, among others, support of other decommissioning work or surveillance and maintenance activities. Area decontamination may result in plant rezoning.

FIG. 13. Typical end-of-life messy environment at a research reactor.

Figure 14 shows a scabbling operation at Trawsfynydd Magnox reactor in the UK. Decontamination activities of this kind aim to reach a state compatible with a long term safe enclosure.

A specific problem is whether to decontaminate systems (e.g. the primary coolant system) during PSE and to what extent, or to defer system decontamination to later phases of decommissioning. In some cases, natural decay with no decontamination may allow dose rates to decrease to a point of minimal concern to those doing the final dismantling. In fact, radioactive decay is one of the main arguments favouring safe enclosure as a decommissioning strategy. On the other hand, the permanence of contaminated systems throughout the safe enclosure phase may add some hazards for the workers inspecting the safe enclosure or doing maintenance work. Airborne or liquid leaks from contaminated systems and (re)contamination of surrounding areas are another concern. It may also happen that ongoing physicochemical processes affecting the contaminated oxide layers inside the piping make later decontamination less effective, e.g. by making the oxide layers more tenacious.

Full system decontamination is a well known technology; in fact it is routinely carried out at a number of nuclear facilities. Consideration should be given to using more aggressive chemicals or higher temperatures in view of achieving safe enclosure configuration, because presumably the piping will not be reused as such and some local damage to it can be acceptable. There are numerous cases of full system decontamination in the technical literature, e.g. Refs [36, 37].

3.4. SHUTDOWN OF SYSTEMS

All systems not required for safe enclosure ongoing activities should be drained, flushed if necessary, isolated at the source and opened where appropriate. When draining systems, caution should be employed to ensure the safety of the workers, facility and environment. Flushing of piping systems, for example, may have left chemical residues or pockets of concentrated solutions. If the facility could experience freezing, pockets of fluids left in

FIG. 14. Pond scabbling at Trawsfynydd, UK (courtesy of Magnox Ltd).

systems may freeze, damage the pipes and leak. When a system is shut down, isolation points should be clearly identified and all other valves, blinds, etc., placed in appropriate positions. Consideration needs to be given to the possibility of having to reuse these systems during future decommissioning stages. Figures 15 and 16 illustrate component sealing activities at two Magnox NPPs in the UK.

Electrical and control systems might be minimized by isolation at the source and physical separation or air gapping the connections (Fig. 17). A good practice is to install a new dedicated safe enclosure electrical system with clearly labelled cabling (e.g. colour coded cable) to identify it as the live system. If the building is isolated at the source, this will leave an upgraded electrical system, safe enclosure dedicated circuits and, for future dismantling activities, a visible live system to minimize human error when cutting cables for removal.

FIG. 15. Dungeness A NPP: Sealing of large pipes (courtesy of Magnox Ltd).

FIG. 16. Hunterston A NPP: Pilecap standpipe sealing in reactor vault (courtesy of Magnox Ltd).

FIG. 17. Systems locked and tagged that are no longer in-service, Douglas Point, Canada (courtesy of AECL).

Other systems may be shut down or reconfigured to meet the requirements of safe enclosure. Fire detection and suppression systems may need to be modified. Security systems, heating, ventilation and air-conditioning (HVAC) controls, radiological control and monitoring systems need to be reviewed when entering into the safe enclosure stage.

Sump and drain systems in safe enclosure facilities may need to remain functional to handle rainwater, groundwater or condensation depending on location, groundwater level, building tightness, system integrity or frequency of inspections [35]. Discharge points and system integrity should also be considered to ensure that systems will remain functional as expected.

A lesson learned from projects at the Hanford site (e.g. PUREX and UO_3 plants) was that fixing contamination of unnecessary sumps and trenches by filling them with concrete might increase the difficulty of further decommissioning. Therefore, it was decided to use sand and a fixative, e.g. a coating of the water based polymeric barrier system, which could be easily removed at a future date if necessary [35, 38–40].

3.5. DRAINAGE OF SYSTEMS

The systems and components that were used during facility operation are drained as part of the transition phase prior to the implementation of safe enclosure. Experience has shown that the drainage of systems and components can result in new hazards, since it may cause changes in radiological or non-radiological conditions, or unexpected factors.

Planning for the drainage and isolation of these systems starts when the operator of the nuclear facility determines which structures, systems and components may be placed in a storage configuration. In general, the systems selected may no longer be necessary for the safe performance of safe enclosure activities.

The operator determines when drainage can occur by determining first what plant conditions are necessary to support drainage of the systems and components. In addition to determining whether and when the system or component will be drained and placed into a laid up condition, the operator evaluates the effects of the draining. Changes in, and the effects of, the following are evaluated:

— Criticality;
— Dose rates;
— Oxidation and other corrosion mechanisms triggered by the lack of liquids;
— Generation of radioactive or toxic gases and aerosols.

The drainage of systems can result in the spread of radioactive contamination to other systems not intended to be drained. Special conditions may occur in facilities where full system drainage had never been made before. For example, if resin beds are utilized, the compatibility of the chemical composition of the resin with the temperature, affinity, particulate nature and other parameters of the media being drained needs to be considered. In all cases, the drainage needs to be evaluated as to its potential impact on receiving systems, on radiation monitoring procedures that need to be implemented, and on contamination control devices to be installed to monitor for local transitory radiation and contamination levels. In this regard, and in view of subsequent phases of decommissioning, it is vital to make sure that drainage has fully removed the intended inventory or to be aware of how much of it remains (e.g. at low points or other system pockets). The permanence of residual amounts of liquids, especially if unintended, will impact on safe enclosure activities (e.g. higher dose rates during inspections) and final dismantling (e.g. unexpected spills while cutting pipes).

Engineering evaluations need to be performed to assess whether:

(a) Partial drainage of systems will adversely impact the functionality or operability of the remaining system or part of the system. For example, pump head, head loss and flow are evaluated to ensure that they are sufficient and within design specifications following the partial drainage.
(b) The drainage process may result in changes in radiation exposures due to a loss of water shielding.
(c) There is an impact on intersystem relationships (e.g. heat exchanger differential pressures for leaks and liquid separation).
(d) The liquid processing system is of sufficient capacity to handle the large volumes of liquids.
(e) The locations for venting, siphon break and drain path are adequate.

Operators have to also determine whether preservation efforts are needed to support future storage of the drained system or component. Drying, atmospheric control of humidity and temperature, and introduction of a corrosion inhibitor are all viable preservation techniques [2]. A case study of improper drainage is described in Annex II–19.

It is common practice to drain spent fuel ponds in PSE. Figure 18 shows the Bradwell Magnox pond in the UK being drained and decontaminated by pressure jet.

3.6. FACILITY ASSESSMENT

The purpose of a facility assessment for buildings to be decommissioned is to determine the feasibility of long term storage and document the adequacy or baseline of the structures, systems or components for an extended

FIG. 18. Bradwell pond being drained (courtesy of Magnox Ltd).

period of safe enclosure. A graded approach, starting with the safety assessment report for the facility moving to decommissioning, is appropriate with a level of detail based on future use, remaining hazards which are a potential danger to workers or the public, the safe enclosure plan and associated impacts and corrective actions [35]. For example, the safe enclosure may or may not include heat sources, which could lead to premature deterioration. An ageing management plan may be developed from these assessments that will provide information to support extended safe enclosure requirements.

Assessments of the remaining service life of the building envelope, which includes outer structures and roofing systems, is usually focused on engineering solutions to repair structural defects [35]. A good maintenance and capital asset programme should be established to minimize the level of unplanned financial expenditure.

More details about the deterioration of structures, systems or components and potential safety impact of deteriorating conditions are given in Section 5.4.

3.7. PROTECTION FROM ANIMAL INTRUSION AND OTHER BIOHAZARDS

Placing a facility in safe enclosure is likely to change the habitat presented to wildlife (flora and fauna), which in turn is likely to affect the species and populations on-site. The intrusion of birds, rodents and other animals, along with vegetation, into a shutdown facility is undesirable. As far as animals are concerned, there is a need to eliminate any safe haven wherein the population could multiply and create health hazards for surveillance and maintenance, and decommissioning workers [35]. Other risks, such as damage from nibbling of electrical cables by rodents, are not to be disregarded. Additionally, since some parts of shutdown facilities may be contaminated, intruders could spread contamination within the facility and could also provide a pathway for contamination migration to the environment [35]. Illustrative examples of animal presence and intrusion into nuclear and non-nuclear facilities in safe enclosure are given in Figs 19 and 20.

If protected species establish themselves at plants, delays to the decommissioning project are possible. A case in question is the nesting of peregrine falcons on the Bradwell buildings in the UK [41].

While few, if any, safe enclosure facilities can be expected to be airtight, there are many engineering controls that may be considered to keep animals out of the facility [35]. These include, for instance, the installation of locked gates, physical security fences and locks on all access doors to the facility; closing, covering and/or sealing of all building exterior openings not required for access to the safe enclosure; covering and sealing of broken panes of windows left in place; and maintenance of exterior doors required for ongoing use to prevent unauthorized ingress.

FIG. 19. Chimney swifts: Protected species of birds have taken up residence in the Nuclear Power Demonstration Reactor ventilation stack following shutdown of ventilation fans (courtesy of AECL).

FIG. 20. Rodent holes in protective cover at the Superfund site in Arvin, California, USA (courtesy of Zaidee Stavely).

Other methods of animal control could include the reduction of edible materials in the facility, removal of materials used for nesting [35] (e.g. pipe insulation), creation of alternate habitats, or installation of deterrents or repellents to discourage the animals from entering the site.

A related problem is the growth of fungal contamination and bio-aerosols at shutdown nuclear facilities. A comprehensive discussion on how to prevent or mitigate such problems at a specific facility is given in Ref. [42].

3.8. SIGNAGE AND BARRIERS

The status of systems after shutdown needs to be clearly marked in the field and configuration of the plant updated to reflect the shutdown state. The current configuration of the site is extremely important for future decommissioning stages and worker protection. Good practices include locking out and tagging systems out of service or in-service using different colour coded locking and tagging devices. Locking devices can be numbered, tamper proof devices that can be recorded and confirmed during future safe enclosure and decommissioning activities to minimize the possibility of working on the wrong item. A programme can also be established to ensure that the integrity of these devices is maintained with a log of where they are located and expiry dates.

Many of the physical hazards can be resolved by installing physical barriers (e.g. chains) and/or warning signs (e.g. ‘Danger’ or ‘Caution’) for the protection of personnel during surveillance and maintenance [35].

3.9. USE OF SEALANTS TO INCREASE ISOLATION

The use of sealants for isolation might be recorded with data such as location, life expectancy and maintenance required. Sealants may be used for many different purposes including the building envelope, piping, ducting and other openings. Sealants may deteriorate over time or change chemical structure (and mechanical properties) if exposed to other hazards (e.g. plastic deteriorates when exposed to radiation).

As introduced above (see Section 3.4), the use of a polymeric barrier system has proved to be a practical solution. The chemicals used in this system dry to a clear solid state, although dyes could be added to increase the visibility of the resulting barrier [35]. A recent development consists of polyurethane resin foam that is injected into a fabric bag that holds the foam in place as it expands (FOAMBAG) [43]. The use of commercial rigid polyurethane foam was developed and implemented to stabilize fissile and non-fissile residual radioactive materials present in contaminated equipment and process pipes at the US DOE’s K-25/K-27 facilities at the East Tennessee Technology Park. A feasibility study was conducted and custom formulation of rigid polyurethane foam was developed for use at K-25/K-27. Additionally, a comprehensive performance testing programme was conducted by the Argonne National Laboratory to determine the ageing behaviour of polyurethane for infiltrating contaminated process gas equipment and piping. The study included ageing effects due to mechanical stresses, heat, moisture and temperature cycling, biodegradation and radiation exposure. This technology is considered best practice by the US DOE [44].

3.10. SALVAGE AND REUSE OF MATERIALS AND EQUIPMENT

Reusable and recyclable material, supplies and equipment can be removed from the facility as early as possible if not required. Materials planned to be left behind following shutdown that may attract vandals and burglars include, among others, valuable equipment and copper. These materials need to be removed as a priority to minimize attraction to and unauthorized access into the facility.

3.10.1. Regulatory position on reusable materials

In some countries, the licence or other authorizations for safe enclosure do not allow the decommissioning of any part of the nuclear facility. This is due to legal considerations, as decommissioning any (even if small and uncontaminated) part of a facility is considered to be nuclear decommissioning, and therefore a decommissioning licence is needed. The removal of steel, copper and other reusable materials cannot be done without a prior agreement or licence in place. Applying for a licence only for the removal of small amounts of valuable materials may not be cost beneficial as many regulatory bodies charge for licensing costs.

3.10.2. Copper

A safe enclosure might contain a significant amount of non-contaminated, reusable materials such as copper. In the turbine generator (stator and alternator) there is a large volume of copper. Grounding equipment, wiring, power lines, copper piping and bust bars are all sources of copper. Although it may seem to be a good idea to remove all this material and sell it during or even before the start of the safe enclosure period, this is not generally advisable. In order to remove the material, quite an effort is required. The physical removal may take many person-hours, and the unrestricted release measurements may also take many hours and need a complete infrastructure and recordkeeping system. Therefore, in some cases, it may be more cost effective to remove the copper and other valuable materials only at the beginning of the final dismantling. Figure 21 shows the handling of copper during an initial phase of the decommissioning of Trino NPP in Italy.

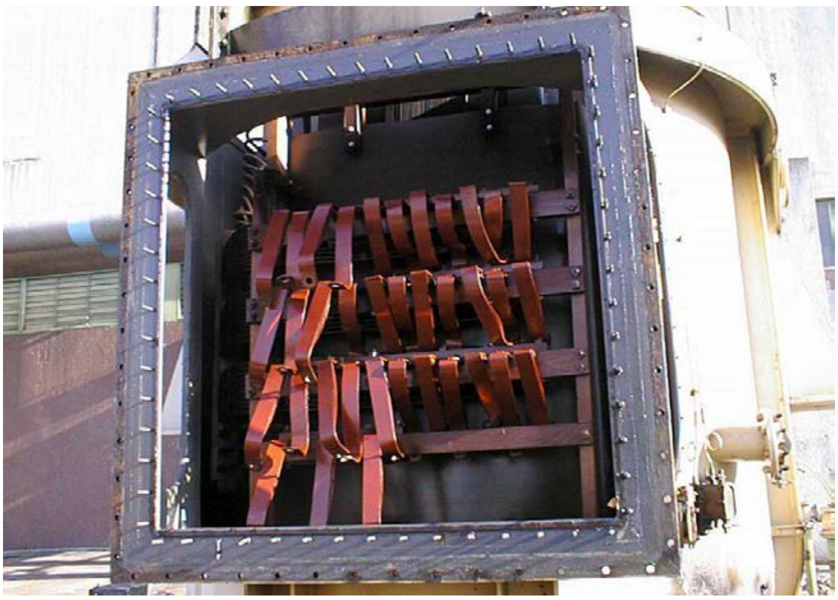

FIG. 21. Trino NPP: Copper from the main transformers in preparation for sale (courtesy of SOGIN).

3.10.3. Steel

Steel used to reinforce concrete, structural steel, and electrical or mechanical systems and equipment is often non-contaminated or can be readily decontaminated. A strategy should be developed that takes into account both the generation of valuable scrap metals and the possible use of material such as copper wire or ventilation fans in future phases of decommissioning. Removal of steel from the facility at too early a stage can have an impact on the infrastructure and resources required for eventual decommissioning and ultimately require more person-hours to re-establish lost functions.

4. FIRE PROTECTION

The risk of fire and its potential impact on the workforce, site and the public is possibly the biggest concern for most safe enclosures. Mitigating the risk requires the expenditure of substantial amounts of human, technical and financial resources. A general reference addressing all aspects of fire protection for safe enclosures, based on DOE requirements and standards, is given in Ref. [45]. See also a comprehensive discussion of several fire issues arising during decommissioning in Ref. [46].

4.1. FIREFIGHTING PRINCIPLES AND RESPONSIBLE PARTIES

To determine whether firefighting objectives are met for a given facility, some organizations and countries (e.g. the US DOE) require a fire hazards analysis that includes a comprehensive assessment of the risk of fire in that facility [45]. The risk of fire in a safe enclosure can be mitigated by removing combustible materials and ignition sources as far as possible during the PSE phase. However, this will not completely rule out the risk of fire. Therefore, a firefighting plan and equipment needs to be put in place. The available firefighting plan for the operational phase needs to be amended as the fire risk, building layout, water supply, access routes, etc., may have changed for the safe enclosure period. The new plan needs to be developed and agreed to by the responsible fire brigade and the regulatory body. In some facilities, because of the limited fire risk, an on-site fire brigade is no longer required for safe enclosures, while in other facilities, firefighting requirements are actually increased because of a lack of workforce on-site that could launch an early warning. For multireactor sites, the safe enclosure can benefit from a site fire brigade. For stand-alone safe enclosures, the external fire brigade may deal with fires.

Agreements need to be in place where local fire departments provide first response services to the site, including familiarization, fire preplans, exercises and testing. Fire department response is an important element of safety reviews of inactive facilities. It is essential that response personnel have knowledge of the facility (i.e. its construction features, hazards and fire protection provisions). Communications, cooperation and coordination between the facility's staff and the fire department are as important for a facility that is in a shutdown status as for an operating facility. As the status of a given structure changes, fire department officials update their fire plans. The area fire department needs to be kept informed of facility status and decommissioning activities and participate in training exercises.

The fire brigade response also needs to be reviewed where an inactive structure is located in close proximity to an active facility with a fully trained fire brigade.

It is expected that an (external or on-site) emergency plan will be available for the shutdown facility and will include response to fires.

4.2. COMBUSTIBLE MATERIALS

Details of fire hazards within the structure have to be included in the fire hazards analysis. Fire hazards within inactive structures need to be eliminated to the greatest possible extent. This may include removal of as many combustible items as possible from the structure. Combustibles around the structure (e.g. vegetation and storage sheds or similar structural attachments) also need to be removed. Shutdown electrical transformers that pose a fire hazard to the main structure need to be removed or drained of their combustible oils. Oil lines and oil reservoirs in pumps, turbines and tanks should be drained. Storage of flammable or combustible liquids needs to be minimized to the greatest extent possible. Storage containers, including above ground and underground tanks, need to be emptied and secured either by purging or removing the container, or filling with sand or concrete [47]. Accumulation of combustible dusts is another concern that needs to be minimized.

The quantity and associated hazards of flammable and combustible materials coupled with ignition sources that can be expected to be found within the structure should be factored into the analysis. Consideration also needs to be given to the presence of transient combustibles associated with storage and maintenance activities (e.g. gas cylinders for oxy-acetylene cutting). This may include an analysis of combustible materials, the heat of release rates and fire dynamics in relation to the decommissioning plans. Risks from fire expected in inactive contaminated structures may include direct flame impingement; hot gases; radiant heat; smoke migration; toxic, biological and radioactive emissions; and firefighting water damage [45].

To limit the risk of fire, unnecessary oil within the safe enclosure needs to be removed. Although this can be removed during the safe enclosure preparation phase, it can be difficult and may not be fully achieved. Residual oil may still be present in certain areas and components, such as in motor operated valve carters and in walls and concrete structures. Due to temperature changes the oil might become more fluid and start leaking. Therefore, carter stops or oil spill collectors need to be in place. Where oil spill collectors are in place, great care needs to be taken to reduce the risk of overflow. If overflow occurs, oil may spread on the floor, and might even reach the lower levels of buildings. In this case, there is a chance that oil may accumulate so much that it becomes a fire risk. Oil on the floor is a slip hazard as well. Therefore, oil spill collectors should be checked and, if necessary, emptied on a regular basis.

Special attention should be given to the turbine carter. In many power stations there is some oil leakage from the turbine carter during operation. Although sometimes there is no real leakage, the amount of oil coming from the sweating of valves and gaskets can be a serious problem. During the first years of a safe enclosure, this problem is not ruled out, but oil may accumulate in the lowest parts of the system. In many cases the oil system drain is not situated at the lowest point of the system. Because of this, the volume of the accumulated oil can become so great that it becomes a fire hazard. Therefore, the oil collecting system of the turbine should be inspected and, if necessary, drained at regular intervals.

During operation there are many examples of concrete structures being contaminated with oil. This contamination is difficult to remove without removing the concrete itself. It not only causes a slipping hazard, but can, if water ingress occurs, lead to further oil contamination or oil escaping into the surrounding ground or into groundwater.

Ventilation filters should also be included on the list of combustible materials, as the case described in Ref. [48] proves.

4.3. UTILITIES

In many safe enclosures the water source has been taken out of service. In this case the safe enclosure project needs to plan for an additional firefighting water supply that may include external pumping capacity from a firefighting truck, sucking water from other water sources including deep wells, regional water supplies, or a combination of these.

To save on operational costs, utilities that are deemed unnecessary are often disconnected. This most often will include gas, electricity (Fig. 22), water and telephone services. Those utilities that serve active fire protection systems are required to remain operational (i.e. water for automatic suppression systems and electrical power for fire alarm systems). The assessment of which utilities should remain in-service or be redesigned and upgraded, and to what extent, needs to be a coordinated effort between the nuclear operator, the regulatory body and the fire brigade [45]. A relevant case history is given in Annex II–1.

FIG. 22. Disconnected and isolated appliances at Dodewaard NPP, the Netherlands (courtesy of Gemeenschappelijke Kernenergiecentrale Nederland (GKN)).

4.4. FIREFIGHTER ACCESS TO SAFE ENCLOSURE

Safe enclosures may not have staff on-site during parts of the day and night, but safety needs to be secured at all times. Fire response personnel need to be properly trained and outfitted in a proper way to safely access the site. They need to also have access to the safe enclosure in the case of a fire. An automatic alarm system needs to be in place to alert the fire brigade. This alarm should be connected to both fire brigade personnel and safe enclosure staff. In case the fire brigade needs access to the site and the safe enclosure, there needs to be a system that allows access even when there are no staff on-site. Members of the safe enclosure staff need to be on call to assist the fire brigade as needed.

As the number of fire trucks and the amount of water supply is normally limited, it might be necessary to have more than one access point to the safe enclosure. In the safe enclosure itself, passive metal firefighting water transport lines may be available. There need to be enough firefighting hoses available to establish connections between the water supply point, pumping truck and transport lines.

4.5. SECURITY AND LIFE SAFETY CONSIDERATIONS

Security considerations related to fire protection are many and need to be documented. Physical security of a structure provides multiple benefits. Secured doors, windows, building ventilation and other openings prevent unauthorized entry and limit natural draught. Natural draught can contribute considerably to the severity of an unplanned fire (as well as to the transfer of airborne contamination). Control of potential damage by vandals, arsonists and vermin is another important benefit ensured by security provisions.

Safety needs to be considered to the extent that access into and egress from locations within an inactive building is necessary for maintenance and surveillance personnel. Elements of the egress system that should not be overlooked include, but are not limited to, doors, corridors and electrical (lighting) systems. For example, fire doors need to be secured to prevent unauthorized entry but they can continue to provide the necessary safe means of egress to personnel [45].

Agreements need to be in place that will allow access to the building or site by firefighters. The responding firefighters need to be security cleared and properly trained for the hazards that they may encounter.

4.6. IGNITION SOURCES

To avoid short circuits or sparks, as much electrical equipment as possible should be switched off when no personnel are working in the safe enclosure. In those areas where electrical equipment will remain operational, adequate fire detection equipment could be installed. It is advisable to have an automatic system in place at the entrance of the safe enclosure that controls the electrical system. When the last operator leaves the safe enclosure at the end of the day, all non-essential power lines and lights can be switched off using this system.

Other ignition sources need to be controlled. Hot work control within or around the facility is one mitigation measure to minimize potential ignition sources of fire from cutting, grinding, welding, etc.

Wild land fires and lightning strikes are other potential ignition sources. Mitigation measures that need to be maintained include fire roads, control of vegetation growth around the safe enclosure and maintenance of engineered systems such as lightning rods and grounding pads.

4.7. EMERGENCY RESPONSE DRILLS

Emergency and firefighting drills need to be performed on a regular basis. Although the impact of a fire or emergency in a safe enclosure cannot be compared to an event in an operating nuclear facility, any emergency needs to be treated similarly to one in an operating facility and attended by a well trained response team. It is good to be aware that the building configuration, contacts, number of responders, etc., might have changed during PSE, and the number of entry options is more limited than during former operation and new equipment might be in place.

4.8. FIRE COMPARTMENTS

The fire compartments of a safe enclosure need to be clearly defined and engineered. As new equipment is brought in (e.g. new ventilation air dehumidifiers), redundant equipment may no longer pose a fire hazard. Different fire compartments might be needed around the new equipment while other compartments can become obsolete. As the ventilation system has the capability to spread fire, sufficient fire dampers and detection systems need to be in place and maintained between the compartments. It is advisable that these valves are linked and closed by the fire detection system in the case of a fire. The fire dampers can also close if the temperature inside the duct becomes too high: typically a passive system is used to this end, such as a connecting piece of lead that will melt and allow the damper to close once the temperature reaches a certain level.

4.9. FIRE EXTINGUISHERS

For immediate response to a small fire, handheld fire extinguishers are a good solution. A minimum number of extinguishers need to be kept available at the site and on each floor in each building, or at the entrance to the building depending on local regulations and the fire hazard of the area.

Normally a safe enclosure is not heated, except for the offices and change rooms. This means that during the winter the temperature inside the buildings that form the safe enclosure can fall below the freezing point. This is especially the case for basements and higher floors that are not insulated from outside air and wind. As a result, the liquid in the fire extinguishers on these floors might be affected, making them inoperable when needed. This can be avoided by using fluids which contain an anti-freeze chemical. As an alternative to liquid, the use of powder in the extinguisher can be considered.

4.10. OTHER FIRE CONSIDERATIONS

The fire hazards analysis will determine whether or not the safe shutdown state of the facility reflects on the fire requirements, e.g. whether additional sprinklers, smoke detectors or heat detectors will be required due to the change in the use or state of the facility.

There are many systems on the market to meet these demands, including infrared detection, wireless detection, remote monitoring and linear heat detection systems, just to name a few. Consideration during the evaluation of such systems should be given to the activities that may be performed over the life expectancy of the systems within the facility. Reference [49] gives one example of the technologies in use.

Means of egress might also need to be reassessed and the fire protection plans or fire hazard analysis documentation updated for safe enclosure.

5. MANAGING A SAFE ENCLOSURE FACILITY

5.1. AGEING MANAGEMENT

During the safe enclosure period, the structural integrity of the facility needs to be maintained. This is achieved by routine monitoring, periodic inspection and review and, if necessary, intervention to maintain integrity. The following need to be considered in this context:

(a) Stability of buildings;
(b) Stability measurements.

During the operational lifetime of the facility, settling of the building structure continues to take place. Depending on the type of soil, there may be increasing ground movement over the years (e.g. as perimeter drains begin to fail and increased water is allowed to sit at the foundation walls). During PSE, removal of fuel, cooling pool water and redundant buildings affect the pressures exerted on the soil and their points of interaction, which means compensation movement may occur. Although the impact is normally limited, this phenomenon cannot be underestimated. As some facilities consist of separate buildings with connecting pipelines, forces can develop in the supporting pipe bridges. This might lead to tension on flanges and piping systems. If flanges open up, or pipelines break, an uncontrolled release of internal contamination might spread into the building or local environment. To anticipate uncontrolled tensions on support structures, a regular survey of building positioning needs to be performed. An example of this is the removal of cooling pool water from a pool building that is directly connected to the reactor building by means of a fuel transfer tunnel. At the subterranean connecting joint there is potential movement and ingress of groundwater. The potential impact of this is therefore addressed by the safety assessment and managed as part of the safe enclosure arrangements. It is important to consider all structures, systems and components within the ageing management programme.

Reference [50] describes a project at Trawsfynydd NPP in the UK, where it had to be ensured that the reactor structure could safely withstand the additional loads introduced by the lifting of heavy components. A structural monitoring system was designed to measure the stresses in the concrete reactor walls and boiler box walls.

5.2. PROTECTION AGAINST WATER INGRESS

Commonly with operational sites, protection against water ingress from rainwater, snowmelt, flood and groundwater intrusion is essential. Protection can include methods such as sealing, installation of flood doors or maintaining an active collection, detection and pump out system. At the UO_3 plant at Hanford, two of the roofs were known to leak. A commercial mobile home roof sealant was applied to seal them [51].

In some countries, facilities are situated on grounds that can become very wet due to high water levels in the surroundings, as illustrated in Fig. 23. To prevent the buildings from moving towards and away from each other due to ground forces, a joint is normally put in place between the buildings. A particularly important instance of this, requiring special attention to isolation from adjacent water bodies, is where the structures abut a lake or river, and their lower portions are directly in contact with the water body (as in the case of a water treatment facility). However, as a safe enclosure does not contain large quantities of water, and many safe enclosures deliberately keep the air dehumidified, these joints can become so dry that they can crack. In this case, groundwater can enter the

FIG. 23. Control of water ingress during safe enclosure: Sump water is redirected to one outfall during the safe enclosure period at Gentilly-1 (courtesy of AECL).

safe enclosure. After entering the safe enclosure, this water cannot simply be disposed of as it may be contaminated and needs to be treated as radioactive water. The safe enclosure may have no arrangements to treat or dispose of contaminated water. In this case, the water needs to be transferred into drums, and sent to a radioactive waste treatment plant. The costs of these transports and treatments are high. To avoid this situation, joints between buildings should be checked on a regular basis and repairs need to be performed in a timely manner.

SOGIN enriched uranium extraction in Italy is a pilot fuel reprocessing facility in decommissioning. During a river flooding event on 16 October 2000, water entered the ventilation system and cable room, located 3 m below ground level, causing the system to be out of service for some days. The water in the room was slightly contaminated by the radioisotopes contained in the ventilation system filters. The room was emptied by transferring the water to the ponds. In any case, the contamination levels were well below the allowed limits for discharge. The ventilation system was put back into service a few days later. Similar events occurred at the SOGIN enriched uranium extraction facility in 1994 and at a nearby facility. The event was classified as Level 1 on the International Nuclear Event Scale [52].

Annexes II–8 and II–14 provide more case histories relevant to this issue.

5.3. EXTREME WEATHER PROTECTION

It is possible over an extended period of safe enclosure that seawater levels, groundwater levels, river flows and water courses may change, or that local infrastructure changes will affect groundwater levels or the plant's original flood protection design. Furthermore, the reference extreme weather definition for rainfall or wind speed may also change. The return periods and potential impacts of such changes should be considered as part of the periodic safety review and protective measures adopted if necessary. Figures 24 and 25 show weather protection claddings installed at two Magnox reactors in the UK.

5.4. DEGRADATION OF STRUCTURES

The performance of nuclear facilities' safety related concrete and metal structures has been generally very good. There have only been a few isolated incidents of degradation caused either by improper material selection, construction deficiencies or inappropriate design. An example of water infiltration into a facility, leading to high humidity, accelerated deterioration of concrete and corrosion of mild steel components, is shown in Fig. 26.

FIG. 24. Dungeness A NPP: Installation of new reactor cladding (courtesy of Magnox Ltd).

FIG. 25. Hunterston A NPP: Weather barrier installed (courtesy of Magnox Ltd).

FIG. 26. Example of water infiltration into a facility, leading to high humidity and accelerated deterioration of components.

There is plenty of literature about the mechanisms of concrete and metal deterioration in civil structures, monitoring and repair, and estimated lifetimes of building structures [53–58]. Well planned periodic inspections, maintenance and repairs are the most important actions to effectively manage the ageing of concrete and metal structures.

Over an extended period of safe enclosure, internal painted surfaces will weather and deterioration is accelerated where the ambient air is not conditioned. This not only gives the impression that the structure is not being maintained, but may also introduce degradation to the surface beneath, something which is difficult to visibly identify. Anecdotally, there is evidence that removing loose paint flakes accelerates the degradation through the leading edge. A suitable maintenance regime needs to be established to provide adequate protection over the extended time period.

Further to maintaining structural integrity, it is important that the safe enclosure acts as a weather barrier, prevents unwanted intrusion (human or biological) and prevents any escape of material. This is achieved by a number of options such as brick, concrete or metal over-cladding. In all cases, it is important to consider the structural and functional integrity of this structure and carry out repairs in a timely manner so that it can continue to perform its function until final dismantling.

To achieve this objective, a comprehensive programme needs to be in place from the start of the safe enclosure period. This programme may contain routine monitoring and maintenance as well as periodic inspection. The programme will review the findings of these investigations against the safety case and, where applicable, modern standards to confirm the overall integrity of the facility. Structural integrity reviews include recommendations, where necessary, of any improvements (repairs, back fitting, extra inspections, etc.). Annexes II–2, II–8 and II–21 describe case histories relevant to structural degradation.

5.5. DEGRADATION OF PLANT

Similar surveillance and maintenance regimes can be identified for a plant that remains during the safe enclosure period. A plant that is in an operational state or in standby for operations may experience higher levels of component failure in poorer ambient conditions, but this is normally recognized and additional inspection or preventive repair activities are enacted. Often overlooked, however, is the degradation of the redundant plant which was not removed prior to the safe enclosure phase. Common examples of such equipment are heat exchangers and building cranes that were installed prior to the original structure being complete and would have required substantial efforts to remove them in the early decommissioning phase. In the case of heat exchangers, the removal of thermal insulation introduces potential degradation pathways, while a crane is difficult to drain of all fluids and liable to leak over time. Furthermore, the lifting capacity of a crane may reduce over time and the crane is difficult to return to service if compliance checks lapse. Other plant systems prone to degradation are pipework, metalwork such as walkways and staircases, elevators, pressure vessels and electrical systems.

5.6. CORROSION CONTROL

All facilities use some type of corrosion control. Most facilities use coupons which are inspected on regular bases by an external laboratory specializing in corrosion issues. The number of coupons exposed depends on plant layout. If the facility has many small, poorly ventilated areas and rooms, more coupons are required than if there are only large, well ventilated areas. If the corrosion rate is going up or is already above the limits, the humidity in the facility needs to be adapted. Regulatory control of this programme varies from country to country.

As one example, Ref. [59] addresses air monitoring programmes inside the reactor building of the Vandellòs NPP reactor currently in safe enclosure.

5.7. THERMAL INSULATION

Thermal insulation is found around coolers, hot pipelines, the turbine section and wastewater evaporators. Special insulation that is contaminated by oil can be a potential fire hazard and might be removed early for that reason. If thermal insulation has become wet during operation of the facility, corrosion of the material under the insulation might have started or may develop. If covered, this corrosion may not be detected easily. The specific problem of asbestos insulation is described in Section 3.1.1.1.

Some facilities remove thermal insulation from the site during the PSE period. The decision on whether or not to remove the thermal insulation will be taken at an early stage, as removal during the safe enclosure period may be impractical. This is due to the large volumes of material, the lack of infrastructure to manage the work and the difficulty of treating the waste.

As insulation can be radioactively contaminated, it needs to be checked for contamination and disposed of in a proper way [57]. Thermal insulation that is slightly radioactively contaminated at the start of the safe enclosure period may be non-radioactive at the end of it due to natural decay. As the volumes of thermal insulation are often high, it can be more cost beneficial to keep the insulation in place, instead of transporting it to a radioactive waste disposal storage plant.

Degradation of the insulation over time deserves adequate attention. Some material used contains fibres that can cause damage to lungs. Asbestos is a typical material in question (see Section 3.1.1.1). It is possible, even where most of the insulation has been removed, that residual airborne fibres will continue to appear during the safe enclosure phase. Insulation should be inspected while wearing appropriate breathing protection, and environmental checks on the air within the safe enclosure should be made before routine entries.

It does not matter what type of insulation is found in the facility, whether it is in the structures, systems or components, insulation is prone to mould growth and saturation by condensation. Care needs to be taken to manage humidity within the structures to minimize the occurrence of this.

5.8. OTHER ISSUES TO BE CONSIDERED

The nuclear security of a safe enclosure is an important issue to be considered. The IAEA's nuclear security series publications provide a set of fundamentals, recommendations, implementing guides and technical guidance to be followed, such as in Refs [60, 61].

As long as the safe enclosure is under the IAEA safeguards regime, periodic inspections by safeguards teams will take place, which is another aspect to be addressed. A system needs to be in place to grant the inspectors access to the facility. As inspections can be performed without notice, it needs to be ensured that the responsible person can be reached by the security guards (either on-site or off-site) within an acceptable time.

6. SYSTEM FUNCTIONS AND CONFIGURATION

This section focuses on the specific aspects of managing and maintaining systems during the period of safe enclosure. In defining the expectations for systems in this section the influence of obsolescence on system performance needs to be considered. For systems such as ventilation, electrical distribution, lighting and components such as cranes that have been in-service for several decades prior to safe enclosure, particular attention needs to be given to the choice between the continuing in-service of ageing equipment versus replacement with 'fit for purpose' equipment designed with the safe enclosure duration in mind.

6.1. HEATING, VENTILATION AND AIR-CONDITIONING SYSTEM

A safe enclosure facility needs to continue to operate an HVAC system for containment support, moisture control and management of airborne emissions. Ventilation systems consist of ducts and dampers (for air distribution and collection), chillers, air-conditioning units or fan coil units, which may be used to cool the air passing through the ducts. Heaters may be required to keep the temperature in the safe enclosure facility within the desired range. Fans are used to circulate the air in such systems and filters are required to remove radioactive and other particulates, e.g. asbestos, from the air prior to exhausting it. Ventilation exhaust (sometimes referred to as the ‘purge-balance’ exhaust) is necessary in order to maintain subatmospheric pressure in the buildings and to transport particulates to a designated trap, usually a HEPA filter. Where elevated humidity is an issue, the facility’s dehumidifiers should be used to keep the humidity below a preset level, thereby preventing condensation and thus corrosion. Without corrosion, the structure may remain accessible and stable for a long time. Condensation on surfaces has multiple impacts in addition to corrosion, including leaching of adsorbed contaminants that can spread contamination, degradation of insulation leading to release of asbestos fibres, creation of slip and trip hazards where the water pools, promotion of mould and the sustaining of populations of intruding animals. In addition to water from condensation, any from leakage or rupture of incompletely drained pipes needs to be collected using properly positioned drains, taking into account the gradients in the facility. This collection will in turn require sumps equipped with level indication and pump out (see drainage discussion in Section 3.5).

The amount of make-up air used for this ventilation process is an important design (or reconfiguration) factor. Dehumidifiers and heaters represent a large electrical load, and the costs of electricity can be substantial. Therefore, the level of dehumidification and/or heating and purge-balance exhaust flow to be compensated for through make-up air needs to be chosen, involving a trade-off of operational costs versus the mitigation of anticipated impacts noted above.

The amount of air used for ventilation is facility specific and a proper redesign needs to be completed if the intent is to reuse existing systems. If a new system is installed, then a complete design should also be completed. At some facilities with higher internal contamination or suspected alpha contamination, larger volumes of air are circulated and a small purge-balance flow is used, while facilities with limited contamination and no alpha contamination use limited volumes of once-through ventilation or may be able to justify the removal of the ventilation system for contamination control altogether. The regulatory approach to this issue varies substantially from country to country.

The ventilation air intake structure needs to be robust and should not provide an access point for intruders.

The air brought into the safe enclosure may need to be prefiltered, heated or dehumidified in a conditioning unit before entering the safe enclosure. In most safe enclosures, the air intake conditioning unit is outside the controlled area, in order not to allow the unit to potentially be contaminated. Filters and dehumidifiers need to be maintained on a regular basis and condensate from drainage systems collected and sampled. The filters may get loaded with normal dust and solids. When the service life is exceeded (i.e. when the filters reach the maximum pressure difference acceptable), the filters can be treated as ordinary waste. The material commonly used for dehumidification of the air during operation is usually silica gel. The lifetime of silica gel is typically between five and ten years, depending on its duty cycle. After use, the material should be treated as chemical waste. If the silica gel is also contaminated with tritium it will be considered as mixed waste. The capacity for the uptake of water of the dehumidifier material needs to be controlled at regular intervals. If a less dry environment can be tolerated, use of conventional industrial dehumidification technology presents lower operating costs and avoids the solid waste production of silica gel. However, these units might be integrated into the air distribution system to ensure good mixing, and since the original system may have been designed for much larger circulating air flows, retrofit of the distribution system can also be warranted.

The new requirements pertaining to ventilation under safe enclosure may lead to the installation of a new ventilation stack. One such case occurred at Lingen NPP, Germany, which has been dormant for 25 years and is now getting ready for final dismantling [62], see Fig. 27. Annex II–10 is relevant to ventilation issues.

6.1.1. Once-through ventilation

If a low volume rate of air for ventilation is acceptable due to low radioactive contamination in the facility, it might be beneficial to use a once-through ventilation system. In this case, the air may be conditioned by a pretreatment filter, dehumidifier and HEPA filter. Then the air is distributed through the buildings and collected on a central point (for multiunit stations in safe enclosure, this needs to be done for each unit separately to minimize the risk of cross-contamination between units). Distribution of air and flow control can be achieved by automatically operating valves. The valves are activated by pressure differences in the buildings. The signals are fed to a computer system, which controls the valve positions. At the central point the air is pumped through a HEPA filter and transported to a stack. It will still be necessary to monitor or sample discharges prior to release. Where monitoring is required, it could also be possible to shut down the ventilation system at the moment when

FIG. 27. New ventilation stack at Lingen NPP, Germany (courtesy of Rheinisch-Westfälisches Elektrizitätswerk AG).

radioactivity above set levels is detected in the gas release. An air discharge limit is normally in place as part of the plant's licence condition.

The advantage of the once-through system is that the dehumidifier's position is outside the controlled area. This keeps the installation free from contamination, while the water coming from the dehumidifier is not contaminated and can be released without activity monitoring. The disadvantage of this system is the relatively large volume of air to be conditioned.

An overview of a once-through ventilation system for a safe enclosure is given in the Appendix.

6.1.2. Circulation ventilation

If a large volume of ventilation is required, a circulation system is preferred. Large volumes of ventilation air are used in the case of highly contaminated areas or where specific contamination is present, such as alpha emitters. In this system, large volumes of air will circulate in the safe enclosure, being filtered and dehumidified by a separate HEPA filter and a second dehumidifier. A small amount of fresh, filtered and dehumidified air is added on a continuous basis and an equal amount of air is released, after passing the HEPA filter and a monitoring and sampling station (providing purge-balance as previously noted). The advantage of this system is that a limited amount of energy is needed for the dehumidification system in the fresh air supply. Also, if the circulating air meets humidity specifications, the dehumidifier can be bypassed. The disadvantage is the possible contamination of the dehumidifier in the controlled zone and the cost of extra HEPA filters, due to the large volumes of circulating air. Water coming from the dehumidifier in the controlled zone needs to be checked for activity before release. This means a water release permit is in place. However, this option is cheaper than once-through ventilation if larger volumes of ventilation air are required.

An overview of a circulation ventilation system for a safe enclosure is given in the Appendix.

6.1.3. Passive ventilation

Where the safety assessment does not require ventilation for the control of radioactive contamination, the ventilation system may be removed prior to safe enclosure. Ventilation may, however, be required for conventional reasons, for example the control of temperature and humidity within a building. A common means to achieve passive ventilation involves a combination of louvres for air entry at low points and self-powered turbines on the roof or other high points. A passive ventilation system may also utilize a differential pressure regulator or a breathing vent where air can enter the safe enclosure via valves if the outside pressure is higher than the inside pressure; conversely, when the inside pressure is higher than outside, air will leave the safe enclosure. A filtration system may be inserted to prevent radioactive materials from leaving the buildings. Wind catchers are examples of a novel system used by Magnox at Berkeley in the UK to force air through the plant in the safe store to regulate the humidity, considering low residual contamination [63].

An overview of a passive ventilation system for a safe enclosure is given in the Appendix.

6.1.4. Sources of chronic low level radioactivity

Whether once-through circulation or passive ventilation is used, special attention should be given to radon and its accumulation in closed areas. If the ventilation flow in the safe enclosure is low, radon concentration might build up to unacceptable levels. Particular attention needs to be given to areas with low ventilation, such as basements. Radon emanates from materials containing natural uranium, e.g. soils and granite. In order to mitigate the effect of alpha radiation coming from radon decay, some facilities prescribe workers to wear protective clothing. It is also advisable to do regular radon surveys in the most accessed rooms of the safe enclosure. If a passive safe enclosure is established, special attention should be paid to radon. It may be necessary to vent infrequently accessed areas prior to entry. Similar precautions need to be taken where there is a history of chronic contamination by other nuclides, such as tritium, which may evolve slowly from building surfaces.

6.1.5. Airborne effluent disposal

It may be appropriate to control discharges from the safe enclosure to the environment, depending upon the nature of the hazard present in the area, the ventilation system supports and the potential impact. Commonly, a satisfactory solution is the channelling of all exhaust flows through a HEPA filter, as described above, since radionuclides in particulate form are most commonly encountered during safe enclosure. To provide a higher degree of control, the activity in the air may need to be assessed continuously post-filtration and this may interlock with a system shutdown function. Where the activity concentration and the potential impact of the discharge is low, particularly associated with passive facilities, it may be sufficient to sample the effluent periodically to control the plant condition. The sampling and analytical methods used and the records kept regarding the radionuclide composition of the waste also need to be retained and kept up to date.

6.2. WATER SUPPLY

Water may be necessary for consumption and personnel hygiene, particularly on an active site; water may also be needed for decontamination purposes. It is advisable to keep water usage minimized to reduce the surveillance and maintenance burden, while the use of enclosed water tanks is recommended to minimize the potential contribution to building humidity levels. During the winter, water may freeze in storage tanks and lines unless a source of local or trace heating is supplied, as most areas in safe enclosure not served by ventilation will be unheated. If water is present in an unheated facility in safe enclosure, it might freeze, resulting in damage to tanks, pipelines and other equipment. Therefore, all facilities in safe enclosure have to be drained of water at the beginning of the safe enclosure period. Considerable effort may be needed to drain and dry such equipment to take into account bends and traps, and afterwards the lines should be capped off to prevent a recurrence of water in these low points due to condensation. A relevant case quoted in the literature [64] concerns the freezing and breaking of pipes, releasing water from the spent fuel pond at the Dresden 1 NPP in Illinois, USA, during its safe enclosure and ultimately threatening to uncover the spent fuel.

To avoid water leakages from service lines it is recommended to close a central valve in the service water line when the safe enclosure is fully established. This valve can be situated at the entrance of the service water line to the site. Some facilities operate an automatic closure of this valve, activated when the lights are switched off in the safe enclosure. As there might be substantial periods of time when the site is unmanned, it might take a while before a water leakage may be detected. As noted above, special attention should be given to water volumes in U-bends and low points. Another issue can be the unexpected transport of remaining water in pipelines due to pressure differences in the lines (water hammer). This might lead to leakages from open valves.

If water is retained on a safe enclosure for hygiene or consumption, the system needs to be maintained for the prevention of *Legionella* or other bacteria; where the system has not been configured with this in mind or water is infrequently used, this may be a significant burden.

6.2.1. Liquid effluent disposal

Effluents, whether radioactive or otherwise, need to be disposed of, which increases the operational activities and therefore cost of managing a safe enclosure. As with airborne effluents, it may be appropriate to control discharges to the environment depending upon the nature of the hazard present and the potential impact. The anticipated quantities of such effluents depend strongly on the manner in which the facility has been prepared for safe enclosure: if a facility has been well prepared for passive safe enclosure, the sources of contamination which can lead either directly or indirectly to aqueous contamination will have been minimized. However, if a facility is in active safe enclosure, routine maintenance, salvage activities and cleanup of local spills are likely to require that both liquid and solid waste handling facilities be kept in-service (usually at a central point). Of special importance is the likely absence or diminution of cooling water flows that would normally be available for dispersion of low activity liquid wastes during operation. In this case, a new environmental discharge point may have to be defined and assessments of emission limits recalculated. A safety assessment will likely be required to determine if it is necessary to abate the level of radioactivity in the effluent, for example by processing higher activity liquid wastes for disposal as solids, and discharge the balance at sufficiently low concentration to minimize the impact of the discharge. As noted above, such a plant is likely to be associated with an active safe enclosure where the level of hazard present is typically higher than that of a passive site. Where aqueous effluents are generated and do require disposal, it is not normally a continuous operation and therefore requires some degree of plant status monitoring to determine the need and to enact the disposal. For low volume, low activity effluents, it may be appropriate to store the effluent and dispose to another (e.g. operational) facility by tanker. As the management of such effluent can represent a significant demand on resources during safe enclosure, the importance of the control of volumes through effective decontamination in PSE and the minimization of water from condensation, leakage and ingress through the building envelope is of paramount importance. The impact of leaking water can be significant and consequently the maintenance burden for any plant is relatively high.

6.2.2. Surface water systems

The surface water system needs to be capable of coping with the reasonable extremes of rainfall expected over the safe enclosure period. This will typically be defined by safety assessment. As a general statement, careful attention needs to be paid to storm water management and the continued functioning of all building perimeter drainage. Since reactor buildings frequently have deep basements, the collection and pumping of water from sumps needs to be foreseen, which will require either periodic entry to confirm the status, or — to reduce the frequency of entry — the provision of remote notification of water levels and pump status.

Passive storm water drainage systems are common. Where a site is managed remotely, in the absence of personnel on-site, a mechanism to monitor extreme rainfall events such as through weather stations or cameras, if extreme weather conditions are predicted, should be considered.

6.3. ELECTRICAL SYSTEM

During shutdown operations and in PSE the electrical system can be simplified and adapted for future needs. This also permits better control of the segregation of live versus deactivated circuits, where errors in isolation, possibly due to lack of configuration control, can pose a serious safety risk. If an electrical supply is only necessary for limited services and safe enclosure activities, the need for a fit for purpose installed power supply might be considered. In the absence of the need for an installed power supply, battery supplied equipment with suitable redundancy may be used for lighting during inspections and maintenance, while also permitting complete isolation of the safe enclosure from external power — a desirable situation for safe enclosure. If an installed power supply is necessary, the system needs to be sized to manage the safe enclosure period and not final dismantling, unless the safe enclosure period is relatively short. This may mean reducing the size of the existing system, as discussed above, or installing an overlay. It is unlikely that a need for high voltage supply will be present on single facility safe enclosure sites, so all such connections can in general be completely isolated.

6.3.1. Electrical power supply

Loads during the safe enclosure may require electrical power from the local grid. If the local grid breaks down, a suitable auxiliary power system needs to be available. The main reason for the power backup is to warn safe enclosure personnel that a problem has occurred. Additionally, relevant systems such as fire detection and security (e.g. cameras or gate control systems) should be kept operable. During a power cut, the ventilation system may shut down, and air intake and release valves shut. There is generally no need to connect the ventilation system to the backup power system, where the power cuts are normally short. Running the safe enclosure for short periods without ventilation is considered acceptable in general but may need to be subject to a safety assessment.

The capacity of the backup needs to be large enough to allow sufficient time for recovery. It is advisable to have a connection point at the safe enclosure outer wall available for a mobile diesel generator. This generator can be installed if restoring of power to the safe enclosure takes longer than the capacity of the backup system allows. To have a diesel generator available, an agreement with the supplier needs to be in place. In the case of multireactor sites, external power from diesel generators serving the NPPs in operation might be used, and following shutdown of all units, one or more backup generators might be kept in-service, particularly if the safe enclosure period is foreseen to be short.

Modification to the grounding system may be needed prior to entry into safe enclosure to avoid short circuits from the operating equipment, but also to deal with buildup of static electrical power in any generators, transformers and powerful electromotors. It is advisable to ground these components not only to the grounding grid, but also directly to the earth at the spot. The grounding grid itself needs to be checked on a regular basis.

A series of electrical events occurred at Savannah River while teams preparing the plant for safe enclosure were performing electrical isolation activities. In each case, workers believed that all electrical hazards had been evaluated and no hazardous energy was present. However, as the examples given in Ref. [65] show, incorrect assumptions and inaccurate drawings led to errors in determining that no electrical hazards remained.

6.3.2. Lighting

The safe enclosure needs to have sufficient lighting. Options vary from leaving part of the installed system operable, to total dependence on portable lights [35]. As the existing lighting system for the operational nuclear facility is often old, most safe enclosures install a new fit for purpose lighting system at the start of the safe enclosure period. Consideration should be given to the type of lighting. Some areas may not need the amount of illumination that was needed for the operational phase. Therefore, the intensity of the lighting can be reduced to cut down on electricity costs. Some areas only need enough light for transient traffic. Additionally, to reduce maintenance on the illumination system, special types of lamps can be used. These lamps should have a long operational life, such as that offered by light-emitting diode (LED) lights. Preferably, they will last for the expected duration of the safe enclosure. These lights are expected to be used only when inspections and maintenance take place. Although long-life lamps might be a little more expensive, they are well worth the extra cost, as the replacement of lamps during the lifetime of the safe enclosure is also expensive. The lamps that are replaced might be radioactively contaminated, in which case they would have to be disposed of as radioactive waste. Flashlights can be relied on only for local (spot) lighting enhancement or to provide an additional level of backup.

If decontamination work or maintenance is performed in the safe enclosure, more illumination on the work spot might be needed to gain more visibility and to keep the work spot safe. Portable illumination on stable, secure mountings can be used in these situations in addition to the existing lighting system. However, care needs to be taken when using this equipment as cables can be a trip hazard and the lights themselves can become a heat source. This heat source is a potential fire hazard and can make the working conditions unpleasant.

Using compact fluorescent lamps and low cost LEDs allows a project to benefit from their design and availability. Compact fluorescent lamps and compact LED designs allow workers to position lamp fixtures so as to provide more effective, specific illumination for the job(s) being performed. Installing light fixtures in locations that are inaccessible (e.g. ceilings) and in permanent locations diminishes the flexibility required by workers to perform jobs that change continuously. Alternatively, small compact light fixtures, positioned by the worker where needed, contribute towards higher efficiency and greater safety, especially when work is being performed in a hazardous environment.

Recently, development has led to the production of LED fixtures that are not restrained by their 'droop' factor (i.e. the lowered reliability of LED lighting that may be caused by elevated ambient temperatures). At the lighting levels currently needed for adequate illumination, droop kicks in, lowering the efficiency of LED lighting to unsatisfactory levels. To compensate, LED bulbs are forced to increase output, but this results in dramatically lowered efficiency because of the high temperatures in which they are required to operate.

A general discussion on lighting in hazardous environments — which is generally applicable to safe enclosures — can be found in Refs [66, 67]. Reference [68] highlights the hazard that lighting equipment may pose as an ignition source.

6.3.3. Connection points

As there might be maintenance requirements and repairs may be needed during safe enclosure, connecting points to the electrical system should be put in place well above floor level to avoid water ingress. The power on the connector needs to be sufficient to supply electrical equipment likely to be in use. Such power lines can also be used during final dismantling of the plant. At some sites the non-essential power supplies are de-energized and secured; in the case of such systems, it is advisable that this be performed either by physically breaking the connections (air gapping) or by locking out the supply from a central location.

6.3.4. Lightning protection

The main function of the lightning protection system installed on the existing building is to conduct a lightning discharge current safely to the ground. The need for any lightning protection needs to be identified in the safe enclosure safety assessment and any system requires considered design to provide robust protection.

6.4. SURVEILLANCE AND MAINTENANCE

Surveillance and maintenance activities are conducted throughout the facility life cycle, including when a facility is not operating and is not expected to operate again [8]. During the end-of-life period, it is important that surveillance and maintenance be adequate to maintain the safe enclosure through a seamless transition to the final disposition of the facility. Surveillance and maintenance is adjusted during the facility life cycle as the shutdown, transition, safe enclosure and dismantling phases are completed.

Surveillance includes any activity that involves the scheduled periodic inspection of a facility, equipment or structure as required by legislation and regulations. Maintenance includes any activity that is required to sustain property in a condition suitable for the facility to be used for its designated purpose [8]. In some cases, major maintenance actions are needed to keep safe enclosure in the required condition, as illustrated in Fig. 28.

An important objective throughout operation to decommissioning transition and disposition is to maintain an integrated and seamless process linking deactivation, decommissioning, and surveillance and maintenance with the previous life cycle phases. Facility transition and disposition activities have to incorporate integrated safety management at all levels to provide cost effective protection of workers, the public and the environment [69].

FIG. 28. Major maintenance of reactor building: Reactor dome insulation and roof membrane replacement in 2013, Douglas Point NPP (courtesy of AECL).

Typical surveillance and maintenance plan contents include [70]:

— Regulatory compliance;
— Description of surveillance and maintenance activities;
— Facility operation;
— Facility maintenance;
— Quality assurance;
— Radiological controls;
— Inspection of stored wastes;
— Hazardous material protection;
— Health and safety and emergency planning and preparedness;
— Environmental protection and monitoring;
— Safeguards and security;
— Organizational responsibility;
— Cost and schedule.

Reference [71] addresses priorities in allocating resources to surveillance and maintenance at different facilities. This is particularly relevant for organizations (e.g. the US DOE or the UK Nuclear Decommissioning Authority) owning or managing a large number of shutdown facilities, but could in principle be applicable to different parts or buildings of one and the same facility. The inspections can be a significant part of the surveillance cost: to this end, the DOE has a research programme under way to develop a remote monitoring system for closed down facilities. As one example, Florida International University has designed, tested and delivered, under a DOE grant, a remote surveillance system at the TAN-616 facility at the Idaho National Engineering and Environmental Laboratory. The system uses a data logger that operates the sensors and transmits data from the sensors to an off-site computer via a radio modem. The sensors include water level for tanks and sumps, moisture for sumps and floors and a temperature sensor. Personnel are able to monitor the system and obtain data from a computer outside TAN-616 and thus can monitor the facility without having to enter [72].

At defined intervals, a walkdown of the buildings and rooms of the safe enclosure can be performed. A passive safe enclosure is less visited than an active safe enclosure. During the walkdown, the operator checks for abnormalities in the operating equipment. Additionally, the status of structures needs to be checked and a close eye needs to be kept on leakages from roofs and equipment (e.g. oil leakage). Such operator rounds can cover all buildings and rooms. However, as some rooms might have high radiation sources, a balance between the radiation dose and the value of the operator round needs to be identified. After periods of heavy rain or high winds, it is advisable to check the inside and outside of the buildings for damage. The operator rounds can be performed following a checklist to make sure all relevant places are visited.

See Annex II–9 for an interesting case pertaining to surveillance and maintenance.

A full description of the safe enclosure strategy including surveillance and maintenance provisions for a US research reactor is given in Ref. [73].

The frequencies of routine rounds and periodic inspection depend on the conditions established at the beginning of safe enclosure and potential changes to these during safe enclosure. This is strongly dependent on the degree to which the conditions supporting passive safe enclosure have been implemented. Furthermore, regulators will expect a defensible rationale between frequencies applied during operation, PSE and safe enclosure, whereby reductions in frequency correspond to reductions in risk. Once stable conditions have been established, quite long intervals between inspections may be supportable, for example once in five years, where the frequency is likely to be dominated by confirmation of structural integrity. Initially, surveillance rounds for safe enclosure may be weekly or monthly, gradually increasing as event-free history builds during safe enclosure. This history may be acquired during PSE as the site demobilizes to safe enclosure configuration, thereby permitting the immediate use of extended frequency surveillance regimes.

For passive safe enclosure facilities, there may be significant benefits in cost and control by aligning surveillance activities to ‘mobilized phases’ where planned, and remedial activities can be completed during a discrete period.

6.5. WASTE MANAGEMENT

Wastes from operational activities, generated during preparations for and during safe enclosure have to be managed.

Most facilities in safe enclosure will have some low and intermediate level wastes in storage under conditions prescribed in the facility licence. These wastes might be in containers suitable for the safe enclosure conditions and designed to last at least until the availability of a disposal facility. Arrangements for the management of these wastes and their records need to be in place with the safe enclosure organization.

Storage of wastes within the facility, or otherwise on-site, during the safe enclosure phase will depend on factors such as the availability, adequacy and capacity of on-site stores, long term waste projections or the regulatory body’s position. IAEA guidance on the management of waste is given in Refs [74, 75].

In some cases, higher activity wastes or irradiated fuel will also be stored on the same site, or in a separate portion of a facility in safe enclosure. However, special licence conditions or a separate facility licence will normally be required for this.

During the safe enclosure period, some waste will be generated from surveillance and maintenance activities, such as local cleanup of detected contamination, personal protective equipment, ventilation and filters. Such wastes will be typically low volume with low levels of contamination, from either radioactive or non-radioactive sources. Liquid wastes will require special consideration for facilities in safe enclosure, as discussed above under liquid effluent disposal. Arrangements can be put in place to segregate the radioactive waste from waste which can be classified as non-radioactive. For the non-radioactive waste, the normal local waste collecting services can be used to dispose of the waste, subject to the application of procedures and practices to ensure contamination of this waste is below established limits.

A system can be put in place for the collection, characterization, sorting, conditioning, packaging and storage of radioactive waste, as needed. The radioactive waste will consist of items such as filters, discarded equipment and general personal protective equipment waste. Regular shipments ensure transport of radioactive waste to an approved storage or disposal site. Regular removal of these wastes helps to ensure any fire loading requirements in applicable safety assessments are not compromised. Where the safe enclosure exists as part of a multiunit or multipurpose facility, and where these remain fully or partially in operation, it makes sense for wastes arising at the safe enclosure facility to be managed through these adjacent facilities.

A relevant case in question is the Berkeley NPP, in the UK. In 2010, Berkeley was the first Magnox site to place its two reactors into safe enclosure. The Berkeley site reached a major milestone in April 2014 when the first package of nuclear waste was placed inside the newly constructed interim storage facility.

Once decommissioning is complete, the interim storage facility will hold around 850 waste packages from Berkeley in interim storage until a national disposal facility becomes available. The decommissioning programme at Berkeley is well under way with full implementation of care and maintenance (safe enclosure) expected in 2021. The intermediate level waste will be stored in this facility until the national geological disposal facility becomes available at the current planned date of 2040. The UK Nuclear Decommissioning Authority is considering sending 142 containers from the nearby Oldbury NPP to the Berkeley storage facility to reduce the cost associated with the construction of temporary storage plants. If stored at the newly constructed interim storage facility, their transportation will require 100 lorry trips over seven years, expected to be done outside of peak times [76].

In general, operational waste stored in less than optimal conditions (e.g. in vaults or pits) needs to be retrieved and conditioned in PSE. Reference [77] can be usefully consulted in this regard. The Berkeley decommissioning project also exemplifies a typical activity preparatory to safe enclosure, namely the removal off-site of large components to simplify the management of safe enclosure. The 15 boilers (steam generators) which were located external to the Berkeley reactor building (and as such would have complicated surveillance during safe enclosure) were shipped to Studsvik, Sweden for melting. The steel ingots resulting from the melting were kept at Studsvik for decay as needed and eventual release, while the much smaller slag fraction was returned to the UK for final disposal. In this way, the operation achieves a considerable reduction of radioactive volumes [78]. Figure 29 shows the transport of a huge Berkeley boiler.

FIG. 29. Berkeley boiler in transport (courtesy of Magnox Ltd).

6.6. ON- AND OFF-SITE ENVIRONMENTAL SURVEILLANCE

Most safe enclosures have an environmental control programme that is typically derived from the programme used for the facility while in operation. Regulatory bodies are likely to require the continued monitoring of the behaviour of radionuclides discharged to the environment during the operational life of the facility, until a justification for change is provided and accepted.

Features of the safe enclosure environmental programme need to be proportionate to the potential residual environmental hazards on the site. During the transition to safe enclosure, it is advisable to keep all components of the environmental control programme in place, such as gamma dose measurements in air and sampling deposition on grass and water. This is because work at the safe enclosure may result in unforeseen changes in the release paths. As soon as the safe enclosure is fully established, the environmental control programme may be reduced, in agreement with the regulatory body. Following the implementation of this revised programme, there may be a period required to re-establish the baselines of the environmental monitoring data for the site in its new configuration. This is especially true for passive safe enclosure facilities. As an example of progressive reduction in the requirements of environmental monitoring, direct radiation measurements in the vicinity of the facility might stay in operation for five years after the establishment of safe enclosure. After that period, assuming that the safe enclosure has operated steadily without incidents or uncontrolled releases, a further reduction of the programme can be considered.

Special attention needs to be given to managing areas of known land contamination, radioactive and conventional, and quantification of any leaching of material into groundwater surrounding the safe enclosure. It is also possible for uncontrolled leakages to occur from contaminated buildings and pipes (especially underground) around the safe enclosure [6].

If a radiation dose monitoring system is in place at fixed locations in the plant or at the site boundary, the number of monitoring points can be reduced after a few years of establishment of the safe enclosure. Over time, the frequency and number of locations for these measurements may remain constant or decrease. To monitor for potential unplanned releases, passive sampling, for example using passive dust collection shades, may be particularly appropriate for facilities in safe enclosure.

7. SAFETY MANAGEMENT

Safety management is a high priority throughout the entire life cycle of a nuclear facility. In a safe enclosure, hazards similar to those in an operating facility exist, while new hazards are introduced (e.g. poor lighting). Hazards can be both radiological and conventional. This section describes the most common hazards.

7.1. GENERAL

Shutdown activities will seldom remove the majority of hazards from a facility. Examples of hazards that remain in and around a facility are listed below [35]:

- Confined, unventilated spaces;
- Radiation and contamination hazards;
- Chemical residues inside systems;
- Combustible materials (e.g. electrical wiring insulation);
- Unguarded/unblocked ladders and open sided platform hazards);
- Personnel slip, trip and fall hazards;
- Vehicle hazards inside fenced area (e.g. abandoned steam/sewer/propane gas lines);
- Oil residues inside transformers including polychlorinated biphenyl and other chemical additives (Fig. 30);
- Loose or ill-fitting grating and floor openings;
- Asbestos in piping, equipment and building materials;
- De-energized lighting ballasts;
- Poor lighting conditions;
- Air quality (e.g. mould);
- Standing fluids in systems (see Section 3.5);
- Potential for isolated energized systems;
- Unmarked facility escape lanes and sealed egress doorways;
- Stored energy in redundant plant (e.g. duct hangers, roller shutter doors);
- Objects falling, see Annex II–18.

In fact, the length of shutdown may increase the risk of hazards if not managed properly (e.g. degradation of systems leading to premature failure of supports or release from dried out gaskets).

FIG. 30. Dismantling of the main transformer at Caorso NPP (courtesy of SOGIN).

7.2. NUCLEAR SAFETY

With the establishment of the safe enclosure, nuclear fuel will have been removed from the site or put into safe interim storage on the site. It is therefore not expected that special arrangements be retained for the management of nuclear safety. Nuclear matter is likely to be stored on the site and the arrangements for the safe management of this material will be detailed in the safety assessment.

7.3. CONVENTIONAL SAFETY

Conventional safety can be one of the biggest hazards encountered during safe enclosure. At regular intervals, an industrial safety walkdown of the facility should be performed by a safety professional to determine the status of the facility and its potential hazards. Attention needs to be given during pre-job briefings to the plant's industrial hazards. All safe enclosure activities need to be in accordance with controls specified in the risk assessment for the work to be performed. Prior to establishing the safe enclosure, it is good practice for the hazard assessments to be reviewed by departing personnel to ensure the appropriate information is retained for the safe enclosure period.

Good industrial safety practices should be followed when managing a safe enclosure, as there are still hazards that could endanger personnel. Regular checks on climbing equipment (movable stairs), movable electrical equipment (extension power lines) and mechanical tools need to be performed. All equipment needs to be maintained and checked at regular intervals. As the material ages, replacements may be necessary.

In the safe enclosure, most of the available equipment is out of service. However, some new equipment is installed during the PSE and old equipment may still be in operation during safe enclosure. It may be difficult to tell the difference between equipment that is out of service and equipment still in operation, therefore all equipment, power lines, measurement equipment, etc., in operation needs to be clearly marked. Some facilities use one colour to mark equipment still in operation. In such a case, it is advisable to use paint, as stickers might come off over time. The colour applied needs to not have been previously used in the facility.

Annexes II–3 and II–13 are relevant to conventional safety hazards from operational equipment.

As is consistent with the operational phase of a nuclear facility, the performance of pre- and post-job safety briefs is important in the management of safety, as is appropriate supervision of the work.

7.4. HEALTH PHYSICS

The health physics work in a safe enclosure does not differ in principle from that of an operating nuclear facility, although the frequency of performing surveys may decrease as facilities are no longer routinely accessed. The same type of health physics equipment, training, etc., needs to be available to support safe enclosure activities. Typically, this would include handheld radiation monitors, portal monitors (exit monitors), laboratory equipment (e.g. to measure swipes), and a dosimetry system. The set-up and the work of the health physics team follow standard protocols on this issue [17, 79]. Consideration should be given to the location of this equipment to minimize damage and improve functionality. Generic radiation protection information and guidance by the IAEA is considered fully applicable to the decommissioning phase [80, 81]. As degradation and ageing may occur, new health physics equipment may be needed from time to time.

A person officially responsible for the health physics of the safe enclosure needs to be designated to ensure compliance with regulations. The person responsible for health physics accesses the results of routine monitoring, takes proper actions in the case of unexpected health physics issues, ensures adequate maintenance of health physics equipment, deals with waste management and prepares regular reports.

At the point when the facility is put into safe enclosure, it is good practice to perform a full survey of the facility to a consistent method. At a regular frequency, health physics surveys need to be performed in the safe enclosure; this may be especially important where new ventilation systems have been installed or reconfiguration of the building has taken place to understand any movement of loose contaminations. In an active safe enclosure, a periodic cleanup of built-up contamination might be necessary.

7.5. EMERGENCY PLANNING AND PREPAREDNESS AND SECURITY INCIDENTS

Emergency planning and preparedness (EPP) is necessary for a safe enclosure as it contains large amounts of radioactive materials due to structures, systems or components activation and contamination in various parts of the facility. The bulk of the radioactive inventory is likely to be in the reactor building and waste stores for NPPs in safe enclosure. However, other areas can be contaminated as well, especially the waste handling and waste treatment building.

As the risk and impact of residual activity during an incident in the safe enclosure phase is lower than during the operational phase, the EPP organization can be commensurately downgraded and is therefore expected to be smaller than the one in place during operation.

The facility management reviews and rewrites emergency plans to make them fit for purpose, and ensure they are balanced against the risk of an incident (e.g. an unexpected release or fire). As there is still a risk of incidents, all EPP measures need to be checked at the onset of the safe enclosure phase. The off-site measurement equipment can be reduced, but is still required and needs to be maintained. It might be hard to convince local authorities of the need for an up to date emergency plan and of the requirement that they participate in EPP, but periodic drills should be run. The importance of EPP during safe enclosure lies in dealing with protestors, intruders, etc.

Arrangements can also be put in place to manage security incidents at the safe enclosure; demonstrations from interest groups are the most likely threat but threats from organizations attempting to acquire nuclear materials should be considered too. Cooperation with local authorities, principally police forces, is important in the preparation of arrangements that need to be reviewed and tested periodically.

7.6. CONTRACTORS

Contractors are likely to have been used extensively during the PSE phase and may be used to fulfil safe enclosure activities and maintenance requirements as well as security services.

7.6.1. Contractor skills

As the maintenance workload for a safe enclosure is much lower than for an operational nuclear facility, it makes little sense to retain all existing maintenance personnel. Therefore, most of the maintenance work will be handed over to contractors. The operator and the contractor need to realize that although the risk in the safe enclosure is less significant than in an operating facility, there are still industrial safety issues, and contamination and exposure hazards. Many contractors — if specialists in their own field — are not familiar with work under the rules and regulations of a nuclear facility; working with ionizing radiation in particular may be completely new to them. Training and instruction should be given to them by the staff of the safe enclosure, including plant orientation. Although work can be delegated to contractors, the operator cannot delegate legal responsibility. This means the operator needs to keep a sufficient measure of coordination and supervision of contracted work. The skills and culture expected of the contract workforce may need to be well established in the contractual arrangements.

7.6.2. Prime contractor

At some safe enclosure facilities the enactment of all maintenance activities is handed over to one contractor (the prime or leading contractor). In this case, this contractor is responsible for the delivery of all the maintenance, including the reports to the regulatory body, usually through the operator. In most countries, the regulatory body will discuss the safe enclosure status, including maintenance reports, only with the operator as the licence holder.

If equipment breaks down, the contractor needs to be contacted to start the repair process. If a subcontractor is needed to do the job, a delay may occur. Secondly, there is a potential issue in communication as the leading contractor might not fully understand the problem. This problem can be tackled by direct communication between safe enclosure personnel and the subcontractor, but this would undermine the role of the leading contractor. Therefore, a leading contractor can only be adopted if they offer a comprehensive package of services.

Where no leading contractor is appointed, the planning and execution of the maintenance work needs to be done by the safe enclosure staff. Depending on the number and skills of the staff this is a potential cost saving option, taking into account the advantage of availability of staff familiar with the facility from its operational phase.

7.7. EVENT REPORTING

Event reporting is an important element of safety culture in conventional and nuclear facilities. It is important that event reporting and analysis of event trends is maintained during safe enclosure. The recording of minor incidents caused by defects in the plant or in procedures needs to be communicated to staff and contractors as an expectation. Minor incidents can include slips, trips and near misses where no physical injury has occurred.

In the absence of good event reporting, safety culture and awareness typically erodes rapidly, particularly where small teams of people consistently work together and bad practices may become common practices. It may not be necessary for event reporting and trending to be managed locally, as the capability may be provided through a partner facility or the central organization.

8. ORGANIZATION AND MANAGEMENT

There are a number of issues to consider and organizational models that could be adopted to manage sites during safe enclosure. These are outlined below. However, whatever approach is adopted, the overarching, consideration is to ensure that safety management is the top priority. This includes all aspects of safety, such as licence compliance, inspection, radiological and industrial safety and plant configuration. These themes are discussed at length throughout this publication, but the starting point needs to be safety. Safe enclosure can be in place for many decades and as such the people who manage and oversee these facilities are required to provide safe stewardship for several generations. The arrangements put in place need to reflect that.

A comprehensive overview of organization and management factors and issues during decommissioning phases is given in Ref. [82].

Safe enclosure can be managed in a number of ways, depending on the parent company, the number of sites or location. The two principal options are local or remote organization and management.

In local surveillance and maintenance, a site manager is based at or close to the site. In remote organization and management, the site manager is based at a location remote from the site. In either case, an appropriately sized and structured team may be in place, particularly during active phases, to safely take the site through to final dismantling. Team size and structure can depend on a number of variables; for example, availability of skills and personnel, specific hazards at the site (or sites), potential combination of functions and the extent to which third party (contractor) resources are used to support activities. It is also possible for the remote team to manage multiple sites. Licence requirements may impact on the location, size and roles and responsibilities of the organizational structure adopted. In either model, the site manager will usually report and be accountable to a higher position.

Before the safe enclosure phase begins, there is usually a significant reduction in personnel at the facility, which may impact on the local community, particularly in the case of remote, economically depressed regions where an operating facility is the main employer. Local communities can also have an impact on the smooth organization and management of the safe enclosure; for example, if the safe enclosure is perceived to be managed poorly, the local stakeholders will form a bad image of their counterpart and difficult relationships could develop. Another potential impact is the availability of skills and knowledge from former workers and their willingness to support the new decommissioning phase; factors such as age profile or alternative employment options can have a bearing here. Annex II–7 discusses a case of staff reduction in the context of decommissioning.

A safe enclosure is expected to be there for a defined period of time. The number of staff needed needs to be estimated with great care. A passive safe enclosure requires access by maintenance staff a few times a year. Maintenance staff need to be informed about the safe enclosure activities, operations and maintenance by means of well written manuals and detailed instructions. Also, accurate layout drawings of buildings, systems, equipment and components need to be available to the staff with specific emphasis on operating systems.

In active safe enclosure, the need for staff is higher than in passive safe enclosure, as there will be more frequent activities on-site. Typical work may be the collection of samples from ventilation air in the stack or groundwater samples, performing patrols and operating systems. Additionally, more maintenance is needed in active safe enclosures, as there are a lot of operating components. This means the number and skills of the staff are not easy to estimate. Staff need to have a broad knowledge of what is going on in the safe enclosure, and required maintenance, repair and operation. The more staff employed, the higher the operational costs for the safe enclosure will be. The operational costs of the safe enclosure should be kept to a minimum, but safety cannot be compromised. Some regulatory bodies require redundancy in staff numbers. Defining the workload and qualifications needed is a good way to convince all stakeholders (e.g. the regulatory body and the operating organization's top management) of the staff needed for safe management of the safe enclosure.

8.1. STAFFING FOR LONGER PERIODS

The duration of safe enclosure in most cases may be longer than the working lifetime of its personnel, thus knowledgeable staff can become a problem in the longer term. In general, the first crew is recruited from the operations staff or the staff who prepared the facility for safe enclosure. Staff who have been involved in the PSE phase can be particularly valuable, as they have the knowledge of how to operate the new equipment and are familiar with the configuration of the safe enclosure. Staff who were involved during the operational lifetime of the facility are also valuable because they know the facility's operational history. They also know about operational problems and maintenance, along with other issues and how they were solved during the operational period. This includes any legacy hazards such as local contamination or hot spots.

When experienced personnel retire, there may be two problems to deal with. First, there is the recruiting of new qualified personnel, and second, the task of transferring knowledge to the new recruits.

As work during the PSE period and during an active safe enclosure phase requires specific skills, it might be difficult to recruit personnel with the appropriate skills. This is particularly relevant when the safe enclosure is a stand-alone facility. Recruitment of personnel who can meet appropriate response times is essential so that they are able to arrive in an acceptable time at the safe enclosure to address problems. When there is no nuclear network in the area, recruitment focuses on individuals with a broad set of skills and knowledge, as the work may consist of mechanical jobs, electrical jobs, chemical and health physics work. The second problem is how to train the new personnel and how to transfer experience. This can only be achieved by a training programme dealing with all aspects of safe enclosure management. Learning from information from records and experience gained during the safe enclosure phase needs to be part of the training programme. Section 11.4 highlights the importance of records in a safe enclosure strategy.

As well as ensuring that there are personnel trained to do the required work at any time, it is also important to consider the longer term requirements. Planning for the succession of skills or roles will ensure that adequate knowledge and capability are available for the full term of the safe enclosure phase and that this phase can be completed safely. Mismanagement of the safe enclosure period can result in a lot of regulatory attention; therefore, a resource plan may be required that includes contractors, specialists and other resources to have the minimum number of personnel available so that proper succession management can be demonstrated.

8.2. MULTIDISCIPLINE WORK FORCE

During a safe enclosure phase there are several tasks to be performed by the staff. In principle, these are the same as in an operational nuclear facility. The workload for each task, however, is much lower in a safe enclosure than in a nuclear facility in operation. A typical example of this situation is the health physics routine. In principle there is no difference between taking a smear test in a safe enclosure or in a nuclear facility in operation. The only difference is the number of smears to be taken. The system for the maintenance and calibration of the equipment and the reporting and record keeping of results is the same. Therefore, the time it takes to do the job is shorter in a safe enclosure than it is in a nuclear facility in operation. This applies to almost every job. This brings the opportunity to combine several functions of staff. Combining staff functions leads to staff reduction. It is advisable to have staff functions combined in a logical way. A typical combination of staff functions are health physics with chemistry, and all maintenance in general. There is, however, a limit to combining functions. It is obvious that not all work can be done by one person. Also, some positions may require acceptance by the regulatory body, such as for the person responsible for health physics or the person responsible for security. Some regulatory bodies require distinct responsible persons, and do not easily allow different functions to be combined in one position. One reason for this regulatory approach is the potential loss of knowledge if such a multiple-task person leaves the company or is unavailable.

8.3. ORIENTATION AND TRAINING

The staff and contracting organizations of a safe enclosure need to be trained and periodically retrained to remain qualified for the job. Such training can be on-the-job training for routine work inside the safe enclosure but can also consist of special task training such as firefighting or first aid. Where safe enclosures are entered infrequently, initial off-the-job training may be required via, for example, drawings, manuals, lectures or 3-D simulations. The costs of training should not be underestimated, as such training can be compulsory for the whole lifetime of the safe enclosure (e.g. as a regulatory requirement or an insurance condition). External training can be expensive and may take time to be planned and implemented. New recruits will require more extensive in-class training, site induction and on-the-job training.

8.4. STANDBY REQUIREMENT

A standby schedule for safe enclosure personnel — staff and/or contractors — is necessary, because during the time when there is no personnel, on-site issues may come up that need immediate attention. The issues can be anything from intrusion detection, fire, alarms, deliveries of goods and inspection visits by the regulatory body. It is obvious that the need for people on standby is more important for stand-alone safe enclosures than for multifacility locations. Safe enclosure personnel assistance to the (off-site) fire brigade can be essential. An appropriate response time between a call being raised and arrival on-site needs to be determined. The person on call needs to be capable of accomplishing the required actions and needs to be fit for duty and have the authority to make decisions. Straightforward instructions should be available to the persons performing the call duties and an overview of what actions should be performed in case by case situations is very helpful. Therefore, a record system describing responses to certain problems needs to be in place. This system should be updated every time an incident or equipment malfunction has occurred. As call duty can be an unpleasant burden to the persons who are on call, a rolling schedule can be put in place with sufficient personnel rotating the call duties. On call duty may be shared by staff and contractors in the case where contractors are the specialists and the responsibility remains with the licensee.

9. REGULATORY CONSIDERATIONS

Several Member States still do not have clear and accurate legislation and regulations addressing decommissioning. This is going to cause delays while at least an interim policy is established by the regulatory body. Annex II–20(a) provides some insight into this situation.

The IAEA is developing reference (model) regulations for decommissioning based on the new safety requirements and guides. The objective is to develop reference regulations for decommissioning to be used by the Member States in establishing a regulatory framework for the preparation and implementation of decommissioning of facilities containing radioactive materials.

Once fully established and licensed, it is expected that a safe enclosure phase will be subject to relatively minor regulatory interactions. However, some changes to the routine operation of a safe enclosure may be dictated by other stakeholders or new national or international rules, reflecting on regulatory positions. It is also possible that limited dismantling activities will be initiated in view of final dismantling. These will require regulatory approval. The following sections will elaborate on these aspects.

9.1. LICENCE AMENDMENT

The licensing process for decommissioning can be demanding in terms of cost, schedule and resources. It varies extensively among IAEA Member States. For example, in the UK the (site) licence does not change throughout plant lifetime, including decommissioning; in Germany, there are sequential decommissioning licences that are issued stepwise in relation to the progress of decommissioning. The description given here assumes only one transition from the operations to the decommissioning licence.

When an operating facility is permanently shut down, the operational licence can remain valid until all fuel is removed from the reactor (the timing depends on national legislation). This means that all fuel related safety requirements as described in the operational licence should be kept in place. With the fuel transferred from the core to the spent fuel pool and off-site, some safety rules and regulations might no longer be applicable and can be lifted. However, as long as the fuel is on-site, there will always be a risk of incidents related to the fuel. The moment all spent fuel has left the site, the rules and technical specifications concerning the fuel can be abandoned and security measures may be relaxed.

A licence is still required since there is a risk of contaminating the environment with corrosion or fission products present in waste on-site or deposited on building surfaces and components. After removal of the spent fuel, the risks decrease tremendously and the licence for the transition of the operating facility to a safe enclosure might take account of the changed circumstances. Generally, this means less strict regulations.

The same applies after the above mentioned transition is completed and a safe enclosure is installed. Most safe enclosures include limited access to the facilities, often all (liquid) waste is removed and routine plant activities are infrequent or even nil. The licence for the safe enclosure should be balanced to the level of risk. An example of this is the position of a fire brigade on-site. A full fire brigade might be required on-site for the operating nuclear facility, while during a safe enclosure period an automatic fire alarm connected to the local fire brigade will do the job. In this way, a great deal of human and financial resources are spared.

The licence for managing the safe enclosure needs to be supported by relevant information. This is usually found in a safety report, dealing with items like siting issues, a plant description, operational matters and potential emergencies. Operational limits are set in technical specifications. Straightforward procedures for operating equipment in the safe enclosure need to be in place.

The safe enclosure activities and related documentation need to be governed by a quality assurance programme. Some downgrading compared to the operating facility can be applied to the quality assurance programme. The quality assurance programme can be audited at certain intervals by independent auditors.

9.2. CHANGE OF RULES AND REGULATORY DEMANDS DURING THE SAFE ENCLOSURE PERIOD

A potential disruption to the operation of the safe enclosure is when there is a change in rules and regulatory demands when the safe enclosure has already been fully established, perhaps for years. Due to developments in international positions, a country might adopt new or modified rules and regulations. These are tailored by the national regulatory body to a specific country and even shutdown nuclear facilities may be requested to adopt these new rules within a certain period of time. Often, changes in rules and regulations lead to plant modifications, or simply to additional paperwork. In the case of safe enclosure, these changes can become a serious burden, as typically a safe enclosure's management has a small staff and limited financial, technical and scientific resources. If significant refurbishment is required (e.g. a reconfiguration of the safe enclosure), funding can become a problem. As the funds originally allocated to decommissioning will be needed to pay for such works, a shortage of funding for final dismantling may occur. The extra funding may have to be secured and new agreements established.

During the lifetime of the safe enclosure, the regulatory body staff will also change, as will the personnel of the safe enclosure. Great care needs to be taken to ensure proper training of newcomers in the basic principles, design criteria and operational functions of the safe enclosure. New regulatory reviews might tend to require changes to the safe enclosure based on state of the art practices. Although rules and regulations applicable to newly designed facilities may change, their applicability to old structures (i.e. safe enclosures) needs to be cautiously addressed. First, compatibility with the original design criteria of the safe enclosure needs to be ensured and the costs of modifications considered. Periodic reviews consider new regulations or technologies. Sometimes a trade-off may be needed. Annex II–5 provides an example of the impacts arising from a change in the regulatory rules.

9.3. LOCAL GOVERNMENT

Sometimes the local government is in control of some aspects relating to the safe enclosure site. As the local government will change during the operational phase of the safe enclosure it is advisable for the nuclear operator to keep close relationships with local government at all times. Typically, when the responsibilities of the operator, the regulatory body and the local government are not well defined, misunderstandings can easily occur. If spent fuel, for example, was sent to a reprocessing plant or a repository before safe enclosure was established, the risk of contaminating the environment due to an accident in the safe enclosure is very small. However, as the transport of fuel off-site might have been performed years back, the (new) local government might not be aware of the safe conditions of the plant and may want to restart a discussion on safe enclosure safety, perhaps after an incident has occurred at a nuclear facility somewhere in the world in totally different circumstances. This might lead to lengthy discussions and delays. Another lesson learned is not to underestimate the interests of the original land owner, interested buyers or external interest groups. Interest may be expressed in the reuse of the whole site for new and possibly more profitable purposes, which would generally conflict with the very presence of the safe enclosure. Pressure can be then exerted to reduce the duration of the safe enclosure phase. The land owner may also be interested in regaining control of, or selling portions of, the site for redevelopment purposes which would have potential impacts on the safe enclosure. Intrusion barriers are typical in safe enclosures to prevent or hinder intentional or unintentional access to sensitive areas and components. Barriers can also be installed to intercept or redirect ventilation streams for safe enclosure, create required fire barriers due to reconfiguration of the plant, and/

or confine contamination. In this sense, their functions are complementary to sealants. Barriers are constructed either within the safe enclosure or outside, and consist of such permanent or semi-permanent features as concrete walls, brickwork, fire doors and the like. One important concern about barriers is that they should not unduly complicate access to other areas/components for surveillance or maintenance, or complicate final dismantling. To take into account such conflicting requirements a trade-off may be needed.

9.4. REGULATORY INVOLVEMENT

9.4.1. Periodic safety reviews

Many regulatory bodies periodically require a review of the safety of nuclear facilities under their responsibility in support of continual licence renewal. As the licence for safe enclosure is often based on the operational licence, a ten-year review plan might be required even for shutdown plants. Only significant issues need to be addressed in a ten-year review. For a steadily running safe enclosure, the items to address may include site related issues (e.g. changed demography, likelihood of floods or new uses of the land surrounding the plant), security, health physics and results of corrosion control programmes. For example, as a result of new land uses or changed international positions, new types of external impacts may have to be considered. Additionally, the EPP should be revisited, and interactions in this matter with the local government are not to be disregarded.

9.4.2. Inspections

The prime responsibility for safety remains with the operator. The frequency of regulator inspections may decrease when a site enters into safe enclosure. Although at first glance this may look like a relief for the safe enclosure management, there might be some negative aspects to this situation. In the case of an incident at the plant at some future time, members of the public may ask about the track record of regulatory inspections. If the regulatory body's involvement is considered insufficient by the public, the regulatory body may be criticized for the problems that occurred. Another aspect is the positive stimulus provided by regulatory inspections. As the safe enclosure workforce is small in number and may feel somewhat isolated from the outside world, they might not have enough motivation to keep up high quality standards and low tolerance for underperformance. It is the responsibility of the operator to remain proactive and keep the safe enclosure staff alert and motivated. A suitable inspection frequency needs to be defined.

9.5. PROPERTY MANAGEMENT

In some IAEA Member States, land planning is revisited at certain intervals at the national and/or local level. This might lead to a new foreseeable use of the land around the safe enclosure. As some land planning priorities may conflict with each other, there might be a pressure on the safe enclosure management to start full dismantling earlier than planned. Therefore, the safe enclosure staff need to actively interact with the stakeholders as land planning issues are brought forward. If final dismantling had to start earlier due to a change in the land plan, extra costs would be incurred and there would probably not be enough money available in the decommissioning fund. In this case, the various stakeholders (plant operator, fund managers, land planners, national and local authorities, regulatory body, etc.) need to reach an agreement — based on national legislation — on how the extra costs would be covered.

The IAEA has recently provided information and guidance on the reuse and redevelopment of decommissioned sites and the role various stakeholders play in the related decision making [83–85].

9.6. ADVANCE DISMANTLING WORK

During the safe enclosure period, it is possible that the operator may be required to carry out certain dismantling activities in preparation for final dismantling, or to refurbish deteriorating systems, structures or components as needed; or the operator itself may wish to take advantage of opportunities (e.g. the availability of contractors doing work at other facilities on-site). The way in which these dismantling activities are regulated will depend on the licence in force. For example, it is possible that minor interventions will be considered as routine maintenance and will require no regulatory approval (or perhaps a dedicated regulatory check, e.g. an inspection, will be sufficient). In other cases, a formal relicensing process or licence amendments might be required.

10. PRINCIPLES OF COST ESTIMATION FOR SAFE ENCLOSURE

10.1. GENERAL CONSIDERATIONS FOR COST ESTIMATION

Costs associated with safe enclosure include both the phase of preparing for safe enclosure and the phase of managing the safe enclosure. Costing in general is based on identification of all relevant decommissioning activities for both these phases.

Costing for safe enclosure is normally part of the baseline costing case for a decommissioning project, prepared in support of a preliminary decommissioning plan. The costing report for the baseline costing case defines in detail the extent of the safe enclosure and technical/managerial parameters of safe enclosure based on data in the decommissioning plan [86]. The main activities within a decommissioning project with safe enclosure are presented in Fig. 31. Use of the International Structure for Decommissioning Costing (ISDC) facilitates the identification of activities and their associated expenditures for the period of PSE and for the period of safe enclosure itself.

If, as expected, the selection of the safe enclosure option is based on evaluating this option quantitatively in support of a regulatory submission, this analysis provides a baseline for safe enclosure costing. Costs for a decommissioning project are normally re-evaluated, for example after each decommissioning phase or at predefined intervals (e.g. completion of a phase) in the overall planning and execution of decommissioning. PSE typically takes several years. In this case, the actual expenditures can be considered against those planned. For extended safe enclosure, cost estimates need to be periodically re-evaluated due to the longer duration of the safe enclosure period and the likelihood that there are changes to the assumptions and conditions set out in the baseline planning.

The following section presents the general approach to decommissioning cost estimation, a review of decommissioning activities involved in PSE, those associated with managing safe enclosure and selected considerations for management of costs during safe enclosure. Overall, the costs associated with safe enclosure are taken to be those associated with the transition period/PSE plus safe enclosure itself. Although the phases shown in Fig. 31 depict transition and PSE as separate phases, these are generally combined in practice.

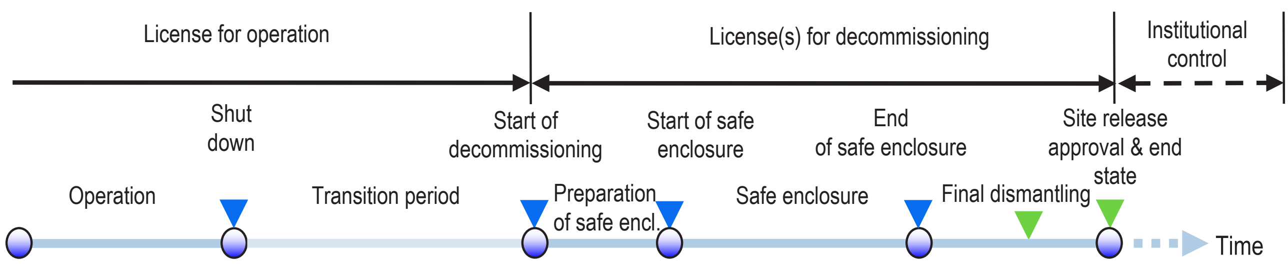

FIG. 31. Typical distribution of ISDC principal activities for decommissioning projects with safe enclosure [86].

10.2. APPROACHES TO DECOMMISSIONING COST ESTIMATION

General IAEA recommendations for decommissioning costing as reviewed in Ref. [7] involve the following approaches:

— Bottom-up approach: Identification of all elementary decommissioning activities. Costing is performed at the level of elementary decommissioning activities. Upper levels of cost structures are aggregating levels.
— Definition of cost elements: Allocation of basic types of decommissioning costs to identified elementary decommissioning activities. Basic types being the activity-dependent costs, period-dependent costs and collateral costs. Different cost drivers are identified for these basic types of decommissioning costs.
— Unit factors approach: Costing based on using unit factors and inventories under ideal working conditions and respecting local working constraints by using the work difficulty factors.
— Estimating the contingency at the level of elementary decommissioning activities as the specific provision for unforeseen elements within the scope of a decommissioning project.

Presenting the cost in ISDC format facilitates common understanding of cost items. An extended use of ISDC is to apply it as the base for cost calculation structures; this approach is actually implemented in IAEA projects related to decommissioning costing for research reactors.

ISDC decommissioning activities are organized in a hierarchical structure, see Fig. 32, with the first and second levels being aggregations of basic activities identified at the third level. Four cost categories should be presented at each ISDC level. At Level 1, eleven principal activities are identified [86]:

(1) Pre-decommissioning actions;
(2) Facility shutdown activities;
(3) Additional activities for safe enclosure or entombment;
(4) Dismantling activities within the controlled area;
(5) Waste processing, storage and disposal;
(6) Site infrastructure and operation;
(7) Conventional dismantling, demolition and site restoration;
(8) Project management, engineering and support;
(9) Research and development;
(10) Fuel and nuclear material;
(11) Miscellaneous expenditures.

The basic ISDC format for presenting decommissioning costs is the ISDC matrix involving, vertically, the numbered ISDC items at three levels, and, horizontally, the cost categories. Data for the ISDC presentation matrix may be prepared by converting cost data from cost structures other than the ISDC as well as the preferred approach in which cost data are calculated using ISDC cost structures.

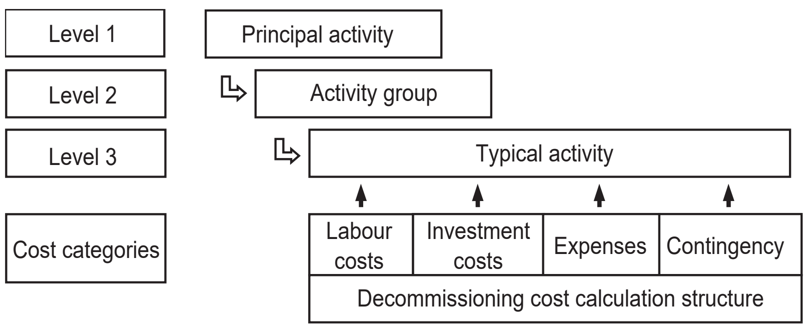

FIG. 32. Hierarchical structure of ISDC [86].

10.3. COST ESTIMATION FOR PREPARATION FOR SAFE ENCLOSURE

The basis for cost estimation for PSE is the list of decommissioning activities relevant to this period. Table 1 presents the typical ISDC decommissioning activities relevant to safe enclosure.

TABLE 1. INTERNATIONAL STRUCTURE FOR DECOMMISSIONING COSTING ITEMS AT THE THIRD LEVEL DIRECTLY RELEVANT TO PREPARATION FOR SAFE ENCLOSURE

ISDC item	Title of ISDC item for PSE	ISDC precursors not included in PSE	Comments
03.0100	**PSE**		Activities related to buildings that will be part of safe enclosure
03.0101	Decontamination of selected components and areas to facilitate safe enclosure	02.0201 02.0202 02.0203 02.0301 02.0302	Decontamination of areas and equipment that will be part of safe enclosure and those that will facilitate safe enclosure managing activities; minimization of safe enclosure controlled area
03.0102	Zoning for long term storage	02.0101	Defining/realizing the layout of the safe enclosure controlled area; modification of systems within the new controlled area; security and surveillance of new controlled area
03.0103	Removal of inventory not suitable for safe enclosure		Partial dismantling/removal (out of safe enclosure) of selected inventory items in premises; majority of inventory items remain; actualization of the inventory database needed
03.0104	Dismantling and transfer of contaminated equipment and material to containment structure for long term storage		Partial dismantling/relocation of selected inventory items in premises; items remain in premises of safe enclosure; structural and accessibility enhancement in buildings; actualization of the inventory database needed
03.0105	Radiological inventory characterization for safe enclosure	01.0201 01.0202 01.0203 02.0401	Final inventory characterization after completing items 03.0101–03.0104; actualization of radiological data in the inventory database
03.0200	**Site boundary reconfiguration, isolating and securing structures**		Activities related to site that will be involved in safe enclosure
03.0201	Modification of auxiliary systems		Reorganization/modification of systems, support facilities and services on-site essential for safe enclosure; modification of systems in buildings is in 03.0102
03.0202	Site boundary reconfiguration		Reconfiguration, modification of site boundary, access points for personnel/vehicles, fences, barriers, intrusion prevention; ensuring the security of safe enclosure; new automatic, remote systems; permanent for whole period of safe enclosure

TABLE 1. INTERNATIONAL STRUCTURE FOR DECOMMISSIONING COSTING ITEMS AT THE THIRD LEVEL DIRECTLY RELEVANT TO PREPARATION FOR SAFE ENCLOSURE (cont.)

ISDC item	Title of ISDC item for PSE	ISDC precursors not included in PSE	Comments
03.0203	Construction of temporary enclosures, stores, structural enhancements, etc.		Construction of temporary items defined in 03.0203 as needed during PSE
03.0204	Stabilization of radioactive and hazardous waste pending remediation		Construction, operation, decommissioning of additional facilities and/or equipment on-site needed for specific waste that will be involved in safe enclosure; waste items not covered in 03.0104 using normal procedures
03.0205	Facility controlled area hardening and isolation for safe enclosure		Blocking, securing entrances to the controlled area no longer used; protection of remaining entrances; isolation of controlled area and/or site
05.0100	**Waste management system**		Preparation of the waste management systems that will be used only for waste generated during safe enclosure
05.0101	Establishing the waste management system		Establishing new waste management system for waste generated during safe enclosure
05.0102	Reconstruction of existing facilities for decommissioning waste management system		Reconstruction/reuse of existing waste management system for safe enclosure period
06	**Site infrastructure and operation**		Only items of 06.0101 for procurement of general security equipment may be relevant; modification of systems for safe enclosure is included in ISDC 03; other ISDC 06 items; see comment below the table
08	**Project management, engineering and support**		Several items of ISDC 08 may be relevant for PSE such as training, studies, safety assessments, scheduling, etc.; these items should be clearly stated in assumptions and boundary conditions for the costing case; see comment below the table
11	**Miscellaneous expenditures**		Relevant items related to the phase of PSE should be included properly; see comment below the table

Note: Table 1 was developed based on methodology and findings provided in Ref. [86].

A proportion of the costs for activities listed in ISDC 06 (site infrastructure and operation), ISDC 08 (project management, engineering and support) and ISDC 11 (miscellaneous expenditures) could be included in the cost for PSE based on the activities in Fig. 32. There are several technical options for PSE, such as:

— Only activities for PSE as listed in Table 1 are included.
— Partial dismantling and demolition of systems and structures are included; as an example, non-active buildings will be decommissioned, and the reactor building and auxiliary active buildings will be included in safe enclosure.

- Safe enclosure may be limited only to the reactor building; sometimes the extent of safe enclosure is limited to part of the reactor building. All activities for partial dismantling and demolition are performed in the phase of preparation of safety enclosure.
- Site boundary modification and site remediation may be performed to various extents.
- Waste management systems may be in operation during partial dismantling and site remediation.
- In some cases, historical and legacy waste may remain for processing during PSE.
- R&D, the costs of which may be attributable to safe enclosure, may be performed during PSE.

The assumptions and boundary conditions for the costing case clearly define the content of activities for PSE and also the way in which the cost of ISDC items 06, 08 and 11 will be allocated to PSE.

If the additional, parallel activities listed in the bullets above are performed during PSE their costs should be allocated to the appropriate ISDC categories, for example: ISDC 04 (Dismantling activities within the controlled area), to ISDC 05 (Waste processing, storage and disposal), ISDC 07 (Conventional dismantling and demolition and site restoration) or ISDC 09 (Research and development).

10.4. COST ESTIMATION FOR MANAGEMENT OF SAFE ENCLOSURE

Management of safe enclosure mostly involves the activities of ISDC 06 (site infrastructure and operation), ISDC 08 (Project management, engineering and support) and ISDC 11 (Miscellaneous expenditures). The ISDC items typical for managing safe enclosure are listed in Table 2. Note that the cost items included in the table below are at ISDC Level 2, while those in the preceding table are presented at a greater level of detail (ISDC Level 3).

TABLE 2. ISDC ITEMS AT THE SECOND LEVEL TYPICAL FOR MANAGEMENT OF SAFE ENCLOSURE

ISDC item	Title of ISDC item for PSE	Comment
05	**Waste processing, storage and disposal**	Very limited generation of waste is assumed during management of safe enclosure; some waste items are only collected and processed after safe enclosure period
05.0100	Waste management system	Only limited items of 05.0104 are considered for waste management during safe enclosure; waste management system for safe enclosure was established during PSE
05.0900 05.1000	Management of decommissioning low level waste (LLW) and/or very low level waste (VLLW)	Only limited items of 05.0900 (LLW) and 05.1000 (VLLW) will be relevant for management of safe enclosure; limited LLW waste may be generated during maintenance, VLLW items are mostly PPE items; limited waste management techniques are assumed
06	**Site infrastructure and operation**	Staff, duration and selected period specific cost are the main cost drivers for ISDC 06 for managing safe enclosure
06.0100	Site security and surveillance	06.0101 is included mostly in PSE; extent of activities for 06.0102 to 06.0104 depends on parameters of safe enclosure and on technical solutions implemented (remote systems); selected activities may be contracted
06.0200	Site operation and maintenance	06.0201 depends on physical extent of safe enclosure and periodicity of inspections and maintenance activities; activities for capital maintenance should be defined; 06.0202 activities depend on site area; selected activities may be contracted

TABLE 2. ISDC ITEMS AT THE SECOND LEVEL TYPICAL FOR MANAGEMENT OF SAFE ENCLOSURE (cont.)

ISDC item	Title of ISDC item for PSE	Comment
06.0300	Operation of support system	Systems are modified for safe enclosure period in the PSE and are operated mostly occasionally; maintenance is adjusted to limited operation and may be contracted; cost for energy and consumables is normally included here
06.0400	Radiation and environmental safety monitoring	Procurement is included mostly in PSE; extent of 06.0402 activities is adjusted to 06.0100 to 06.0300; 06.0403 may be organized on a periodical basis and also as external services; multifacility sites/owners provide some advantages
08	**Project management, engineering and support**	Staff and duration are the main cost drivers for ISDC 08 for managing safe enclosure
08.0200	Project management	Staff may be reduced to several permanent persons, even less in alone standing safe enclosure cases; contracting is not assumed to a greater extent; external services may be used; multifacility sites/owners provide advantages
08.0300	Support services	Permanent staff may be very limited; selected activities may be contracted; multifacility sites/owners provide advantages
08.0400	Health and safety	Permanent staff may be very limited; specific activities may be contracted; multifacility sites/owners provide advantages
08.0600–08.0800	Equivalents of 08.0200–08.0400 for the owner	Selected activities of 08.0300, 08.0400 may be contracted; in these cases the costs are moved to relevant 08.0600 to 08.0800 items
11	**Miscellaneous expenditures**	Annual values of taxes and insurance are the main cost drivers for ISDC 11 for managing safe enclosure
11.0100	Owner costs	Only limited items of 11.0103 and 11.0104 are assumed
11.0200	Taxes	In principle, all tax items as in PSE will continue; individual tax items may be reduced due to limited extent of activities and changes in property after finishing the phase of PSE; tax items should be clearly identified for costing purposes for safe enclosure
11.0300	Insurance	In principle, all insurance items as in PSE will continue; individual insurance items may be reduced due to limited extent of activities; changes in property are not assumed; tax items should be clearly identified for costing purposes for safe enclosure
11.0400	Asset recovery	Not assumed during safe enclosure

Note: Table 2 was developed based on methodology and findings provided in Ref. [86].

10.5. COST CONSIDERATIONS RELATED TO SAFE ENCLOSURE

10.5.1. Revisions to decommissioning cost calculations

It is advisable to revisit the expected costs for final decommissioning during the lifetime of the safe enclosure. During this period a lot of experience, knowledge and information on new dismantling technology and the safe enclosure behaviour of facilities is gained by the safe enclosure operator; more details may become available on the radioactive inventory (e.g. distribution of contamination and physical–chemical aspects). Additionally, circumstances outside the control of the safe enclosure operator might have changed, such as the costs of the final disposal of the waste and type of waste packaging. The licence for safe enclosure may require the checking of the expected costs of final dismantling at regular intervals. As the parameters that influence decommissioning costs might have changed, it is advisable to update the facility inventory database after finishing PSE and — subsequently — undertake periodic updating of the database during the period of safe enclosure [86]. Other key parameters used in cost estimation also need to be reviewed. After discussion and agreement by relevant stakeholders on the new parameters, calculation of the final dismantling costs can start. Typical costs that might differ over time are the costs for labour, the type of waste packages to be used and the final repository costs. These parameters are the most significant contributors to the costs of final dismantling.

The costs of managing the safe enclosure should be included in the overall decommissioning cost estimates. Experience from former operation and the expected investment costs for maintenance of the safe enclosure need to be taken into account. Typical investment costs may be costs on health physics measurement equipment, electronics like computers and controlling equipment (such as servers and power line communications), replacement of equipment, roof cladding and other capital expenditures on buildings for safe enclosure. Operating costs during safe enclosure can be grouped into two categories: routine and non-routine. The routine costs will include activities such as preventive maintenance, grounds keeping, routine maintenance, etc., whereas non-routine costs will include items such as roof replacements, equipment change out, etc.

10.5.2. Rules on interest and investment

The IAEA recommends that a decommissioning fund be established at the design and construction stage [4]. In other countries, this is done during the last part of the operational phase and some countries fill the fund during the safe enclosure phase. In the case that the period for filling the decommissioning fund is short, the starting amount of the fund needs to be higher than in the case when a longer period is available. The same applies for the interest rate of the decommissioning fund. This rate should be high enough to create enough money for the final decommissioning. Secondly, a correction for inflation needs to be in place. As the interest rate and inflation rate might vary during the buildup of the fund, this period needs to be long enough to reach the required amount of money. The starting amount of finance in the decommissioning fund is usually based on early calculations of the decommissioning costs. Although this is acceptable as a start, these costs may significantly change over time. Therefore, periodic reviews of decommissioning costs need to be performed during a nuclear plant's operational lifetime and during extended periods of safe enclosure.

Some regulatory bodies prescribe the nuclear operator to invest the money of the decommissioning fund in selected bonds or stocks. These bonds and stocks are often of a low risk kind, such as triple-A bonds. Although this is a good way to keep the original amount of money unaffected by market turbulence, the profit on these investments is usually low. Sometimes inflation rates are equal to or even higher than the interest accrued. In this way the buildup of the decommissioning fund may not occur. This might eventually lead to a lack of funds at the time when the final dismantling is scheduled to start. As a solution to the lack of money at that time, some nuclear operators can obtain money from the parent company, while others simply defer the final decommissioning for another period in order to obtain the required funding. As the behaviour of inflation and the financial markets cannot be known with certainty, periodic injections of fresh money into the decommissioning fund may be required to stay on track. In all situations there needs to be a balance between risks and profits on investments.

10.5.3. Additional decommissioning studies

Some nuclear facilities are required by their licence to recalculate the decommissioning costs during the period of safe enclosure by using recent improvements to approaches and technologies. For example, cost comparisons involving various decommissioning technologies such as those for dry versus wet cutting may be examined in the cost modelling. These calculations may be performed at regular intervals, e.g. every five years, to capture such improvements. The costs of these studies should not be underestimated and add to the total decommissioning bill. Similarly, uncertainties out of the scope of the decommissioning project that may have an impact on cost for the decommissioning project need to be evaluated [86]. It is prudent for owners to monitor decommissioning costs from other internal/external projects to refine the cost estimate for their particular projects.

10.5.4. Typical cost figures related to safe enclosure

It is hard to give generic cost figures for safe enclosure projects, since each project needs to be assessed on its own merits and circumstances. However, it may be worth mentioning that even in a passive safe enclosure configuration, the costs of running a safe enclosure are not small (in excess of $1 million a year even for a single unit). This could be a surprise for traditional policy making, as it was often assumed that safe enclosure costs would be trivial. This wrong assumption was used in the past to justify a safe enclosure strategy.

A complete study addressing the costs of Magnox reactors in the UK is available in Ref. [87]. As described elsewhere in this publication, Magnox NPPs go through a multi-year PSE including the following programmes: Ponds, Intermediate Level Waste Management; Fuel Element Debris Treatment; Plant and Structures and Waste and Project Management. After completion of these programmes, long term care and maintenance (the UK term for passive safe enclosure) is established until final dismantling and site release. The above mentioned study indicates the yearly schedule and costs until the completion of decommissioning for each site. The study shows that PSE on a reactor basis is estimated to cost several million pounds a year, and costs per reactor during safe enclosure exceed £1 million a year.

11. CONDUCT OF OPERATIONS IN THE SAFE ENCLOSURE PHASE

Conduct of operations creates the culture on operational sites and, effectively used, it ensures plant operations are conducted in a safe, effective, thorough and professional manner [88]. In decommissioning and safe enclosure, these principles are equally applicable, but may be appropriately graded towards the conventional and radiological hazards at these facilities.

In safe enclosure, human factor considerations associated with conduct of operations typically include assessments of human failures in the operation of the plant, ergonomics, fatigue, safety critical communications and competence. Human performance considerations advocate the use of pre- and post-job briefings, peer review, place-keeping and procedural adherence, among other approaches. Many of the human factor aspects should be captured in the safe enclosure safety assessment, while human performance needs to be an embedded expectation in the enactment of safe enclosure activities.

Over the past 20 years, the nuclear industry has progressively evolved and formalized the application of human factor methods to improve system and human performance in the operation of power plants and facilities. The standards, guidance and work practices established have evolved with respect to a design and operation application emphasis. Decommissioning projects exhibit some differences in characteristics from the design or operation project phases. Consequently, some adaptation of current human factor practices may be beneficial in applying human factor methods to the decommissioning phase for a facility.

Examples of the unique characteristics of the decommissioning phase — relating to human factors — in comparison with the design and operations phases are included in Ref. [89].

The safety assessment for safe enclosure considers the dormancy and obsolescence of plant, signage and barriers with regard to human factors. Furthermore, the one-off or infrequent routine of tasks also needs to be recognized, where plant and process knowledge may be significantly reduced. Unique tasks often lead to unique or novel human performance issues. Furthermore, where buildings are infrequently accessed, there is a greater chance of the work party being distracted by the discovery of defects not associated with the planned work. Appropriate control and supervision can help counter this distraction as well as address many of the other issues identified above.

11.1. PUBLIC RELATIONS

Good public relations will help gain public support for the safe enclosure project. It is important to be open and honest in interactions with the general public and other stakeholders, particularly those who live close to the site.

For a multifacility site, the use of an existing visitor centre, if present, is the obvious choice to inform the public about the safe enclosure. Figure 33 shows an informative session at the Jaslovské Bohunice Visitor Centre, Slovakia. For stand-alone safe enclosure, a sign can be posted at the site fence, containing basic information about the building. It is useful to establish a communication plan prior to safe enclosure, to include face to face meeting plans, stakeholder involvement and media communication protocols. Development of a dedicated web site is advisable. The web site should be maintained and updated regularly. Not only can information about the former operational facility be shown on this web site, but also future plans. Additionally, some actual data on the safe enclosure such as radioactive release, the results of regulatory inspections and other information can be given as required or permitted under national regulations.

Stakeholders might also have an opportunity to meet the plant management on a periodic basis, through routine meetings where plans, issues, concerns and successes can be discussed.

The buildings, fences and surrounding area need to be kept well maintained. If the buildings are surrounded by grassy meadows, regular mowing is advisable. In this way the first impression members of the public will get is a positive one. This might lead to better acceptance of the safe enclosure. If the area around the safe enclosure looks miserable or abandoned, the impression will automatically be that the situation inside the buildings will not be any better and that the operator does not care about the facility.

A comprehensive overview of stakeholder interactions in decommissioning projects is given in Ref. [85].

11.2. REQUESTS FOR INFORMATION

During the safe enclosure phase some members of the public might show specific interest. It is advisable to have an email account available for people to ask questions about the safe enclosure. The availability of promotional material, such as brochures and/or DVDs, is necessary. The email account needs to be checked regularly and emails answered in a short time. Requests may come from beyond the local community and may be national or even international.

FIG. 33. Informative session at Jaslovské Bohunice's Visitor Centre (courtesy of JAVYS, a.s.).

From time to time, journalists may show up with requests for information. Depending on company policy, it is best to give them written information. Explaining that the safe enclosure is maintained safely and will stay untouched for the designated time will satisfy most journalists. As filming inside the safe enclosure is often restricted due to security rules and regulations, some photos taken by the safe enclosure operator should be kept available for journalists to use in papers and magazines.

11.3. GUIDED TOURS

Frequent requests for information about the safe enclosure will come from schools and stakeholders. Often, an excursion in the facility is requested by groups. In principle, excursions of general interest are not to be encouraged. First of all, the safe enclosure's priority functions do not include availability for excursions; secondly, extra public relations staff may be needed and each entry to the facility requires specific security and access provisions. Allowing excursions may be a particularly difficult issue for remotely managed sites, or where there is no routine site presence. This leads to extra costs for public relations staff, an extra burden for safe enclosure operators and extra security. A more effective option is to make a film about the purpose of the safe enclosure, and make this film available to the general public (in DVD form or online).

Requests for excursions by the staff of other nuclear sites could be limited to those who will benefit from the entry, particularly for familiarization with safe enclosure features in operation or to learn lessons for future decommissioning projects.

Excursions will also be necessary for regulatory inspections and may be required for government officials, company officials, other company staff who support the safe enclosure activities and other interested groups (e.g. environmental groups).

11.4. KNOWLEDGE MANAGEMENT

Record keeping is essential for operating nuclear facilities and safe enclosures as well as learning the lessons to be applied during future decommissioning projects. As the staff numbers working in safe enclosure are typically small, the collective memory of past events is limited. It is important in the PSE phase to capture all the relevant knowledge about the facility and its operational history to the degree that this is required for the safe enclosure, and to support the subsequent final dismantling phase. This knowledge can come from drawings, manuals, operating instructions, computer files including logs, spreadsheets and event reports. Recording of discussions with experienced plant personnel may also be useful to capture some of the more tacit knowledge. These records may include details of not only the physical plant, waste, environment, etc., but also the personnel (e.g. their radiological and medical records) who worked on the plant during previous phases. In the gathering of knowledge, the information needs to be collated in a consistent manner so it is easy to retrieve during the safe enclosure period; this is typically done by building or plant type and both are considered equally effective so long as they are consistently applied. In the transition to safe enclosure, operating instructions, manuals and drawings and similar information providing instruction on plant operation or maintenance need to be verified by personnel experienced in the task to ensure they are fit for purpose during the safe enclosure phase. The verification is particularly important for infrequent activities or safe enclosure facilities using contractors to perform safe enclosure activities, as they will be less familiar with the plant being operated and will therefore be more reliant upon the accuracy of the instruction.

Personnel records can be important for various events that may come up during the safe enclosure phase (e.g. litigation). Two IAEA publications [22, 23] provide comprehensive information and guidance on identification, assembling and keeping of records relevant to decommissioning.

At some safe enclosures, the records of the operational phase of the nuclear facility are stored on-site and are updated on a regular basis. A duplicate set of records can be stored at another location than the on-site archive, preferably at a location off-site. This is intended to avoid the loss of the records in the case of an incident such as fire or deterioration. If a server is used for electronically storing data from the safe enclosure, a backup system could be in place. The backup is not to be kept at the same location as the server. Some regulatory bodies tend to rely on traditional media (e.g. paper or microfiche) at least for the storage of a duplicate set of records.

The potential for deterioration that may impair the continued legibility and usage of records needs to be factored into the knowledge management system.

As a significant aspect of record keeping, it is important to make provisions to store the most important information to facilitate future decommissioning. Arrangements need to be put into place to ensure that the necessary information is preserved. This refers not only to the physical preservation of information, but also to its legibility and the skills needed to understand its technical meaning and to start active dismantling in due course.

An important aspect of decommissioning planning concerns the capture of historical information from plant operation, which is particularly useful in defining plans for the radiological characterization of plant sites. Several utilities have gained valuable experience in the best practices involved in collecting early data. This will be particularly beneficial to plants planning for decommissioning, in particular those where an extended period of safe enclosure is being considered. Guidance on these aspects can be found in Refs [90, 91].

12. SELECTED EXAMPLES OF SAFE ENCLOSURE PROJECTS

The following selected cases provide examples of different approaches. They can in no way be considered a complete overview, but are intended to highlight various reasons for, and characteristics of, a deferred dismantling strategy.

12.1. DODEWAARD NUCLEAR POWER PLANT, THE NETHERLANDS

The Dodewaard NPP (Fig. 34) provides the perfect example of a safe enclosure with minimum change to the facility (i.e. the active option). The organization GKN, Dodewaard (Joint NPP of the Netherlands, or Dodewaard NPP) is situated on the river Waal, one of the estuary rivers of the river Rhine, and had a boiling water reactor with 58 MW(e). Construction of the plant began in 1965 and commercial operation began in 1969. In the middle of an extensive upgrade operation, the decision to shut down the plant was taken in a very short time. Operation ended on 26 March 1997 after 28 years, although the designated end of operation had been planned for 1 January 2004, and a discussion on further lifetime extension was pending. The decision to shut down and start decommissioning was taken by the owner of the plant, Samenwerkende Elektriciteits Productiebedrijven (SEP, or Cooperative of Electricity Producers), in agreement with the Dutch Government. The decision was based upon a study by a Dutch governmental commission. This commission came to the conclusion that nuclear energy had no political support in the country, although the technical and environmental aspects of this technology were recognized as positive. Additionally, the restructuring of the Dutch electricity market had a negative impact on the plant. As a matter of fact, the plant was owned by four cooperating electricity generating companies, which became competitors from January 2007 on.

All spent fuel was removed from the plant and transferred to Sellafield (UK) for reprocessing. This process was completed in April 2003. In May 2002, a licence was granted to the operator (GKN) to bring the plant into safe enclosure and keep it in this condition. Safe enclosure was achieved on 1 July 2005 and is scheduled to last 40 years. The envisaged end point for this site is a green field condition [92].

The decision in favour of safe enclosure was based on a comparison study in which all relevant aspects for immediate and deferred dismantling were evaluated. The most important differences between the two decommissioning strategies turned out to be lower costs and a lower collective dose in decommissioning with safe enclosure, with the costs estimated to be 30% higher for immediate dismantling, and a dose estimate of 6.6 person-Sv for immediate dismantling and 4.6 person-Sv for deferred dismantling. The overall risk and the emissions of radionuclides were judged to be similar, while the amount of radioactive waste was also judged to be somewhat lower for deferred dismantling.

When planning started, it had to be decided which parts of the plant were to be included in the safe enclosure and which could be dismantled immediately. For assistance with this decision, experience and advice from other installations of similar design in the USA (Humboldt Bay — decommissioning with safe enclosure with fuel elements still on-site in the spent fuel pool; and Big Rock Point — decommissioning with immediate dismantling

FIG. 34. Dodewaard NPP, the Netherlands, in its safe enclosure state (courtesy of GKN).

and fuel transferred in casks to another plant) was taken into account. It was decided that only contaminated buildings should be kept and maintained, while uncontaminated buildings like the office block, warehouse and workshop buildings, cooling water building, some auxiliary buildings and others were dismantled. The free-standing ventilation shaft was also removed and replaced by a much smaller one, directly connected to the reactor building. An evaluation showed advantages in removing those auxiliary buildings and installations that would be needed again for dismantling after the safe enclosure phase, as it could be proven that the maintenance of those buildings and installations for several decades would have been costlier than to rebuild them when needed.

Inside the reactor building and the turbine hall, no dismantling was carried out. All systems in all buildings were cleaned out [92]. The systems needed for controlling the facility during safe enclosure, such as electricity, monitoring systems for air discharges, and dose rate monitoring, were renewed, as the old systems were evaluated as being unable to operate for another 40 years. Only the ventilation ducts were reused, although the ventilation pattern itself was rerouted. A new HEPA filter was placed at the exit of the ventilation system, to filter the ventilation air before release. The result was that only the main building complex (reactor building, turbine hall, central auxiliary building, ventilation building and waste treatment and storage building) remained, which greatly simplified the safe enclosure management. This remaining building is staffed during the day for routine maintenance and surveillance, with surveillance being carried out by a security company during the night and on the weekends.

12.2. VANDELLÒS-1 NUCLEAR POWER PLANT, SPAIN

The Vandellòs-1 NPP near Tarragona in Spain is a good example of the passive type of safe enclosure (i.e. a condition where only minimum surveillance is required). It is thus in direct contrast to the Dodewaard NPP illustrated in Section 12.1.

Vandellòs-1 was a 500 MW(e) gas graphite type NPP, constructed between 1968 and 1972 and operated by the Spanish company Hispano Francesa de Energía Nuclear S.A. (HIFRENSA). The site also included other buildings such as the building for irradiated fuel, the spent fuel pools building, the auxiliary heating plant and the graphite vaults. In 1989, a fire in the turbine house led to the final shutdown of the reactor in 1990. The decommissioning strategy chosen for Vandellòs-1 was partial dismantling followed by safe enclosure. The ultimate aim was to remove the plant completely afterwards [2].

In preparation for decommissioning, some post-operational activities were undertaken by HIFRENSA, such as post-operational clean out, conditioning of spent fuel and treatment of operational wastes, including the graphite components from fuel elements [62]. In accordance with the Spanish legislation, the plant was transferred for the execution of the decommissioning to the Spanish national agency ENRESA, which became the licensee for the duration of the decommissioning project. This transfer took place in February 1998 after the former operator completed several technical activities including the removal of nuclear fuel from the pools for further transportation off-site, while the ownership of the site remains with HIFRENSA.

As it was intended to maintain only part of the reactor building during the safe enclosure period, dismantling work commenced by constructing a new confinement for the reactor shroud, performing demolition and backfilling operations, and releasing a large part of the site. In particular, a new structure around the prestressed concrete pressure vessel was constructed, which serves as general protection for all the reactor structures (Fig. 35). This also led to a marked reduction in the height of the reactor building.

The preliminary end state of this decommissioning work was reached in June 2003. The facility was prepared for the dormancy period, which will last for 25 years and will be followed by total dismantling of the remaining parts of the plant [62]. Maintenance and surveillance have been reduced to a minimum.

The driving factors for selecting the decommissioning strategy of partial dismantling with safe enclosure can be summarized as follows:

- The design of the reactor, i.e. the fact that the prestressed concrete pressure vessel included the reactor and the steam generator, offered ideal conditions for a safe enclosure of this structure and allowed dismantling of the other parts of the plant. The wall thickness of the concrete structure reaches five metres.
- This strategy offered financial benefits.
- The repository for radioactive waste that is operated in Spain, El Cabril, cannot accept, under the current licence, ^{14}C in the quantities in which it occurs in the graphite of Vandellòs-1.

The radiation protection programme established at Vandellòs in view of reaching safe enclosure status is described in Ref. [93]. It is reported that the collective occupational doses during this period amounted to 552 person-mSv. Today, the Vandellòs site hosts the Mestral Technology Centre, which provides support to the regular operation and monitoring during the latency, and coordinates research into technologies, materials and procedures for future decommissioning projects, and the training of qualified professionals for the performance of such projects.

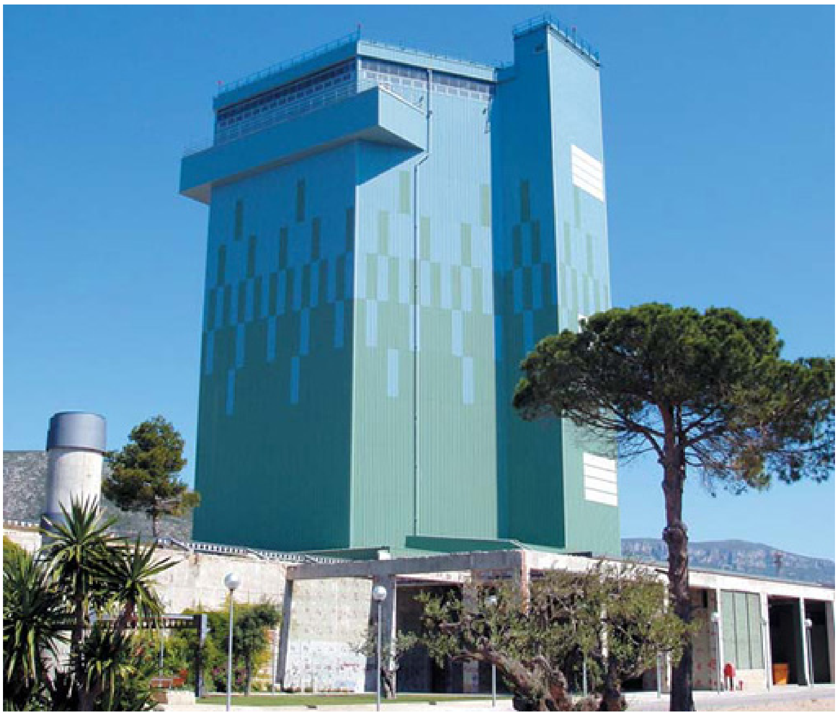

FIG. 35. Vandellòs reactor with cladding installed for a 25-year safe enclosure (courtesy of ENRESA).

12.3. LINGEN NUCLEAR POWER PLANT, GERMANY

Lingen NPP in Germany has been selected as an example of an NPP that has reached the end of the designated safe enclosure period. It is also included to illustrate the problems that prolonging a safe enclosure period might entail.

The Lingen NPP had a boiling water reactor with 514 MW(th) with a fossil superheater and 240 MW(e). Vereinigte Elektrizitätswerke Westfalen founded the subsidiary KWL (Kernkraftwerk Lingen GmbH), which gave the order for a turnkey NPP in 1964. Building activities commenced in late 1964. The first operating licence was granted in January 1968. The plant was shut down in January 1977 because of technical problems with the heat exchangers [62]. A technical improvement of the plant as well as a transformation into a conventional power plant were investigated but not considered possible or economically viable. A detailed discussion of occupational doses to staff and contractors during PSE and the subsequent safe enclosure phase at Lingen is given in Ref. [94]. This reference also expands on the main factors that determined the evolution of occupational doses over time.

Following the decision to permanently shut down the facility, the decommissioning strategy of deferred dismantling was chosen. The decision was taken to perform only a minimum of dismantling work to establish the state of the safe enclosure. In June 1983, a licence for establishing and operating the safe enclosure was applied for, and it was granted in November 1985. The surfaces of the buildings and the stack were renewed where necessary in 1986. Part of the radioactive waste with very low activity was cleared for disposal to landfill sites after approval by the licensing authority. Other waste was conditioned for storage within the safe enclosure. This preliminary work was finished in the first half of 1987. The ventilation system that had been used during the operational phase was switched off, which also ended the ventilation of the primary loop. A new ventilation system for safe enclosure was installed and taken into operation in 1987. Unused openings in the buildings were sealed. The liquid effluent treatment system was taken out of operation, drained and cleaned, but not fully decontaminated.

The Lingen NPP reached the safe enclosure state on 30 March 1988, which according to its licence could be maintained for 25 years. The running of safe enclosure was without major problems or events for years. The work concentrated on, among others, fire prevention, electrical devices and escape ways. In the second half of the 1990s, the possibility of ending the safe enclosure period and switching over to dismantling was considered. The dormancy state was then lifted and preparations for final dismantling as well as removal of waste were carried out. A licence to alter the shut-down installation, its safe enclosure, and the running of safe enclosure in order to dispose of the operating waste stored in safe enclosure was issued in November 1997. This was meant to facilitate a transfer of the waste that had been stored in the installation before the start of safe enclosure to the temporarily operational German repository Morsleben. Because the repository was soon closed, however, this transfer could not be completed.

Safe enclosure made specific demands on the maintenance of the building structure and the installation, in that humidity, levels had to be kept low to prevent corrosion. Initial problems could be resolved by redesigning the dehumidifying system so that the relative humidity within the building could be kept constant at 50% or lower [62].

Planning for the time after the period of safe enclosure began several years before its prescribed end in 2013. The operator took into consideration both a potential extension of the duration of safe enclosure and the prompt start of dismantling works. At first, extension of the duration of safe enclosure was investigated. For reasons of precaution, an application for continuation of the safe enclosure until 31 December 2040 was filed in December 2004 [62]. However, a thorough evaluation of the pros and cons of prolonging the safe enclosure period led to the decision to stay with the initial duration of 25 years. The main reasons were the fear of loss of plant knowledge and the increasing difficulty of performing a radiological characterization after additional decades. After several decades, the key nuclide ^{60}Co would have decayed to very low levels; then it would have been very difficult to estimate the concentrations of hard-to-measure beta emitters, which could only be estimated via correlation to key nuclides. A typical case is ^{63}Ni, which can be measured only through a lengthy radiochemical separation process, but can be correlated to ^{60}Co.

12.4. MAGNOX NUCLEAR POWER PLANTS, UK

The first generation of nuclear power stations in the UK, operated by Magnox Ltd, is progressively being shut down and decommissioned in preparation for extended periods of passive safe enclosure, known in the UK as care and maintenance. The first full site to enter safe enclosure will be the Bradwell site in Essex, while the reactor buildings on the Berkeley site have been in care and maintenance configuration since 2010. The care and maintenance facilities will be centrally managed by skilled contract organizations to fulfil many of the maintenance tasks under the control of Magnox. The reactors will remain in the care and maintenance state until the site is finally cleared in the years 2074–2083 [95].

Since 1993 the majority of internal equipment at Berkeley, including fuel handling machinery and water cooling systems, has been removed. The turbine hall and spent fuel ponds were dismantled after decontamination. Unlike most other Magnox sites, the boilers and significant lengths of primary circuit were external to the main reactor building; with the long planned care and maintenance phase it was necessary to isolate these from the reactor vessel and lower them to a horizontal position. Trial decontamination of one of the boilers was done, but the remaining 15 boilers were stored on their sides outside the reactor buildings. With the availability of new waste disposal options, the remaining boilers were dispatched to Studsvik's specialist recycling facility in Nyköping, Sweden, in 2012 and 2103 [96], where they were dismantled, smelted and recycled. Over 90% of their metal content was recovered and ultimately released for reuse in the metal market.

An intermediate level waste store has been built for the storage of wastes until the UK geological disposal facility becomes available and wastes can be retrieved from their operational storage locations for conditioning in disposal packages. The passive intent of Magnox's care and maintenance programme will also lead to the removal of all administrative buildings prior to the full site entering safe enclosure in 2020.

Preparations for safe enclosure at the other Magnox sites are being implemented using a strategy adopting a lead and learn approach. Turbine halls and administration buildings are being vacated and demolished, and bulk asbestos and auxiliary systems within the reactor buildings are being removed on a risk basis, leaving the buildings permanently, electrically isolated. In addition, the fuel cooling ponds are being decommissioned by the removal of furniture and pond water and the decontamination and sealing of the pond to substantially minimize the levels of loose contamination within the facilities. The water treatment plants associated with the management of pond water are also being removed where there are no significant civil interactions with the buildings that need to remain during the safe enclosure phase. The sites require a water treatment capability to manage only low volumes of low activity liquors typically arising from maintenance activities. Finally, the security systems are being enhanced to support the passive management of the safe enclosure sites.

12.5. ATOMIC ENERGY OF CANADA LIMITED'S PROTOTYPE REACTORS, CANADA

AECL owns three prototype power reactor sites located between Ontario and Québec in Canada. Douglas Point is located in Bruce County in southern Ontario at the Bruce Power site (Fig. 36). It went into operation in 1968 and shut down in 1984. Gentilly-1 was built near Bécancour, Québec (Fig. 37) and is located on the Gentilly-2 site operated by Hydro Québec. The reactor went into operation in 1972 and was shut down in 1979. The Nuclear Power Demonstration reactor located at Rolphton west of Chalk River was the first power reactor put into operation in Canada and operated from 1962 until shutdown in 1987 (Fig. 38). Information on the decommissioning programme and achievements are given in Ref. [97].

AECL, in conjunction with Hydro Québec and/or Ontario Power Generation, has safely shut down the Nuclear Power Demonstration, Gentilly-1 and Douglas Point facilities for an interim storage period called 'static state'.
This decision was based primarily on two factors, the first being to allow for a cool down period to reduce radiological levels in the facility, and the second to provide time to determine where the waste generated from decommissioning will be transferred to.

The static state objective is to reduce the hazards associated with the site while safely maintaining the facilities until decommissioning is completed. Static state is achieved through the removal or containment of conventional and radiological hazards. This process results in the rezoning of certain areas. Modifications were completed to reduce the number of services required to maintain the facility during surveillance. Modifications were also required to control access, manage contamination zones, control hazards and reconfigure the facility from its operational design into a surveillance phase. Modifications at the three sites included physical modifications or reconfiguration of the building heating, ventilation, air-conditioning, electrical and monitoring systems (fire, environmental and security systems) along with modifications to the core building structure to address revised entry and exit points,

FIG. 36. Douglas Point NPP (courtesy of AECL).

FIG. 37. Gentilly-1 NPP (courtesy of AECL).

FIG. 38. Nuclear Power Demonstration (courtesy of AECL).

contamination zones and hazards that remain in the facility. This objective was to leave the site in a state where it could be maintained safely, and at a minimum cost through a combination of monitoring and site inspections.

Maintaining the safe shutdown state of the active and non-active facilities at each site has its own particular challenges as the facilities were constructed, configured and shut down differently, and the only common approach used to bring each site to static state was the removal of the secondary systems and equipment.

In adopting the static state, each site used different strategies in maintaining the atmospheric control of active areas including the reactor building. This resulted in varied success when maintaining the structures and systems during the period after the adoption of static state and consequentially, with the changing requirements of modern standards, additional work is required. The structural integrity of various facilities is now starting to present new challenges that require attention. This includes structural damage such as degradation of concrete as a result of external weather conditions [98], degradation of structural steel and other metallic components due to humidity control, or premature failure of electrical/mechanical or civil components as a result of improper maintenance techniques and ageing systems. In one instance, the concrete mix used during construction has led to challenges in maintaining the exterior of the reactor building as it is failing prematurely.

13. CONCLUSIONS

Challenges arising from planning and implementing a safe enclosure strategy can be divided into the following main categories.

13.1. PREPARING FOR SAFE ENCLOSURE

Preparation of a plan that is acceptable to all stakeholders and regulators is a challenging task. Assessments of options need to be completed to determine the best decommissioning strategy, along with resource plans, environmental protection plans and record keeping. Plans to keep an installation on the site without performing active decommissioning may have a negative image, especially on single facility sites. This will generally depend on the public perception of nuclear energy. The challenge, therefore, is to communicate the plan and its justification in a timely and transparent manner. Some countries have experienced lack of public acceptance when planning for safe enclosure, for example for projects that were initially planned to last for 70 years (e.g. in France) or 135 years (e.g. in the UK). Both countries have realized that it would be wiser to build confidence in decommissioning by demonstrating immediate dismantling to be a viable option in selected projects and move to immediate dismantling (France) or shorten the safe enclosure period (UK).

A further important challenge during the preparation phase will be the availability and long term securing of funding. Depending on how decommissioning funds are allocated and maintained in the country, and on general socioeconomic circumstances, it may be hard to prove that money, which is insufficient to be able to perform early dismantling can really be accumulated during the waiting period.

A challenge is to provide a technical and radiological documentation of the facility that is adequate to perform decommissioning work several decades later without having to redo a complete survey of the facility.

13.2. THE SAFE ENCLOSURE PERIOD

Important considerations during safe enclosure conditions mainly refer to the maintenance of structures, systems or components over several decades. A strategy needs to be found to place the plant in such a condition that maintenance can be kept to a minimum and extensive repairs during the safe enclosure period are unneeded. Otherwise, the effort of performing extensive maintenance work in the facility with only a minimum of operating infrastructure can be costly and conflict with the principle of limiting the effort during safe enclosure to mere surveillance.

Typically, the main challenge remains the development of a safe and cost effective strategy. For example, selection of active versus passive approaches may depend on aspects such as the ability of the ventilation system to keep humidity below the levels where corrosion would be an issue and to keep temperatures above the freezing point. The capacity and operational parameters of the ventilation and air-conditioning plant need to be carefully tailored to the climate in their specific country.

Reuse of the buildings and redevelopment of part of the site need to be considered in the determination of the safe enclosure period. This applies especially to countries with a high population density where real estate is at a premium. Reuse of some buildings in the general context of safe enclosure may alleviate this issue and business needs and overall space requirements should be considered.

13.3. CRITICAL POINTS

The costs associated with conservation of the plant infrastructure and equipment during safe enclosure will increase in time because maintenance will be required for the systems still operating. In addition, replacement of infrastructure may be necessary for tackling final dismantling after a long safe enclosure period [62]. Cost estimates both for operation of and dismantling the safe enclosure need to take these aspects into account thoroughly.

Legislative and financial uncertainties might be associated with long safe enclosure periods. The regulatory framework may change and finance accumulated in decommissioning funds can become devalued due to general inflation, poor yield, unforeseen economic crises or the need for unforeseen investments dictated by new stricter legislation.

The argument that the regulatory framework can be totally different at the end of a safe enclosure period can certainly not be dismissed. Areas where regulatory changes might cause problems are waste management (such as waste acceptance criteria, both in activity content and the physical form of the waste), clearance (such as the lowering of clearance levels for certain radionuclides), additional requirements for environmental impact assessments, and changes to licensing procedures. Financial uncertainties are even harder to cope with for a period of several decades, depending on numerous factors such as the stability of the economy in a particular country and the size of the company to which the facility under decommissioning belongs [62]. Only conservative funding schemes may provide sufficient guarantee that the money will really be available at the end of the safe enclosure period, but reliance on low-interest investments may offset any financial benefits accruing from a long waiting period.

The availability of qualified staff is also an issue for deferred dismantling. Loss of the historical memory of the facility is inevitable during safe enclosure, no matter how much comprehensive and up to date documentation is available. In addition, decommissioning related data may get lost or become unusable in the long term.

The management of plant know-how and the experience of the workforce has been found to be a major issue for decommissioning projects. This point was largely ignored in the early days of the decommissioning industry when many safe enclosure projects were established. It was later found that profound plant knowledge is crucial. The loss of know-how and experience due to staff retiring or leaving the plant for other jobs turned out to be a serious issue. It was noted in a number of decommissioning projects that plant documentation was not complete or accurate. This applies in particular to records about non-standard conditions such as leakages of contaminated liquids or undocumented experiments.

Annex III summarizes the meeting outcomes of the International Workshop on Lessons Learned from Planning and Implementation of the Deferred Dismantling Strategy for Decommissioning, organized by the IAEA in cooperation with Magnox in June 2014 in London.

Appendix

OVERVIEW OF POSSIBLE VENTILATION SYSTEMS FOR A SAFE ENCLOSURE

This appendix includes an overview of possible ventilation systems for a safe enclosure, such as a once-through ventilation system (Fig. 39), a circulation ventilation system (Fig. 40) and a passive ventilation system (Fig. 41).

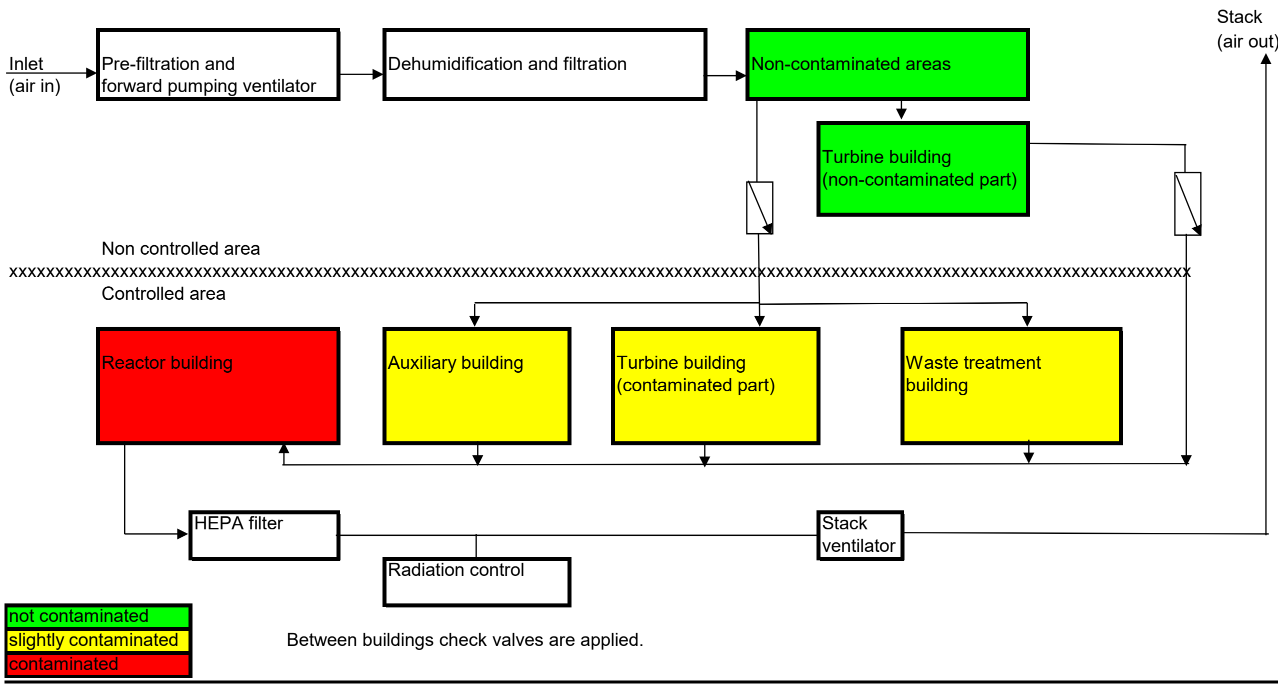

FIG. 39. A once-through ventilation system for safe enclosure.

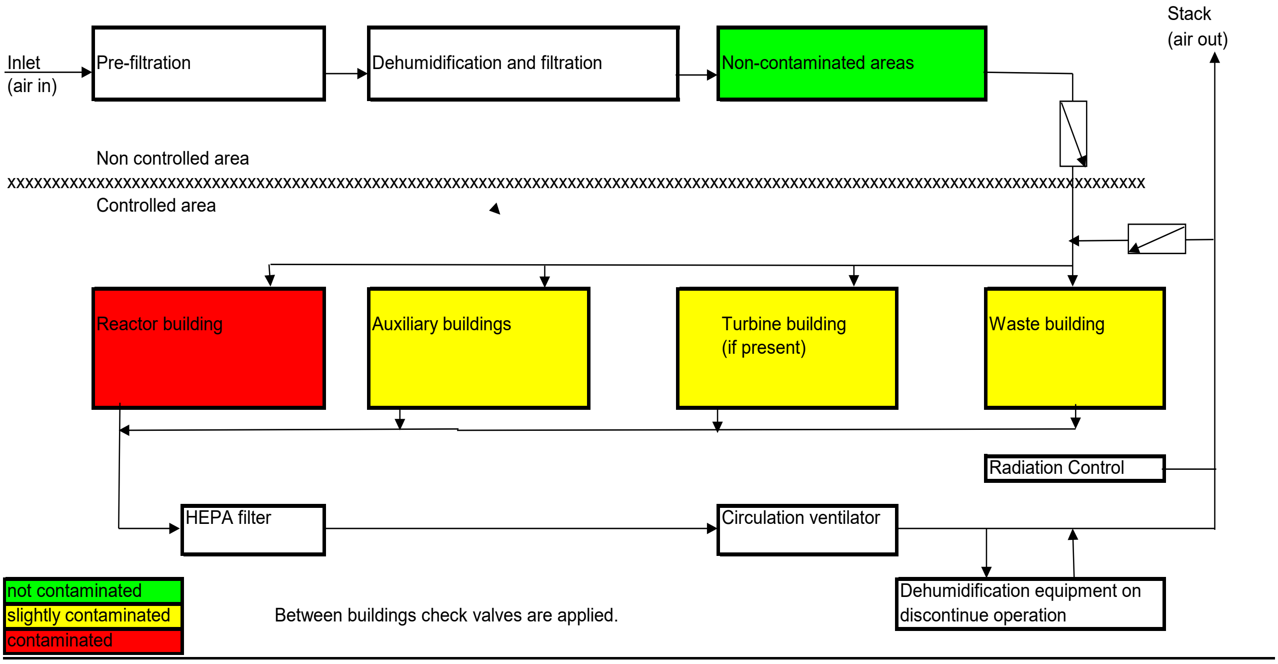

FIG. 40. A circulation ventilation system for safe enclosure.

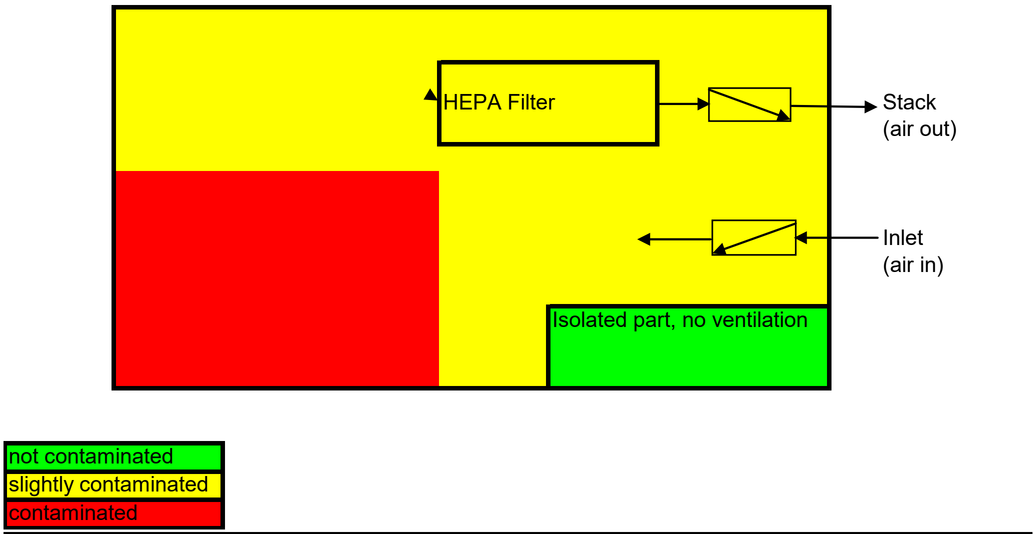

FIG. 41. A passive ventilation system for safe enclosure.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safe Enclosure of Shutdown Nuclear Installations, Technical Reports Series No. 375, IAEA, Vienna (1995).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safe Enclosure of Nuclear Facilities During Deferred Dismantling, Safety Reports Series No. 26, IAEA, Vienna (2002).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning Strategies for Facilities Using Radioactive Material, Safety Reports Series No. 50, IAEA, Vienna (2007).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities, IAEA Safety Standards Series No. GSR Part 6, IAEA, Vienna (2014).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Technology Review 2015, IAEA, Vienna (2015).

[6] EBY, R.S. et al., Research Reactor Decommissioning Planning — it is Never too Early to Start (2003), http://www.igorr.com/home/liblocal/docs/Proceeding/Meeting%208/sld_01.pdf

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Financial Aspects of Decommissioning: Report by an Expert Group, IAEA-TECDOC-1476, IAEA, Vienna (2005).

[8] US DEPARTMENT OF ENERGY, Decommissioning Handbook — Procedures and Practices for Decommissioning, Office of Environmental Management, US DOE, Washington, DC (2000).

[9] NUCLEAR REGULATORY COMMISSION, Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities, Rep. NUREG-0586, Office of Nuclear Reactor Regulation, Washington, DC (2002).

[10] BAUMANN, B.L., Evaluation of Nuclear Facility Decommissioning Projects Program — Status Report, Rep. NUREG/CR-4316, UNC Nuclear Industries, Richland, WA (1986) 105.

[11] LEWIS, B. K., GILMOUR, J.C., WILLIS, M.L., The Cold & Dark Process at the Savannah River Site (2009), http://www.wmsym.org/archives/2009/pdfs/9509.pdf

[12] BRIGGS, M., BUCK, S., SMITH, M., Decommissioning, Mothballing, and Revamping, Institution of Chemical Engineers, London (1997).

[13] OFFICE OF NUCLEAR REGULATION, De-licensing of a Part of the Oldbury Power Station Nuclear Licensed Site, ONR, Bootle, UK (2011),
http://www.onr.org.uk/delicensing-part-oldbury.pdf

[14] MAGNOX, Trawsfynydd Site — Strategic Environmental Assessment Site Specific Baseline, Magnox, Berkeley, UK (2013), http://www.magnoxsites.co.uk/wp-content/uploads/2014/02/ Trawsfynydd-SEA.pdf

[15] HENRIES, W., "SAFSTOR and license renewal: making them coexist" (Proc. 2007 ANS Topical Mtg on Decommissioning, Decontamination and Reutilization, Chattanooga, 16–19 September 2007), American Nuclear Society, LaGrange Park, IL (2008).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations in the Transition from Operation to Decommissioning of Nuclear Facilities, Safety Reports Series No. 36, IAEA, Vienna (2004).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Transition from Operation to Decommissioning of Nuclear Installations, Technical Reports Series No. 420, IAEA, Vienna (2004).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Managing the Early Termination of Operation of Nuclear Power Plants, Safety Reports Series No. 31, IAEA, Vienna (2003).

[19] US DEPARTMENT OF ENERGY, Deactivation Implementation Guide, DOE G 430.1-3, US DOE, Washington, DC (1999), https://www.directives.doe.gov/directives/0430.1-EGuide-3/view

[20] US DEPARTMENT OF ENERGY, Transition Implementation Guide, DOE G 430.1-5, US DOE, Washington, DC (2001), https://www.directives.doe.gov/directives-documents/400-series/0430.1-EGuide-5

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Managing the Unexpected in Decommissioning, Nuclear Energy Series No. NW-T-2.8, IAEA, Vienna (2016).

[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Record Keeping for the Decommissioning of Nuclear Facilities: Guidelines and Experiences, Technical Reports Series No. 411, IAEA, Vienna (2002).

[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Long Term Preservation of Information for Decommissioning Projects, Technical Reports Series No. 467, IAEA, Vienna (2008).

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purposes, Technical Reports Series No. 389, IAEA, Vienna (1998).

[25] BASTIN, S., "The HIFAR safety analysis report for transition and safe enclosure" (Proc. R^2D^2P Workshop on Transition Phase, Sydney, 2007), IAEA, Vienna (2008).

[26] AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION, HIFAR Facility Safety Analysis Report for the Possess and Control Period (2007),
https://www.arpansa.gov.au/sites/g/files/net3086/f/legacy/pubs/hifar/partc.pdf

[27] CHARTERS, G., AGGARWAL, S., Upfront Characterization of Nuclear Reactor Concrete Bioshields, Walls, Slabs & Subsurface Materials Using TruPro® Proprietary System,
http://ndreport.com/upfront-characterization-of-nuclear-reactor-concrete-bioshields-walls-slabs-subsurface-materials-using-trupro%C2%AE-proprietary-system/
[28] ELECTRIC POWER RESEARCH INSTITUTE, Radiological Characterizations for Reactor Pressure Vessel and Internals Enhanced SAFSTOR (2003),
https://www.epri.com/#/pages/product/1008018/
[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Problematic Waste and Material Generated During the Decommissioning of Nuclear Facilities, Technical Reports Series No. 441, IAEA, Vienna (2006).
[30] PAINT AND COATINGS INDUSTRY NEWS, EPA fines DOE over Nuke Site Asbestos (2013),
http://www.paintsquare.com/news/?fuseaction=view&ID=10429
[31] NUCLEAR ENGINEERING INTERNATIONAL, Dealing With Hidden Problems (2011),
http://www.neimagazine.com/features/featuredealing-with-hidden-problems
[32] TAYLOR, J.N., BELL, J.C., MATTHEWS, W.L., Decontaminating Radioactive Lead Solids (1992),
http://www.wmsym.org/archives/1992/V1/44.pdf
[33] HORNUNG, F., BUTEZ, M., CEA's Contaminated Lead Recycling Routes (2009),
http://www.wmsym.org/archives/2009/Final_program.pdf
[34] STUDSVIK UK Ltd, Studsvik Metal Recycling Facility,
http://investors.studsvik.com/files/product/Studsvik-UK-MRF.pdf
[35] US DEPARTMENT OF ENERGY, End Point Implementation Examples, US DOE, Washington, DC (2013),
http://energy.gov/sites/prod/files/2013/06/f1/END_POINT_IMPLEMENTATION_EXAMPLES_10.pdf
[36] MORRIS, R., Experience of chemical decontamination, Nuclear Engineering International (2002),
http://www.neimagazine.com/features/featureexperience-of-chemical-decontamination
[37] TOPF, C., SEMPERE-BELDA, L., TSCHESCHLOK, K., REUSCHLE, K., Aqueous, In Situ Primary Circuit Decontamination (2014),
http://www.neimagazine.com/features/featureaqueous-in-situ-primary-circuit-decontamination-4295654/
[38] D&D KM-IT, Hanford ALARA Center and D&D Knowledge Management Hotline Information Update (2010),
https://www.dndkm.org/DOEKMDocuments/GetMedia/Technology/706-ALARAReport_October21_2010.pdf
[39] CHIAO, T., Stabilization of Residue Plutonium in L-9 Hood in Product Removal Room of PUREX with Polymeric Barrier System (1996),
http://www.osti.gov/scitech/servlets/purl/657346
[40] CONLEY, T.B., et al., Use of fixatives to accelerate building decontamination and decommissioning (Proc. WM2009 Conf., Phoenix, 1–5 March 2009), WM Symposia, Tempe, AZ (2009), http://www.wmsym.org/archives/2009/pdfs/9047.pdf
[41] WORLD NUCLEAR NEWS, Bradwell Welcomes Falcon Chicks (2013),
http://www.world-nuclear-news.org/ON-Bradwell_welcomes_falcon_chicks-2106135.html
[42] WASHINGTON SAVANNAH RIVER COMPANY, Evaluation and Control of Airborne Fungal Populations for Worker Protection during the Deactivation of an Abandoned Process Facility (U) (2007),
http://efcog.org/wp-content/uploads/2015/09/BP49_Control_of_Airborne_Fungal_Populations.pdf
[43] STEVE VICK INTERNATIONAL, High Integrity FOAMBAG™,
http://pdfs.findtheneedle.co.uk/109144-1711.pdf
[44] BECHTEL JACOBS LLC (BJC), Use of Commercial Rigid Polyurethane Foam for Decontamination and Decommissioning, BJC/OR-2725/R1, US DOE, Washington, DC (2007),
http://efcog.org/wp-content/uploads/2015/09/BP51-Rigid-Poly-Foam.pdf
[45] WYATT, D.M., Fire Protection For Inactive Contaminated Structures (1994),
www.wmsym.org/archives/1994/V2/112.pdf
[46] MERRICK, D., "Fire protection for D&D operations — special considerations" (Proc. Int. DOE Symp. on D&D), DOE, Knoxville (1994).
[47] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Underground Structures, Systems and Components, Technical Reports Series No. 439, IAEA, Vienna (2006).
[48] INSTITUTE FOR ENVIRONMENTAL PROTECTION & RESEARCH, Start of a Fire in Decontamination Machine of Former Nuclear Manufacturing Plant of Bosco Marengo (AL) Under Decommissioning (2012),
https://www-news.iaea.org/ErfView.aspx?mId=bf105e85-8a5b-46a6-b2b9-dab79430a3bc
[49] NUCLEAR DECOMMISSIONING REPORT, Wireless Fire Detection System (2012),
http://ndreport.com/wireless-fire-detection-system/
[50] NUCLEAR ENGINEERING INTERNATIONAL, Stressed out: a 36-channel wall monitoring system which measures stresses in concrete reactor walls and boiler box walls is being used to help the decommissioning of Trawsfynydd's twin Magnox units (2008),
http://business.highbeam.com/5474/article-1G1-176374880/stressed-out-36channel-wall-monitoring-system-which

[51] US DEPARTMENT OF ENERGY, Facility Deactivation Guide — Methods and Practices Handbook — Emphasizing End Points Implementation, DOE/EM-0318, Rev. 0, US DOE, Washington, DC (1996).
[52] MAGNONI, M., et al., Environmental Monitoring of the Main Nuclear Sites of Piemonte (North-West Italy) (2002), http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/37/115/37115690.pdf
[53] NAUS, D.J., The management of ageing in nuclear power plant concrete structures, J. Min. Metals Mater. Soc., **61** 07 (2009) 35–41.
[54] PAIK, J.K., MELCHERS, R.E. (Eds), Condition Assessment of Aged Structures, Woodhead Publishing, Cambridge, UK (2008).
[55] KARBHARI, V.M., ANSARI, F. (Eds), Structural Health Monitoring of Civil Infrastructure Systems, Woodhead Publishing, Cambridge, UK (2009).
[56] BERTOLINI, L. et al., Corrosion of Steel in Concrete, Wiley, Weinheim (2004).
[57] DELATTE, N. (Ed.), Failure, Distress and Repair of Concrete Structures, Woodhead Publishing, Cambridge, UK (2009).
[58] BIJEN, J., Durability of Engineering Structures, Woodhead Publishing, Cambridge, UK (2003).
[59] OTERO, E., et al., Corrosividad de la Atmósfera Interior del Cajón del Reactor de Vandellòs 1 (Corrosivity of Internal Atmosphere of the Vandellòs 1 Reactor Containment), Vas Jornadas de Investigación y Desarrollo Tecnológico en Gestión de Residuos Radiactivos, Empresa Nacional de Residuos Radioactivos, Vol. **1** (2003) 104–113 (in Spanish).
[60] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), Nuclear Security Series No. 13, IAEA, Vienna (2011).
[61] INTERNATIONAL ATOMIC ENERGY AGENCY, Objective and Essential Elements of a State's Nuclear Security Regime, Nuclear Security Series No. 20, IAEA, Vienna (2013).
[62] THIERFELDT, S., "Safe enclosure and entombment strategies in nuclear decommissioning projects", Nuclear Decommissioning: Planning, Execution and International Experience, Woodhead Publishing, Cambridge, UK (2012).
[63] LARAIA, M. (Ed.), Nuclear Decommissioning: Planning, Execution and International Experience, Woodhead Publishing, Cambridge, UK (2012).
[64] ANAGNOSTOPOULOS, H., Cold Weather Effects on Dresden Unit 1, Brookhaven Natl Lab., Upton, NY (1994).
[65] US DEPARTMENT OF ENERGY, Be Alert for 'hidden' Electrical Hazards when Performing D&D Activities (2005), https://ehss.energy.gov/oesummary/oesummary2005/OES2005-15screen.pdf
[66] DOOLEY, K.J., VARGAS, J. L., SLOVAK, M., "Illumination of cold and dark projects during decommissioning and deactivation" (Proc. Decommissioning, Decontamination, and Reutilization Topical Mtg, DD&R 2010, Idaho Falls, 29 Aug–2 Sep 2010), American Nuclear Society, LaGrange Park, IL (2010).
[67] NOVAK, P., The Challenges of Lighting Equipment in Hazardous Environments (2013), http://www.bluetoad.com/article/The_Challenges_Of_Lighting_Equipment_In_Hazardous_Environments/1322687/147011/article.html
[68] LARSON ELECTRONICS, Environments which Challenge Lighting Equipment (2013), http://www.larsonelectronics.com/ArticlesDetail.aspx?id=206
[69] US DEPARTMENT OF ENERGY, Implementation Guide for Surveillance and Maintenance during Facility Transition and Disposition, US DOE, Washington, DC (1999).
[70] AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM), Standard Guide for Post-Deactivation Surveillance and Maintenance of Radiologically Contaminated Facilities, ASTM E2420-10, ASTM, West Conshohocken, PA (2010).
[71] VELEZ, L.Y., CONLEY, T.B., "Decision support tool for prioritization of surveillance and maintenance investment" (Proc. WM2009 Conf., Phoenix, 1–5 March 2009), WM Symposia, Tempe, AZ (2009).
[72] EBADIAN, M.A., Remote Surveillance of Facilities Awaiting D&D (2001), http://www.ntis.gov/search/product.aspx?abbr=DE2001772509
[73] US DEPARTMENT OF ENERGY, Surveillance and Maintenance Plan for the 105-C Reactor Safe Storage Enclosure, DOE/RL-98-44 Rev. 1, US DOE, Washington, DC (2004).
[74] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Processing, Handling and Storage of Radioactive Waste, IAEA Safety Standards Series No. GS-G-3.3, IAEA, Vienna (2008).
[75] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Radioactive Waste, IAEA Safety Standards Series No. da habe ich festgestellt, dass der Cache auf der kleinen Insel liegt. Heute habe ich überlegt, ob man rüber waten kann. Im Log von Crazy Gustav stand „Gummistiefel haben gereicht WS-G-6.1, IAEA, Vienna (2006).
[76] GAZETTE NEWS, Berkeley nuclear waste storage begins (2014), http://www.gazetteseries.co.uk/news/11171116.display/
[77] SHAW, I.J., "Retrieval of intermediate level waste at Trawsfynydd Nuclear Power Station" (Proc. WM2001 Conf., Tucson, 25 February — 1 March 2001), WM Symposia, Tempe, AZ (2001), http://www.wmsym.org/archives/2001/10a/10a-6.pdf
[78] MAGNOX, End of an era as the final boiler leaves Berkeley (2013), http://www.magnoxsites.co.uk/2013/03/end-of-an-era-as-the-final-boiler-leaves-berkeley/
[79] HEALTH PHYSICS SOCIETY, Health Physics Considerations in Decontamination and Decommissioning (1986), http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/17/043/17043847.pdf?r=1

[80] Occupational Radiation Protection: Protecting Workers against Exposure to Ionizing Radiation (Proc. Int. Conf., Geneva, 26–30 August 2002), IAEA, Vienna (2003).
[81] INTERNATIONAL ATOMIC ENERGY AGENCY, International Labour Office, Occupational Radiation Protection, IAEA Safety Standards Series No. RS-G-1.1, IAEA, Vienna (1999).
[82] INTERNATIONAL ATOMIC ENERGY AGENCY, Organization and Management for Decommissioning of Large Nuclear Facilities, Technical Reports Series No. 399, IAEA, Vienna (2000).
[83] INTERNATIONAL ATOMIC ENERGY AGENCY, Redevelopment of Nuclear Facilities after Decommissioning, Technical Reports Series No. 444, IAEA, Vienna (2006).
[84] INTERNATIONAL ATOMIC ENERGY AGENCY, Redevelopment and Reuse of Nuclear Facilities and Sites: Case Histories and Lessons Learned, IAEA Nuclear Energy Series No. NW-T-2.2, IAEA, Vienna (2011).
[85] INTERNATIONAL ATOMIC ENERGY AGENCY, An Overview of Stakeholder Involvement in Decommissioning, IAEA Nuclear Energy Series No. NW-T-2.5, IAEA, Vienna (2009).
[86] OECD NUCLEAR ENERGY AGENCY, INTERNATIONAL ATOMIC ENERGY AGENCY, EUROPEAN COMMISSION, International Structure for Decommissioning Costing (ISDC) of Nuclear Installations, OECD/NEA No. 7088, Paris (2012).
[87] NUCLEAR DECOMMISSIONING AUTHORITY, MAGNOX, Magnox Plan Summary: Magnox Lifetime Plan 2013 (2013), https://magnoxsites.com/wp-content/uploads/2014/02/Magnox-Plan-Summary-2013.pdf
[88] INTERNATIONAL ATOMIC ENERGY AGENCY, Conduct of Operations at Nuclear Power Plants, IAEA Safety Standard Series No. NS-G-2.14, IAEA, Vienna (2008).
[89] DAVEY, E., “Incorporating human factors in decommissioning projects — opportunities for adapting application” (Proc. Canadian Nuclear Society Conf. on Waste Management, Decommissioning and Environmental Restoration for Canada’s Nuclear Activities: Current Practices and Future Needs, Ottawa, ON, 8–11 May 2005), Canadian Nuclear Society, Toronto (2006).
[90] ENERGY INSTITUTE, Guidance on Managing Human and Organizational Factors in Decommissioning, 1st edn, Energy Institute, London (2010).
[91] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Facilities: Training and Human Resource Considerations, IAEA Nuclear Energy Series No. NG-T-2.3, IAEA, Vienna (2008).
[92] KERS, D., Preparation for safe enclosure of the NPP Dodewaard, J. NVS-Nieuws (Eindhoven), **29** 4 p. 6-7, 9 (in Dutch).
[93] ORTIZ, T., GONZÁLEZ, O., “Radiological protection during the dismantling of Vandellòs I Nuclear Power Plant” (Proc. 12th Congress of the Int. Radiation Protection Association (IRPA 12), Buenos Aires, Argentina, 19–24 October 2008), IAEA, Vienna (2010).
[94] ACKERMANN, L., PFEFFER, W., Decommissioning and dismantling of nuclear power plants: Radiation protection experience in Germany (2001),
https://www.eurosafe-forum.org/sites/default/files/pe_316_24_1_sem3_4.pdf
[95] NUCLEAR ENGINEERING INTERNATIONAL, Berkeley starts 60-year wait (2011),
http://www.neimagazine.com/features/featureberkeley-starts-60-year-wait/
[96] MAGNOX NEWS, End of an era as the final boiler leaves Berkeley (2013),
https://magnoxsites.com/2013/03/end-of-an-era-as-the-final-boiler-leaves-berkeley
[97] KENNY, S., PARSONAGE, R., “Management and up keep of AECL’s prototype reactors being held for deferred decommissioning” (Proc. Waste Management, Decommissioning and Environmental Restoration for Canada’s Nuclear Activities, Toronto, Canada, 11–14 September 2011), Canadian Nuclear Society, Toronto (2011).
[98] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management of Concrete Structures in Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-3.5, IAEA, Vienna (2016).

Annex I

EXPERIENCE WITH NATIONAL PROJECTS

The examples provided in this annex reflect the experiences and views of their contributors and, although generally consistent with the main text, are not intended as specific guidance. This text has only been edited to the extent considered necessary for the reader's assistance.

I–1. STAKEHOLDERS IN DECOMMISSIONING OF NUCLEAR FACILITIES, ITALY

I–1.1. Introduction

Annex I–1 is based on Ref. [I–1], which introduces the role of a variety of stakeholders in the planning and implementation of the decommissioning strategy including any safe enclosure phases.

The peaceful use of nuclear fission for energy purposes began in Italy early in the nuclear era. Three nuclear power plants (NPPs), a 160 MW(e) gas cooled reactor at Latina, a 270 MW(e) pressurized water reactor (PWR) at Trino and a 160 MW(e) boiling water reactor (BWR) at Garigliano, were in operation in the mid-1960s. In 1981, a fourth unit, an 882 MW(e) BWR at Caorso, began its commercial operation and, in the years that followed, more NPPs were under construction. In the same period, fuel cycle activities were developed both at industrial and experimental-pilot scale, such as uranium fuel fabrication, fuel reprocessing and plutonium fuel fabrication. Research reactors were also built, starting with the one at Ispra at the end of the 1950s.

After the Chernobyl accident, a heated public debate took place in Italy on the use of nuclear energy. In November 1987, a referendum was passed: this vote was legally interpreted as a 'no' to nuclear technology. As a consequence, the new National Energy Plan called for the abandonment of nuclear power, and a Parliamentary decision was made to close the Latina, Trino and Caorso power plants and to halt construction of new reactors. Garigliano NPP was already in a cold shutdown condition. At the same time, according to a resolution from the Inter-Ministerial Committee for Economic Planning, the national electricity company ENEL (the national utility) was charged with taking action on the decommissioning of all NPPs.

A presentation of the Italian regulatory regime is given in several publicly available documents such as the Italian Report to the Convention on Nuclear Safety. The main institution in Italy that grants licences for nuclear installations was at that time the Ministry of Industry. The regulatory body that gives advice to the Ministry of Economic Development and reviews decommissioning plans is the Agency for Environmental Protection and Technical Services (APAT).

The state of Italian nuclear facilities is described in this Annex up to the time when safe enclosure remained the strategy adopted; activities following the strategic shift to accelerated dismantling are not described here.

I–1.2. Transition period from operation to final shutdown and to the decision to decommission all nuclear facilities

I–1.2.1. The nuclear referendum and extended plant shutdown

The 1987 national referendum created an unusual condition for Italy's regulatory body, due to the prolonged shutdown period with limited activities on-site, the number of systems to be maintained and preserved for a long, but undefined time, the presence of the fuel in the vessel and in the spent fuel pools of some plants, and the lack of decisions on the destiny of the plants. Uncertainties were predominant.

Several players contributed to the debate, which lasted several years prior to the final decision. A prominent role was played by the local communities in the NPP territory (local towns, provinces and regions), which organized conferences and public debates, and by the personnel involved in the operation of the plant, who manifested their own concerns in several forms and contexts.

The experience of Caorso NPP in this period can be considered to be of particular interest. Around the time of the last shutdown, in 1987, important plant modifications had already been authorized to improve its capability to cope with beyond design basis accidents, but they were not fully implemented due to the uncertainty about the continuation of operation.

In July 1990, the Inter-Ministerial Committee for Economic Planning decided that the plant would be permanently shut down. In the following year, the licensee submitted an application to be authorized to take the plant to a state of safe enclosure.

Further additions to the documents were submitted up to 1996, but the main obstacle to the finalization of the authorization process was the lack of a clear policy for spent fuel management. Moreover, in 1996, the new nuclear law containing specific decommissioning regulations entered into force. In 1997, when the fuel management strategy was defined, a new application was submitted according to the newly issued procedure and, in February 1998, the fuel was removed from the vessel. This operation, usually routine, was followed with great interest by all stakeholders; many issues relevant to the management of interfaces with the stakeholders came up at that time and remained acute in subsequent decommissioning phases.

I–1.2.2. Stagnation of initiatives and the change of decommissioning strategy

In the following years, characterized by long lasting stagnation, it was decided by several stakeholders to reconsider the previously chosen deferred decommissioning option. Some stakeholders began to demand a more active role in the choice of the strategy, which they claimed was not only to be dictated by the needs of the licensees but should take into account general interests. In addition, in view of the ENEL's privatization process, the licensee began to feel the legacy of the nuclear past as an intolerable burden.

As a result of such new attitudes, by the end of 1999, the Ministry of Industry issued a document providing strategic guidelines for the management of liabilities resulting from past nuclear activities.

The pillars of this new policy were [I–2]:

— A commitment to the treatment and conditioning of all radioactive waste stored on the sites;
— The start of a concerted procedure, by means of a specific agreement between the government and the regions (administrative subdivisions of the Italian territory), for the selection of a national site for the final disposal of low and intermediate level waste and for the interim storage of the spent fuel and the high level waste;
— The adoption of the immediate dismantling strategy for all shutdown nuclear installations, thus abandoning the previous safe enclosure strategy;
— The establishment of a new national company SOGIN, licensee of all shutdown NPPs, with a mandate to perform their immediate decommissioning;
— The allocation of special funds for all these activities by means of a specific deduction from electric energy bills.

This policy was confirmed by a decree by the Ministry of Industry, which provided directives to SOGIN for implementing immediate decommissioning of the four national power stations until unconditional release of their sites within a time frame of 20 years. The decree also provided directives to SOGIN for the safe management of radioactive waste and spent fuel associated with the power stations.

I–1.3. New regulation of general scope

From time to time, after final plant shutdown and while the plants were in the process of achieving safe enclosure, it happened that new regulations were issued in the fields of conventional safety, worker protection or civil protection. Many such regulations were directly or indirectly applicable to NPPs. For instance, a specific Italian law was issued in 1991 giving prescriptions about handling asbestos. About 25% of the insulating material in the shutdown NPPs contained asbestos fibres (carbon-silicates enveloped in asbestos tissues, mattresses made of asbestos, enveloped by aluminium or by tissues) [I–3]. On this basis it is easy to imagine the size of the problem. On account of the sensitivity of public opinion, following some press news about asbestos at Trino NPP, the Prefect of Vercelli (the local authority in charge) convened a conference at which a number of institutions and other parties had the chance to disclose their positions. The following organizations were represented at that conference, with intense coverage by the media:

— The Regional Environmental Protection Agency of Piedmont (Piedmont being the region where Trino NPP is located);
— Local public health services, which were tasked with reviewing the cleanup plans from the conventional health protection point of view;
— Trade unions;
— APAT, which was charged with the review and approval of any plant modification from the safety and radiation protection point of view.

It was estimated that the asbestos cleanup in Trino was the largest operation of this kind ever performed in Piedmont. In 2003, an ordinance was issued by the Prime Minister's office, giving criteria for updating the seismic classification of national territories together with the technical regulations applicable to the construction of new buildings, including industrial facilities. In particular, the level of protection to be required against earthquakes needs to be commensurate with the consequences of the event in question [I–4]. Updates of these regulations were issued in subsequent years. Detailed regulations for the implementation in individual areas have to be issued by the regions. No immediate implementation of the above mentioned ordinance was required. However, the impacts of the new rules on the long lasting structures in a deferred decommissioning strategy required evaluation. A similar situation occurred in regard to the updated regulations about electrical equipment in working areas.

I–1.4. Emergency status

I–1.4.1. Emergency status: The origin and the implemented measures

In 2003, due to the worldwide terrorist threat, the Italian Prime Minister promulgated a decree declaring an emergency status in those national territories subject to specific risks associated with radioactive material. Nuclear installations were identified as possible targets for terrorist attacks. The actions required under the emergency status, which was extended from year to year, were implemented through ad hoc ordinances by the Prime Minister. The transfer of the licences of all the interested installations to one national implementer (i.e. SOGIN) needs to be highlighted (SOGIN already had responsibility for the management of the NPPs). The main objectives of the Prime Minister's ordinances were the adoption of provisions for protecting the most vulnerable plants, and the improving of radioactive waste storage facilities with prompt, homogeneous and economical interventions. Of course, given the worry that generated the measures, the improvement of the security provisions was the most important issue to address, but the interfaces with safety, waste management and decommissioning became wider and stronger with time.

For the purposes of these activities, the Prime Minister delegated his authority to a Commissioner (the president of SOGIN) who, under the supervision of a Scientific Committee, was charged to issue ordinances aimed at the execution of the necessary activities by the implementer. The main players for authorizing interventions under emergency status were as follows:

— The Commissioner, who ordered interventions aimed at pursuing the established emergency objectives;
— SOGIN, as the sole implementer;
— APAT, the regulatory body, provided technical advice on the intervention plans, reviewed and approved technical designs, proposed technical specifications and performed control and surveillance on SOGIN's activities;
— The Scientific Committee provided evaluation and supervision on the ordinance objectives, as well as evaluation and validation of the intervention plans before their submission to APAT;
— The National Technical Commission discharged duties established in Article 9 of Legislative Decree 230/95 (to provide independent advice to APAT on the acceptability of technical designs from the nuclear safety and radiation protection point of view) [I–4].

Other stakeholders were:

— The Civil Protection structure that played the role of filling the gap between the Commissioner and the Prime Minister, given also the need for applying instruments typical of civil protection interventions;

— Those installation owners that maintained the rights of property of the installations, even after the transfer of the licence to the implementer.

Given the declared status of emergency, the Commissioner was allowed to proceed without the authorizations required by ordinary legislation, but he was required to take the advice of APAT into account. APAT always recommended the interventions to be subject to a review scheme compliant with the ordinary legislation (i.e. Legislative Decree 230/95 and subsequent modifications). However, a few decisions were taken by the Commissioner alone, enforcing his special powers; some interventions overrode permissions and authorizations that ordinary legislation required of mayors and/or other local authorities.

In December 2006, the government took the decision not to prolong the emergency status to 2007. This meant the Commissioner was no longer in charge, and all the activities on the nuclear sites were managed again under ordinary legislation including authorizations.

The need to exit somehow from the stagnation period, in a timely and effective way, was an issue that had been publicly highlighted by APAT for a long time. This was the reason why no objection was formulated by APAT about the emergency approach to managing the Italian nuclear installations. In fact, most stakeholders did welcome the firm commitments of the government, namely to:

— Assign precise responsibility and authority to someone in a high level position (the Commissioner) who took charge of defining the most appropriate planning and actions;
— Identify a proper subject (SOGIN) to whom the implementation duties were assigned;
— Provide the needed resources;
— Strictly monitor accomplishments.

Timely and cost effective implementation of the measures under ordinary legislation was considered to be almost impossible, mainly due to the veto power attributed by law to a plurality of subjects, some of which did not have the capabilities to speed up their decision making processes [I–3].

In spite of the efforts devoted by SOGIN to communicating with the public, and in spite of the power to proceed without the ordinary authorizations, the Commissioner was reluctant to make full use of his power without first resolving conflicting viewpoints. The aim of avoiding, as far as possible, institutional conflicts was the reason to maintain a prudent and generally agreed path.

It was possible to perform, in a very timely way, a number of activities in the area of security protection of all the nuclear installations, based on specific vulnerability studies.

I–1.4.2. Attempt to localize a waste repository under the emergency status

The endeavours to identify an appropriate site for the national waste repository date back to 1996, when the permanent Commission of the Civil Protection Department decided to establish a task force to this end. The task force was responsible for developing a method for siting and validating suitable areas for the construction of a national repository for low level radioactive waste and of an interim storage facility for high level waste and spent fuel. A final report was issued by this Commission.

Moreover, the Italian research organization Italian National Agency for New Technologies, Energy and Sustainable Economic Development contributed to this task by performing a topical study. From 1998 to 2000 the first phase of the study was completed, the national territory was fully characterized and a database was built. By using predefined exclusion criteria, areas were identified for a more in-depth analysis.

The work of the Commission was concluded in August 2003 and a decree was issued by the government identifying the disposal site in a locality in southern Italy. The chosen site was a saline formation, 150–200 m thick, with an extension of about 10 km^2, protected by a clay layer at 600 m depth (similar to the Waste Isolation Pilot Plant in the US). This area was located in the vicinity of Scanzano Jonico town.

The first news of the resolution of the government appeared in the newspapers just the next day. The strong reaction of national and local environmentalists came instantly. The main arguments against the decision were related to the relevant role agriculture and tourism had in the economy of the affected region and to a recent seismic upgrading of the disposal site territory. Questions were addressed to Parliament, statements were submitted to the Regional Administrative Court and resolutions from the Scanzano Jonico administration were issued in the days immediately afterwards. Doubts were publicly expressed by scientists about the technical studies on which the decision was based. The day after the news was circulated, a committee was established locally to coordinate the opposition. Two days later, large demonstrations took place. Many administrative actions were also announced by the mayors of the towns around the selected disposal site. Consumers' rejection of agricultural products from Scanzano Jonico infuriated the local farmers. Important highways and railways were blocked for days with a significant impact on the national traffic. Attempts were made by the government to mediate the positions, with no result. A local demonstration of about 100 000 people took place a few days later. Even the Italian National Agency for New Technologies, Energy and Sustainable Economic Development criticized the scientific methods adopted and questioned the data used for the siting. About two weeks after the promulgation of the decree, the government was forced to completely change its contents [I–5].

I–2. GKN DODEWAARD EXPERIENCES ON SAFE ENCLOSURE NUCLEAR LAW AND REGULATORY BODY APPROVAL

I–2.1. Before shutdown

When the final shutdown of the Dodewaard plant was announced on 6 October 1996, the nuclear law (known in Dutch as Kernenergiewet) offered no clues on what to do and what rules and regulations would apply. Although two research facilities (the Kema Suspension Test Reactor and the Biological Agricultural Reactor of the Netherlands) had shut down in the past and had been decommissioned to unrestricted release, Dodewaard NPP was the first commercial reactor in the Netherlands to shut down. In the early 1990s the owner, SEP, had performed a study about the decommissioning options. At that time, the conclusion of the study was that both Dutch NPPs (Dodewaard and Borselle) would defuel and move to a safe enclosure condition. The main reason for this decision was the lack of funding for immediate dismantling. It was also noted that a safe enclosure period would be beneficial for future dismantling due to the decay of the radioactive inventory.

The regulatory body was informed of the outcome of the studies. As nobody expected either plant to shut down in the foreseeable future, the study was accepted as merely conceptual. All parties realized at that time that funding for immediate dismantling was not available.

I–2.2. Shutdown

In the period between the announcement of the shutdown and the actual date of shutdown, almost five months later, the regulatory body realized that the nuclear law was not suitable for a final shutdown and a safe enclosure period or immediate dismantling. The nuclear law of the Netherlands only addressed the building, start-up and operation of a NPP. Therefore, a process of changing the nuclear law started. Dodewaard NPP shut down without the nuclear law being changed and had to stay in operational mode 'cold shutdown' for a few months. During that period, no preparations for the safe enclosure period could be made, although transport of spent fuel and conditioning of low level liquid waste was possible under the existing licence.

When the nuclear law was changed, the operator (GKN) filed an application for a transition state (called Buitengebruikstelling en Conservering) and a safe enclosure period of 40 years (called Wachttijd).

However, only at that point did the regulatory body realize that a safe enclosure period would mean that the plant would exist for another 40 years. The regulatory body started a process to force GKN to decommission the plant to unrestricted release as soon as possible. Soon, GKN objected to this process as funds were lacking. After lengthy discussions with the regulatory body that did not bring about any solution, GKN decided to do some new decommissioning calculations. These were performed by a contractor with the support of GKN engineers. The result of the 1999 calculations was challenged by the regulatory body that was supported by the Central Organization for Radioactive Waste (COVRA). The Dutch regulatory body and COVRA maintained that the funds calculated for the decommissioning were too low. Although at that time GKN disagreed with this judgement, it was obvious to all parties involved that the available funds were only sufficient to move the plant to safe enclosure; to start dismantling the funds had to reach an adequate level.

Although the regulatory body was not happy with the outcome, there was no alternative to accepting the situation, and the plant was put into safe enclosure.

I–2.3. Funding

In order to avoid a situation like the one that occurred at GKN Dodewaard in future decommissioning projects, the regulatory body started a process to change the nuclear law. The aim was to force all nuclear facilities in the Netherlands to have sufficient funding for immediate dismantling available at the time of final shutdown [I–6]. Therefore, every facility had to have financial provisions in place that would be large enough to allow dismantling soon after final shutdown. The revised nuclear law did not pass through Parliament without a change. For existing situations (such as GKN Dodewaard) this part of the law was considered inapplicable. This was due to the fact that GKN operated only the Dodewaard NPP. Therefore, it was impossible for GKN to collect in a short period of time the large sum of money needed for full dismantling, as the plant did not generate electricity anymore. The only way for GKN to collect funds was to use the saving system already in place.

I–2.4. New decommissioning cost study

In the Netherlands, all nuclear waste is controlled by COVRA. It was the intention of GKN's parent company to hand over the plant to COVRA, together with sufficient funds for final decommissioning. The regulatory body, COVRA and GKN did discuss the amount of money required for final decommissioning, taking into consideration the interest rates in place during 2007–2009.

As the parties could not agree on a way to calculate the amount of money required, it was agreed that they would sit down together in order to discuss the baseline from which new cost calculations would start. The results of these discussions, which took about a year, were written down in a Technical Requisition File (TRF). This file was signed by all parties, including a representative of the Ministry of Housing, Spatial Planning and the Environment, who was in charge of nuclear regulation and nuclear law at that time [I–7]. The TRF included all parameters considered relevant for the cost calculations. Items like decommissioning techniques, type of waste packages, storage costs, labour costs, unrestricted release criteria and many more were discussed, agreed and recorded.

A contractor performed the final cost calculations. The results were discussed and finalized. The cost calculations and the TRF were brought together in a decommissioning plan. It was agreed that this method would be the basis for future cost updates. Currently, these updates have to be performed every five years. It is recognized that now that the model is consolidated and accepted, parties have only to agree to start the updating of the TRF before cost calculations can start.

I–2.5. Financial security

Another change in the nuclear law forced all nuclear facilities to keep decommissioning funds earmarked and securely stored. This means that the money is transferred to a blocked bank account and cannot be used for anything other than decommissioning of the plant. The facilities are discussing how to have this matter arranged in practice, as most banks are unwilling to cooperate. The facilities have indicated that to be able to grow sufficient interest, they need flexibility to work with the money. This flexibility is no longer in place when the money is transferred to a blocked account.

I–2.6. Insurance versus risk

It is obvious that the level of risk relating to an operating NPP is higher than that relating to a plant in shutdown mode. However, even a plant in shutdown mode or a passive safe enclosure still has some potential risk to the public. During the process of changing the facility from an operating plant to a safe enclosure, the risk gradually reduces. Therefore, the level and amount of insurance can be lowered, in this way reducing the insurance premium.

I–2.7. Insurance during the defuelling phase

The insurance company stated that the potential risk for a major nuclear event would remain in place even after the removal of the fuel from the core and its storage in the spent fuel pool. It was assumed that a criticality incident could also occur in the spent fuel pool. Although this is true, GKN argued that the effects of such an incident would be much less significant than the effects of a reactor incident. The insurance company, backed up by the regulatory body, insisted that full insurance to cover nuclear fuel related incidents remained in place as long as spent fuel was on-site.

I–2.8. Insurance during PSE phase (liquid waste on-site in the process of being solidified)

During the PSE phase, after the fuel was removed from the site, the nuclear insurance obligation was partly reduced [I–6]. At that time calculations were performed in order to find out what would be the biggest risk during this phase and its potential effects. It turned out that a (highly unlikely) failure of three completely full liquid waste storage tanks at the same time would be the worst-case situation. The potential effects of this accident were calculated. As the effects of such an incident were found to be much less significant than for an incident involving fuel, the amount of money needed for cleanup from the insurance would be much lower, and the insurance premium was reduced accordingly.

I–2.9. Insurance during PSE (all operational waste removed from site)

Although discussions did take place during PSE, the insurance company refused to reduce the insurance premium after the waste was removed from site, by stating that the situation at the plant was now even more risky, as systems were retired, buildings were brought down and many contractors were on-site. GKN decided to accept this position, as the PSE period would take two years as a maximum. Lengthy discussions with the insurance company would bring a limited premium reduction only, if any.

I–2.10. Insurance during safe enclosure

After the regulatory body declared the plant to be in a state of safe enclosure, GKN started negotiations with the insurance company about a further insurance premium reduction. GKN stated at that time that the amount of potential released radioactive material was limited, while the radioactive inventory included only ^{60}Co and a limited amount of ^{137}Cs. Although the insurance company recognized GKN's position, it was not willing to change its own position before both Euratom and the IAEA changed the plant status from 'in operation' to 'close down phase' (in state of preservation). Only this statement would convince the insurance company that the risk was so limited that a further premium reduction was possible. Unfortunately, the plant had to remain in safe enclosure for five years before the decision to declare the plant to be in close down phase was finally made by Euratom/IAEA.

I–2.11. Insurance for decommissioning after an accident

If an accident occurs during the period of safe enclosure, there is a fair chance that the regulatory body will force the NPP to start final decommissioning. Therefore, it was agreed after consulting the insurance company that increased cost of decommissioning (ICOD) insurance had to be in place. This insurance would pay the costs of decommissioning after an accident. The amount of money insured is the amount of the expected decommissioning costs as calculated, minus the amount of money already available for decommissioning. As the decommissioning costs are calculated every five years and the amount available for decommissioning increases each year, the ICOD sum is a floating one. Every five years the ICOD sum is calculated and so is the insurance premium for the next five years.

I–2.12. The first decommissioning study

In 1994, the first decommissioning study for Dodewaard NPP was performed. This provided some orientation for the costs. The study was performed by financial engineers from Dodewaard's parent company, supported by a company specializing in calculating decommissioning costs. As the participation of plant personnel in the discussions to estimate the safe enclosure budget was very limited, if any, a lot of the costs of items needed for managing the safe enclosure were underestimated or were not taken into account at all. Also, estimates of plant volumes, activation and contamination were guessed, rather than accurately calculated based on live information and consultancy with plant staff.

I–2.13. The second decommissioning study

During PSE, the regulatory body insisted on new calculations of the funds needed for decommissioning. The regulatory body was backed up by members of COVRA. At that time there was an intention to hand the plant over to COVRA. The second calculations were made by the same engineering company that had performed the first study. Fortunately, plant personnel were allowed to join in the discussions. However, as the total decommissioning funds calculated during the first study were frozen by order of the parent company, only minor changes to the original calculations were made. It became clear that several items had been underestimated in the first study.

The second study was challenged by a group of international consultants supported by COVRA. As a result, COVRA refused to take over ownership of the plant and the official figure for the funds needed for the final dismantling was not changed. The funds needed for managing the safe enclosure were not changed either, but at least at that time a list was added to the study explaining what issues had not been taken into account in the safe enclosure management.

I–2.14. The third decommissioning study

In the nuclear licence for safe enclosure a clause states that the company needs to revisit the decommissioning plan and the cost calculations every five years [I–8]. To avoid lengthy discussions on what was to be included in the study, all stakeholders (regulatory body, parent company, COVRA, safe enclosure operator) discussed a TRF. After agreement to all figures by all stakeholders, this file became the basis for the decommissioning cost calculations. It was a surprise to some stakeholders that the decommissioning costs calculated were almost 20% higher than those calculated in the 1994 and 1999 studies. The main contributors to the cost rise were the increased costs for casks, disposal costs and costs for managing the safe enclosure. It turned out that the real costs for operating the safe enclosure were twice the amount calculated in the first study.

References to Annex I

[I–1] INTERNATIONAL ATOMIC ENERGY AGENCY, An Overview of Stakeholder Involvement in Decommissioning, IAEA Nuclear Energy Series No. NW-T-2.5, IAEA, Vienna (2009).

[I–2] CANDESCO, International Benchmarking on Decommissioning Strategies, File: K-421183-00006 R0, Report Submitted to the Canadian Nuclear Safety Commission (CNSC), 30 June 2014, CANDESCO, Toronto (2014).

[I–3] ITALIAN GOVERNMENT, Implementation of Council Directive 2011/70/EURATOM of 19 July 2011 — Establishing a Community Framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, First Italian National Report, 2015, Italian Government, Rome (2015).

[I–4] ITALIAN GOVERNMENT, INSTITUTION FOR ENVIRONMENTAL PROTECTION AND RESEARCH, Convention on Nuclear Safety, Sixth Italian National Report, ISPRA, Rome (2013).

[I–5] NUCLEAR MONITOR, Controversy over Italian waste burial plans, Issue #599, WISE, Amsterdam (2003).

[I–6] OECD NUCLEAR ENERGY AGENCY, Costs of Decommissioning Nuclear Power Plants, NEA No. 7201, OECD/NEA, Paris (2016).

[I–7] COUNCIL OF THE EUROPEAN UNION, Working Party on Nuclear Safety (WPNS) Final Report, Council of the EU, Brussels (2006).

[I–8] OECD NUCLEAR ENERGY AGENCY, Cost Estimation for Decommissioning — An International Overview of Cost Elements, Estimation Practices and Reporting Requirements, NEA No. 6831, OECD/NEA, Paris (2010).

Annex II

LESSONS LEARNED FROM SAFE ENCLOSURE PROJECTS

The following examples of lessons learned from safe enclosure projects include an outline of the problems and requirements encountered, solutions found and lessons learned. The situations describe typical issues that can arise in the planning or implementation of decommissioning activities. Although the information presented is not intended to be exhaustive, the reader is encouraged to evaluate the applicability of the lessons learned to a specific decommissioning project.

II–1. ABANDONED SYSTEMS ENERGY STATUS, IDAHO NUCLEAR TECHNOLOGY AND ENGINEERING CENTER, USA

(a) Problem encountered

On 2 March 2009, at approximately 5:00 p.m., utility operations personnel noted abnormal cycling of the Idaho Nuclear Technology and Engineering Centre (INTEC) fire water service pumps and notified the INTEC Plant Shift Manager. Upon extensive investigation, they located a leaking water line in building CPP-621 at approximately 5:40 p.m. This particular line was a 2 ft (0.6 m) section of 2 in (5.08 cm) line that protruded from the building slab and was capped on the end. The line had apparently frozen and ruptured the capped end inside the building. Personnel isolated the line by closing a valve below the rupture point.

Upon further investigation, deactivation and decommissioning personnel determined that 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. The line also likely supplied the building's 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 had the original pipe stubs connected to the fire water system as was the case in this event.

The deactivation and decommissioning 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 deactivation and decommissioning 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.

Since the planning walkdown for this work package did not identify this line as being connected to an active system, deactivation and decommissioning personnel assumed that this line was inactive based on the lack of supporting evidence to the contrary.

(b) 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 upfront 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. The line did appear on an inactive aluminium 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 system was built in the mid-1950s. The aluminium nitrate filtration system was removed over 20 years ago, so the availability of personnel with historical knowledge was 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. Additionally, inactive or abandoned systems may still contain hazardous energy or materials that are not compatible with the environment, or may still be physically connected to active systems.

(c) Lessons learned

Controlled zero energy checks need to be performed on all systems — active, inactive or abandoned — to ensure building demolition can proceed safely. Abandoned/not in-service systems do not need to be considered as isolated until a positive zero energy check is completed [II–1].

II–2. AGEING FACILITY DEGRADATION INTRODUCES HAZARDS REQUIRING ANALYSIS, HANFORD SITE, USA

(a) Problem encountered

On 1 September 2006, during deactivation and decommissioning activities within an abandoned tank pit at the Plutonium Finishing Plant, a 3/8 in × 4 ft (1.0 cm × 1.2 m) all-thread rod disengaged from the ceiling after being accidentally struck by the repositioning of a ladder within the pit. This caused it to break loose from the ceiling and fall to the bottom of the tank pit (about 17 ft or 5.1 m), landing approximately 5 ft (1.5 m) behind a worker on the lower level.

Ongoing deactivation and decommissioning activities within the tank pit had removed the majority of piping and equipment from the grating level. Several existing pipe supports (some were previously cut off for bump protection), at a level above worker's heads, were left attached to the ceiling.

Initial characterization and hazard analysis of the tank pit identified a potential corrosion issue with the metal structures within the tank. This corrosion was evaluated by engineering and structural experts to attempt to fully understand the risk to the worker due to this corrosion. However, the focus of the analysis was based on structures that the worker would definitely come into contact with (ladders, grating, tank surfaces, etc.) to ensure the worker was provided with adequate protection. At this time, the corrosion to the conduit supports was not believed to be significant to worker safety. As a result, the work scope focused on the removal of safety hazards, which in this case were believed to be the potential bump hazards. As such, the integrity of the remaining brackets was not questioned as work was not to be conducted in the area of these brackets.

(b) Analysis

The all-thread rod within the abandoned tank pit was severely corroded from its time in-service. When contacted by the ladder it could not absorb the lateral shock without failure. This condition was known; however, the planning personnel did not perceive this condition as a hazard to the workers.

(c) Lessons learned

New hazards are introduced in ageing facilities simply through the degradation of materials over time. Even when the work to be performed has been analysed for hazards specific to the work activity, other hazards may still be present. When performing job hazard analyses for work within abandoned structures (especially those with overhead structures or components) the work planning process needs to take into consideration the potential for structure/component degradation and subsequent failure. Any structure with the potential to fall always poses a risk to workers.

When work activities are planned, ensure that all potential hazards are analysed [II–2].

II–3. DOWNED PERIMETER LIGHT POLE LEADS TO ELECTRICAL NEAR MISS, HANFORD SITE, USA

(a) Problem encountered

On 13 March 2005, during a high wind event, a 30 ft (10 m) perimeter light pole at the Canister Storage Building (CSB) facility failed (fell over). When performing the unmanned facility checklist at the CSB facility, it was noted that perimeter light pole L-25 on the southeast side of the facility had blown down. Electrical Utilities inspected the pole, reported that the electrical wires were intact and placed caution tape around the area. The pole remained in this condition until 6 April 2005.

Investigation determined that during the weeks following the light pole being blown over, the insulation on the wires became degraded to the point where some bare wire was exposed, which created an electrical hazard. Facility Operations was unaware of this condition.

On 6 April 2005, an electrician and engineer were conducting a visual inspection of all CSB perimeter light poles to determine if there were problems with welds, rust, etc. Inspections of poles L-18 through L-24 were complete and the group moved to Pole L-25. This pole differed from the other perimeter lights, because it had a conduit attached to it which contained electrical wires running to a nearby environmental monitor. The electrician noticed that the wires were tight and over the metal edge of the pole base. While visually inspecting the pole, the conduit was accidentally bumped, causing a short and loss of power to the environmental air monitor and perimeter lights L-18 to L-26.

(b) Analysis

Initial assessment of the downed light pole determined that the 480 V wires inside the pole were intact and that it would be appropriate to leave it as it was (energized) for one night. Later it was determined that it would be safe to leave the pole energized and in its downed configuration until it could be repaired. Because the light pole also contained an electrical feed to an environmental monitor, there was a need to maintain power and operability. However, confusion over the ownership and responsibility for the repair of the CSB electrical system delayed the eventual inspection and repair. Further investigation revealed that procedures clearly define the demarcation point between the Electrical Utilities electrical system and CSB electrical system and that a memorandum of understanding was in place that specifies the CSB has the responsibility for the 480 V perimeter light pole breaker.

Leaving the wires exposed to the environment for a long period of time allowed the insulation on the wires to degrade to the point where some bare wire was exposed, creating an electrical hazard. Unaware of this condition, Facility Operations performed an inspection about three weeks after the pole had blown down. During the inspection the wires were moved, causing them to arch against the broken steel pole base and trip the 480 V perimeter light pole breaker.

The primary cause of the light pole failure has been identified as fatigue cracking and is the result of repetitive or cyclic wind loading. A poor welding technique (weld start/stop and size) is likely to have contributed to and accelerated fatigue crack initiation. Many of the light poles on the Hanford site are 30 ft (10 m) long, 5 in square (32 cm^2), 0.180 in (0.5 cm) wall structural steel tube, welded to a 1 in (2.5 cm) thick by approximately 12 in square (77 cm^2) structural steel base plate. Poor weld tie-in, characterized by weld bead cold roll and sharp re-entrant angles, can produce areas of increased stress. This in turn creates a material condition that is more susceptible to cyclic fatigue loading than it would otherwise be. In addition, excessive weld size can affect base material microstructure and residual member stress in a way that can exacerbate the effects of fatigue loading.

(c) Lessons learned

Projects that have interface agreements with the Electrical Utilities should be reviewed to ensure their responsibilities are clearly understood, and the appropriate actions to be taken for similar events which could occur in the future should be discussed with staff.

Plant/facility conditions need to be continually assessed to ensure that unsafe conditions are identified and previously unrecognized hazards are addressed.

Facilities with similar light poles might perform a visual examination to determine if the tube-to-base-plate connection is of similar design and determine whether the weld is oversized. The weld quality might also be evaluated, especially at the tube corners, to determine whether there are signs of cracking at the top toe of the weld. Defective poles need to be repaired or replaced.

Facilities could be especially cautious of leaving equipment in an abnormal status for prolonged periods of time, and may consider interim corrective actions such as removing power if repair actions are delayed. If regulatory body or other considerations require the equipment to remain operating, periodic evaluations should be conducted to ensure hazardous conditions do not develop. Managers need to understand their responsibilities and the interface agreements that exist with other support organizations to ensure that equipment is adequately maintained [II–3].

II–4. ELECTRICAL DEACTIVATION, OAK RIDGE, USA

(a) Problem encountered

While performing pre-demolition activities under an approved work package, contractor workers discovered an unexpected electrical energy source (105 V, A/C) in an instrument panel located in their work area. The building had previously been declared as cold and dark by a previous US DOE contractor, had recently undergone a utilities isolation verification walkdown by the same DOE contractor and current contractor, and was verified by the current contractor's electrical subcontractor as electrically deactivated the day before.

(b) Analysis

The DOE's previous contractor had identified the building as cold and dark, which is typically defined as an abandoned facility where all systems have been shut down and permanently isolated to reduce maintenance and surveillance costs. As a result of this occurrence, the DOE's previous contractor's process for establishing and identifying a building as cold and dark was determined to be suspect in fulfilling the objective of deactivation of electrical sources. The current contractor did not investigate its process but notified the previous DOE contractor of the occurrence.

The current contractor's process for utility isolation and electrical deactivation was determined to be less than adequate in that it did not achieve the desired objective of electrical deactivation verification. It was determined that although all electrical wires were verified going into the building, wires pulled through a floor penetration were not air gapped or tested. The current contractor initiated an effort to review and revise the current verification process with the goal of implementing a more rigorous process to mitigate or eliminate a similar condition.

(c) Lessons learned

Where buildings scheduled for demolition have been classified as cold and dark, workers have to understand that cold and dark does not mean safe with all hazards removed. Because chemical, radiological, electrical, mechanical and residual liquid hazards may remain in a facility, continued hazard analyses have to be performed as work progresses. In this incident, de-energizing at the distribution panels only is not adequate. Unknown sources may come through the slab or from the ground penetrations undetected [II–4].

II–5. RE-EQUIPPING THE SITE AFTER TEN YEARS, LINGEN NUCLEAR POWER PLANT, GERMANY

(a) Problem encountered

The licence for safe enclosure usually requires the removal of all operating media and the limitation of the controlled area to the containment accommodating the entire radioactive inventory. This also implies the termination of the operational licence and a substantial reduction of radioactivity to the environment by air and water discharges. The reapplication of a new decommissioning licence after only ten years of safe enclosure resulted in a significant recommissioning of equipment, e.g. crane, elevators, social infrastructure, etc., in accordance with the existing state of the art regulation as well as in new, more restrictive release limits and discharge levels. For example, Lingen, after approximately 10–12 years of safe enclosure, had to apply for a new water discharge licence invoking more than 17 legal acts by the local communities to increase the discharge amount from 100 m^3 to 1000 m^3. The project was therefore delayed, resulting in an increase of costs and general slowdown of other decommissioning activities.

(b) Solution found

When selecting a decommissioning strategy, one needs to be aware that some strategies are more sensitive than others to changes in boundary conditions and evolving legal frameworks.

(c) Lesson learned

Safe enclosure is vulnerable to changes in legislation and regulatory body requirements. Immediate dismantling is less sensitive to many of the above problems [II–5].

II–6. FALLING FLOOR DECK PIECES, EAST TENNESSEE TECHNOLOGY PARK, USA

(a) Problem encountered

A sprinkler crew was performing sprinkler tests inside the K-309-1 and K-309-3 units of the K-25 building. It was the responsibility of two fire specialists located upstairs (operating floor) to open an inspector test valve while another fire specialist took readings at the sprinkler riser on the floor below (cell floor). The movement of the fire specialists on the operating floor caused 2–3 in (5.08–7.62 cm) pieces of concrete floor decking to drop near the fire specialist taking readings at the sprinkler riser on the cell floor below, resulting in a near miss.

(b) Analysis

The direct cause of this incident was attributed to the deteriorating operating floor (concrete panels) which fell near the fire specialist located on the cell floor below. The deterioration of the floor panels was a result of water leaking through the deteriorating roof of the K-25 building and collecting on the operating floor. Since the K-25 building is in shutdown mode and the operating floor is exposed to cold weather temperatures, the panels are exposed to freeze and thaw cycles. These conditions, coupled with the fact that the roof of the K-25 building has exceeded its design life by several years and maintenance activities to extend the useful life of the roof were not approved, have led to increased degradation of the floor tiles. Tiles will continue to deteriorate unless the roof is repaired or replaced.

(c) Lessons learned

Site and building managers need to be acutely aware of the structural safety status of facilities, especially those that are in a shutdown or standby mode. Personnel conducting necessary activities in these facilities need to immediately report any unusual or changing conditions. Administrative and/or engineering controls need to be investigated to maintain personnel safety and provide compensatory action for deficient structural conditions. Additionally, adequate funding is required for effective maintenance of the structure to ensure the safety of personnel needing access to the facility [II–6].

II–7. FERMI 1 RESUMING DECOMMISSIONING AFTER A LONG PERIOD OF SAFE ENCLOSURE, ENRICO FERMI ATOMIC POWER PLANT, UNIT 1, USA

(a) Background

Fermi 1 nuclear power plant (NPP) is located in Michigan, USA, and its site boundary is completely contained within the Fermi 2 site boundary, adjacent to Lake Erie. In November 1972, the Power Reactor Development Company made the decision to decommission Fermi 1. The facility transitioned from active decommissioning to safe enclosure based on a further decision made in November 2011.

(b) 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 for another safe storage phase.

Over the long time when Fermi 1 had been idle, some staff and labour personnel left or were temporarily reassigned. 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's focus was to use available personnel to support plant outages at Fermi 2 whenever possible. This resulted in further loss of personnel for the Fermi 1 decommissioning project.

While being located on the same site as 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. staff with expertise in radiation protection, environmental issues, etc.) and preapproved programmes (e.g. safety tag outs, radiation protection procedures, etc.). Some of the drawbacks included being locked into unwanted Fermi 2 programmes (e.g. purchasing), heightened security (i.e. the added difficulty in getting material and personnel on-site) and having to always keep in mind how Fermi 1 related actions would impact on Fermi 2. Since there was no fuel on-site at Fermi 1, the heightened 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 who were 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 out.

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

(c) Lessons learned

Long periods of safe enclosure result in loss of knowledge, demotivation of personnel and a general perception of low priority [II–7, II–8].

II–8. INACTIVE WATER HEATER BURST AND SPREAD LOW LEVEL CONTAMINATION, HANFORD SITE, USA

(a) Problem encountered

On 2 September 2003, water was discovered flowing out of Building 327, across the north loading dock and onto the ground below. Personnel were vacated early in fiscal year 2003. Personnel entered the facility and found that a six-gallon (20 L) electric water heater located in a cabinet under a decontamination hood had burst and ripped the cabinet door from its hinges. Approximately 3 in (7.5 cm) of water was discovered in portions of the main floor and basement in contaminated zones, and there were several feet (a few metres) of water in the elevator pit. Water samples taken from the pool of water that had collected outside of the facility contained no alpha and 2 pCi (0.074 Bq) per ml of beta activity.

(b) Analysis

Although no one was injured in this event and the cleanup costs were relatively minor, the impact could have been much more significant under different circumstances.

Facility personnel were unaware that this water heater existed. It is not shown on the mechanical drawings. When the facility was vacated earlier that year, neither the electrical power nor the water to the water heater was isolated. Testimony from building occupants identified that water may not have been used from the water heater for at least the past five to seven years. The co-located decontamination hood's drain had been out of service for that length of time.

Initial investigations focused on a failed thermostatic controller in conjunction with a defective temperature/pressure relief valve. The relief valve was tested and found to operate properly. The controller testing was indeterminate. The controller thermostat contacts were open upon initial investigation, but the bimetallic mechanism appeared to properly open at 142 ºF (61 ºC). The thermal overload contacts were closed initially. The overload contacts opened at 180 ºF (82 ºC), but would not reset. The heater element had electrically failed (1.18 megaohms) and the sheath had visibly failed in three places.

Inspection of the tank by a qualified welding engineer identified no significant pitting or corrosion of the tank in general and no visible anomalies associated with the failed tank seam welds.

Another potential mechanism for the failure was detonation of a bubble of hydrogen gas generated by dissociation of water and/or corrosion. This is a known phenomenon and is documented in water heater owner's manuals. However, no indications of burning or charring were present, nor was there an obvious source of ignition within the water heater itself. There was indication of a water line at the level of the water inlet fitting (the lower quarter of the tank volume). That water line could indicate that a gas bubble was present at some point.

(c) Lessons learned

All facilities need to ensure that water heaters are properly drained and de-energized when no longer needed. If there is no intended use of water from a water heater tank for two weeks or more, the heater needs to be de-energized in accordance with the cautions provided in the owner's manual for the listed residential electrical water heaters. Valving out the water supply and venting need to be considered.

Facility personnel need to know what equipment is installed in their buildings to be able to properly maintain systems and equipment during normal operations and take systems out of service when vacating the building.

All facilities need to ensure that pressure relief valves on residential style water heaters are tested appropriately. Testing could be done in accordance with the manufacturer's recommendation. As a minimum, the 'test or try lever' should be lifted annually to check that the relief valve is free to operate.

If a water heater tank is found energized but no water had been used for an extended period of time (several weeks), a safety hazard needs to be assumed. The system could be de-energized and carefully vented, recognizing that any gases present may contain hydrogen [II–9].

II–9. LACK OF ADEQUATE FACILITY MAINTENANCE

(a) Problem encountered

No attention was given to maintenance at the facility during the closure period. Because of this, decommissioning was made more difficult. For example, because of a broken pipe in the laboratory and a broken window, the water (from the pipe and rainwater through the window) dissolved and transferred the ^{137}Cs to different places at different depths. Additionally, the doorframes (corners) were in bad condition, which facilitated the caesium transfer.

(b) Solution

During the initial survey, the discovery of contamination under doorframes led to comprehensive sampling at various depths. The gamma spectrometric analysis revealed potential contamination to be present under the doorframes. Excavation of the floor around and under the doorframe areas with subsequent removal of material filling up to 50 cm depth was carried out. This work caused a delay of two weeks in the schedule.

(c) Lessons learned

During facility construction and maintenance, special attention needs to be directed to areas where the accumulation of contamination can occur. Even after shutdown, during the closure period, maintenance of the facility is required [II–10].

II–10. MAINTENANCE OF DEACTIVATED FACILITIES, VARIOUS US FACILITIES

(a) Problem encountered

A Bechtel Jacobs Company subcontractor was performing surveillance and maintenance in two deactivated facilities and one partially deactivated facility. A review of ventilation system surveillances determined that system pressures had not been maintained in accordance with the range specified in the subcontractor's general operating procedures.

(b) Analysis

In the mid-1990s, three facilities were deactivated (one partially deactivated) and the source terms were removed to reduce risks. The safety basis documents for each facility were revised to address the shutdown status. Although facilities were put in an inactive/shutdown mode, the ventilation system remained operational in each. For two deactivated facilities there is no safety basis requirement for maintaining the ventilation system; however, negative pressure is being maintained as an 'as low as reasonably achievable' best management practice to prevent spread of contamination from the facilities. The Operations Safety Requirement (OSR) for the partially deactivated facility requires that the ventilation system be operating and that a negative differential pressure be maintained between the interior of the cells and the exterior of the building. The OSR does not identify a specific range for the negative pressure.

The inspection checksheets from the general operating procedures for the facilities were not updated to reflect the deactivated status at each of the facilities. The checksheets reflect the ventilation system/operating parameters that were applied when the facility was operational.

In late 1999, some readings were identified that were out of the specified operating range; however, radiological control surveys continued to indicate no radiological issues with the building.

In January 2000, the current contractor subcontracted the surveillance and maintenance scope and maintenance personnel were transitioned to the subcontractor organization. The operating parameters previously specified on the checksheets continued to be used by the subcontractor. The out-of-range gauge readings continued to be identified on the checksheets. In March 2001, differential pressures indicated a worsening condition of the filters. This was reported in the subcontractor's weekly report. However, no documentation for corrective action, such as a maintenance job request or non-conformance report, was prepared.

The subcontractor considered the problems with meeting the checksheet operating parameters a legacy condition, since the problems began before the subcontract was in place. The non-conformance report procedure excluded legacy conditions and the subcontractor did not address the worsening condition. Therefore, no documented corrective action was taken to correct the worsening ventilation problems being experienced.

(c) Lessons learned

Procedures that provide guidance for addressing non-conforming conditions do not exclude legacy conditions [II–11].

II–11. PLUTONIUM EXPOSURE INCIDENT, IDAHO SITE, USA

(a) Problem encountered

Sixteen workers were exposed to plutonium in an incident at the US DOE's Idaho National Laboratory (INL) on 8 November 2011. The workers — all employed by Battelle Energy Alliance (BEA) — were conducting work inside the decommissioned Zero Power Physics Reactor (ZPPR) when a container was opened for normal scheduled work, resulting in their exposure to plutonium. While unpacking a fuel plate that had been in storage since 1981, they detected corrosion on the fuel cladding and evacuated the room where they were working. Six workers tested positive for contamination based on external surveying and were decontaminated. All 16 employees underwent full body scans to determine internal exposure. Two employees were confirmed to have been contaminated internally with radioactive material, likely plutonium, and took a chelating agent meant to flush much of the radioactive material from their bloodstream. No radioactive material or radiation escaped the facility as no contamination was found outside of the ZPPR facility. The ZPPR was a low power reactor used to test mock-up cores for experimental purposes. It was shut down in 1992. The facility is currently used for storing nuclear material, such as spent nuclear fuel.

(b) Analysis

In January 2012, the US DOE's Office of Health, Safety and Security released its final report on the incident. The report cited critical deficiencies in the safety basis of the facility, repeated instances of disregard from senior management and contractor transition issues, which ultimately led to worker exposure. The report found that the incident was preventable. Two of the employees have not returned to work since the incident. While time-incremented bioassays will provide a clearer picture of these workers' prognosis, it is suspected that both sustained an exposure of over 50 rem (0.5 Sv). The DOE report noted: "when faced with site-wide aging facilities and a limited amount of renovation capital and risk analysis funding, senior management triaged this issue and focused attention, and funding, on facilities still in operation" [II–12].

Interestingly, the report also mentions problems associated with site contractor transitions. DOE facilities like INL are bid to private contractors to manage. BEA, the site's current contractor, took over operations in 2005 from Bechtel. The report found that a significant loss of knowledge and previous practices occur during these transitions. Records of damaged fuel packages were meticulously recorded by the site's previous contractor; however, BEA employees did not utilize these records.

It was also noted that "this incident is exactly what happens when you store hazardous materials in a non-storage setting (where storage is not the focus) for 30 years and have several management changes in-between" [II–12].

(c) Lessons learned

As long as work continues in some areas of shutdown facilities, hazards are present and the safety of activities needs to be carefully assessed and monitored in all areas [II–12].

II–12. RADIOLOGICAL CHARACTERIZATION OF NON-OPERATIONAL FACILITIES, BROOKHAVEN NATIONAL LABORATORY, USA

(a) Problem encountered

The High Flux Beam Reactor (HFBR) has been in shutdown mode since 1998. Since being defuelled in 1999 very little work has been done at the facility and, consequently, it entered into a long term surveillance and monitoring mode awaiting a decision on further remediation. Most active radiological instrumentation that was required when the facility was operating was removed, and radiological support was reduced to that required for routine surveillance activities only.

In late November 2004, the Environmental Management Program decided that further characterization of HFBR systems was necessary in order to support future decisions on facility remediation. Support staff was minimally augmented to support work activities. However, the plans did not include bringing into the facility automated smear counters and liquid scintillation counters to facilitate in-house processing of field samples.

(b) Analysis

During the first portion of the characterization project it was determined that system surveys were requiring an inordinately long period of time to document, and this was jeopardizing the project schedule. Upon further analysis, Radiological Controls Division (RCD) management learned that radiological control technicians (RCTs) were leaving the HFBR to have their smears counted on automated smear counters and liquid scintillation counters in other facilities. This was inefficient for two reasons:

(1) Extra time was required to leave the HFBR, obtain a vehicle and locate available counting instrumentation at other facilities;
(2) HFBR samples were considered low priority at other facilities and were often not being counted for days, further retarding the process of survey completion.

The increase in smear samples over the baseline had not been accurately estimated during the project-planning phase of the work. Consequently, a dedicated RCT had not been requested for this purpose.

(c) Lessons learned

RCD management consulted with the project manager for the HFBR and advised them to purchase quarterly contracts for an automated smear counter, liquid scintillation counter and portal monitor. RCD management also advised the HFBR project manager to further augment RCT staffing. The HFBR project manager concurred with both recommendations.

The rate of completing system surveys accelerated after installing dedicated instrumentation allowing the project to meet its original deadline. It is estimated that the expenditure of US $9500 on additional dedicated instrumentation, equivalent to about 150 hours of RCT support, saved the project two to three times as much in lost RCT productivity.

Overall system characterization efficiency can be dramatically improved at permanently shutdown radiological facilities by:

(1) Importing dedicated analytical-grade field instrumentation such as automated smear counters and liquid scintillation counters;
(2) Analysing the impact of new work on the routine surveillance plan and using this information as part of the basis for adequately augmenting support staff [II–13].

II–13. REMOVAL OF STEAM GENERATORS, LATINA MAGNOX REACTOR SITE, ITALY

(a) Problem encountered

The Latina steam generators were installed, at the beginning of the 1960s, using a huge crane called GOLIA. After the installation, the crane was moved to a corner of the site where it remained unused for more than 20 years. When the local amenity near to the plant started to develop, there was pressure on the electric company to remove the crane, which was visible over a long distance on the landscape. The crane was subsequently removed from the site.

(b) Analysis

At that time the utility did not consider the possible future need for the crane for the eventual operation of dismantling of the steam generators, and agreed to removal of the crane and the rails. Since the beginning of 2000, the Italian decommissioning company has been facing the problem of dismantling the steam generators and cutting them into pieces acceptable to a melting company for recycling. The problem was shown to be more complicated than expected. Great difficulty was caused by the intended use of a modern new crane, being the only type available today. These modern cranes would be able to take a cylindrical sector of the steam generators and then transport it across the site to a suitable cutting facility. The route would pass over redundant embedded condenser cooling water discharge ducts and some effluent piping. The structural strength of the piping and ducts, however, was not sufficient to bear the weight of the crane. The decommissioning company then had to submit a project to remove the large piping and route the liquid effluents a different way. This project, for many reasons, encountered many difficulties with the safety authority.

(c) Lessons learned

Future dismantling needs have to be taken into account in the initial designs and recorded in the decommissioning plan. Only then will the required equipment on-site be considered for retention during the decommissioning phase [II–14].

II–14. SEALED BASEMENT DISCOVERED FLOODED, IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY, USA

(a) Problem encountered

The building now identified as Security Training Facility (STF) 601 was designed in the early 1960s to support the Experimental Organic Cooled Reactor. The three-story building contained a main floor area, a basement and a sub-basement. The building was 90% complete when the work was halted in 1962. The facility was maintained in standby condition until 1966, when it was declared excess. The building was used sporadically throughout the following years to support a variety of programmes and operations. In the early 1980s, asbestos abatement activities were conducted in the main floor area. Abatement activities were not conducted in the basement and sub-basement. Instead, in 1984, the entry doors to those areas were welded shut. The basement is also accessible through hatch covers in the floor of the high bay area; however, because the hatch covers are too heavy to be opened by hand (a crane or similar equipment would be necessary), they were not sealed or locked. Although minimal preventive maintenance activities and safety inspections were conducted on the main floor areas, no one entered the basement or sub-basement between 1984 and 1997. In the fiscal year 1997, the building was scheduled for decontamination and decommissioning. On 19 November 1997, personnel broke the welded seals on the doors to gain access to the basement and sub-basement. The sub-basement and basement were discovered to be flooded with an estimated 200 000 gallons (800 m^3) of water.

(b) Analysis

The water in the basement is believed to have come from snowmelt and rainwater draining into the basement over the previous 13 years. Known leaks in the roof, especially in the high bay area, provided access for snowmelt and rainwater. The water may have seeped through the concrete hatch covers in the floor of the high bay into the basement and sub-basement. No equipment or materials were stored in the basement; therefore, no personal or material property damage was sustained. However, the water may have been contaminated with asbestos. There was no indication in the records of the presence of other hazardous contaminants. Testing and analysis were required to determine whether the water should be considered a hazardous waste/material.

(c) Lessons learned

All facility areas should be inspected annually, especially those areas that are sealed or locked. Facility managers need to ensure that inspectors have access to all facility areas, especially those that are not routinely maintained or accessible. Documentation should be kept on all facility areas, again, especially those areas that are sealed or locked [II–15].

II–15. SHUTDOWN FACILITY BASELINE INVENTORY PRACTICES, OAK RIDGE, USA

(a) Problem encountered

During routine inventory activities, additional material was discovered in the K-25 building at the East Tennessee Technology Park. The documented safety analysis (DSA) identifies the total quantity of the material. The hazard analysis analysed only one specific form of the material identified. The additional material was of a form that was not fully analysed. The K-25 building was shut down in 1964. Since that time, the facility has become a warehouse for discontinued DOE operations. A baseline facility inventory conducted in 2000 to support DSA development was less than adequate. The size of the facility, with numerous types of containers and materials from many programmes and sites, combined with the lack of facility familiarity and the infrequent performance of a detailed inventory lead to misidentification of the drums associated with the occurrence.

(b) Analysis

Large facilities that have been shutdown for long periods of time are often used to house material from discontinued programmes. Typically during programme management, end of project storage concerns are not adequately defined. If a programme ends due to lack of funding, rigour of inventory and labelling may not be adequate to allow for proper data interpretation by personnel not directly associated with the project.

(c) Lessons learned

It is necessary to properly plan for material/equipment disposal during the life of the programme. Identify disposition paths for the material as part of the procurement/planning process. If the material has a future use, keep the material as part of the facility inventory. Shipping material from site to site is not recommended. If the material has no disposal path and needs to be relocated, develop and maintain a good inventory system to adequately track quantities, inspect containers and retain records.

Prior to update or revision of the facility safety basis, assure adequacy, comprehensiveness and accuracy of facility inventory documentation. Assure conduct of additional inventory determinations as deemed necessary.

Prior to accepting a facility into a decontamination or decommissioning programme, project/facility managers should insist on a formal facility turnover. The turnover needs to be accomplished in accordance with current DOE orders and include development of a deactivation/transition plan to formally capture facility inventories.

Personnel with enough corporate knowledge to properly identify equipment and material need to perform baseline facility inventories [II–16].

II–16. TRANSFER OF OWNERSHIP AS A CAUSE OF DELAYED DECOMMISSIONING, UK HOSPITAL

(a) Problem encountered

In the early 1990s, a UK hospital vacated and sold off one of its buildings, transferring work with radioactive materials to another building on the same site. When that work ceased ten years later and a request was made to the regulatory body to cancel the site authorization, the hospital was required to prove that the building it had sold ten years earlier to a new owner was also free from radioactive contamination.

(b) Solution and analysis

Sites such as hospitals and universities often contain multiple buildings covered by a single site authorization/licence. The above example relates to one such building being sold off while the authorization was retained for the other buildings on the site. Perhaps a more common scenario is one where radioactivity ceases to be used in a building, but the building is retained by the organization. No records existed to show that the building had been decommissioned at the time when it was sold to the new owner.

(c) Lessons learned

It would have been far more practical to take the building through a formal decommissioning process in the 1990s when the radiation work ceased, rather than leave it for years until the site needed to be cleared. Decommissioning at the earliest opportunity needs to be a priority, if possible, as local knowledge and expertise will be available, as well as suitable on-site monitoring equipment. Even if only short half-life radionuclides have been in use, plans for decommissioning should be immediately considered. It may be that the preferred strategy is to allow residual radioactivity to decay in situ prior to proceeding further with decommissioning; but in this case, it is then a conscious decision and forms part of the decommissioning strategy [II–17].

II–17. UNKNOWN MATERIAL ENCOUNTERED DURING DECOMMISSIONING

(a) Problem encountered

During the assessment and subsequent characterization of a redundant fuel development laboratory, the source material was assumed to be uranium oxide and type S material. Early during decommissioning, glass bottles of uranium carbide were discovered. None of the persons involved in the decommissioning project, as well as no one in the decommissioning department, had knowledge of or experience with the material. Uranium carbide is a pyrophoric compound that could oxidize and burn when exposed to air. The decommissioning plan did not provide for the handling or disposal of pyrophoric materials. Uranium carbide in powder form needs to be handled in an inert atmosphere.

(b) Solution and analysis

Deferral of decommissioning after operations in the laboratory, as well as inadequate characterization, were the causes of the problem. If decommissioning had been performed soon after the closure of the laboratory, individuals with direct knowledge and experience in the handling of the specific material would have been involved. This specific cause relates to insufficient early decommissioning planning that would have provided appropriate arrangements and record keeping in support of deferred decommissioning. Adequate characterization could have ensured the identification of the specific uranium compound and ensured planning and arrangements that would have prevented the problem.

(c) Lessons learned

When dealing with R&D and smaller facilities, do not defer decommissioning. If deferral cannot be prevented, ensure that source material is removed and that appropriate decommissioning plans are available. Special attention should be given to the presence of unknown materials and compounds during the characterization of abandoned facilities [II–18].

II–18. VENT PIPE FALLS THROUGH A THROUGH-HOLE IN THE CEILING AND CAUSES A NEAR MISS, NEVADA SITE, USA

(a) Problem encountered

Prior to the incident and as part of a strip-out project, a site maintenance crew was stripping out the second floor, including interior walls, for beryllium remediation. At about 8:30 a.m. on the morning of the incident, the crew removed the wall panels between rooms 4113 and 4120, exposing a free-standing, unsupported vent pipe, which was not to be removed as part of this remediation activity.

Later the same day at approximately 11:50 a.m., a galvanized 1.5 in (3.8 cm, inside diameter), Schedule 40 pipe fell, with the force of gravity, from the second floor to the first floor of Building A-1, Room 4525. The pipe stopped about 43.5 in (110 cm) above the first floor and within about 18 in (46 cm) of striking an employee seated at his workstation. The pipe had fallen through its 'through-hole' penetration in the floor/ceiling (7.5 in, 19 cm precast concrete). The pipe came to a stop when a portion of the pipe having a 45 degree bend came to rest on the edge of the through-hole on the second floor.

The employee immediately notified the strip-out crew of the incident and the crew secured the area as well as all other second-to-first-floor penetrations. Additionally, they verified that all remaining penetrations had their first floor supports in place and verified the non-existence of other voids and utility dead ends at the second-to-first floor. Finally, the strip-out crew secured the scene so an investigation could commence immediately.

(b) Analysis

The past facility modifications to this legacy facility constructed in 1975, including the abandon in place action for this vent pipe, were not documented on any of the drawings available at the time of the remediation. After the incident, it was verbally confirmed that approximately 20 years previously (in 1984–1985) a sink and a section of its vent pipe, between the first and second floor, were removed from service. The second-floor section of the vent pipe was not removed but, instead, abandoned in place. The remaining section of pipe ran down from the Building A-1 roof, through the inside of an interior wall (hidden from view), and partially through the second floor through-hole. The current first floor occupants had been in the room where the pipe fell since approximately 1996, and had indicated that they had observed the approximately 3 × 4 in (7.5 × 10 cm) hole in the ceiling but could never see anything inside the hole and, therefore, perceived no threat from its presence.

Due to a previous incident and numerous safety concerns discovered during the remediation process, job safety briefings were given frequently, normally between two and three times daily. If a new hazard was discovered, the crew would stop working in that area until supervision could provide a resolution to the issue. Additionally, two people were assigned to the project to assist the workers with identifying the hazards of the building. One was from the safety area and one from industrial hygiene. Orientation was also provided to the workers by these two people on identified safety concerns, such as electrical issues, to assist them to recognize and to mitigate hazards as they were discovered during the project. However, when the workers removed the interior wall from the second floor of the building, they believed that this pipe was fully functional, supported and not 'abandoned in place' since other walls that contained hidden pipes were removed over the course of this project with no incident.

Although the remediation project focused on worker safety and occupant safety, it did not adequately provide for the safety of occupants on the first floor of the building in this event. On one hand, an inspection of the first floor was conducted to ensure asbestos exposure and other related work controls were put in place; but on the other hand, it was expected that because of the cast concrete construction of the second floor, the second-floor demolition portion of the remediation activity would not in any way impact the first-floor occupants.

(c) Lessons learned

Working in legacy buildings may require additional attention to hazards not readily recognizable by today's standards. Building codes and construction standards have greatly improved over the last 25–30 years. Maintenance actions and demolition work in these older facilities may require additional scrutiny that is far beyond normal expectations by work planners and craft personnel prior to the start of work. A maintenance crew was working on such a facility when a near miss occurred. A subsequent critique and root cause analysis determined that all existing precautions for worker safety were employed. However, a modification occurring 20 years ago to a first-floor room, involving a vent pipe that ran from the roof through the second floor to a first-floor drain, caused a near miss when the vent pipe fell through the second floor/first floor ceiling into an occupied area. An expanded hazard analysis to include lessons learned and previously discovered hazards of the existing project will be used to identify and mitigate potential hazards to workers and occupants of the building for this and future projects involving older buildings [II–18].

II–19. WATER DISCOVERED INSIDE AUXILIARY PROCESS LINE, OAK RIDGE, USA

(a) Problem encountered

During equipment encasement project activities, water was detected inside an exhaust line. A cutting operation was ongoing at the time of discovery. The equipment encasement project was removing and encasing selected equipment for long term storage. The potential for encountering water was recognized and analysed in the nuclear criticality safety evaluation. Workers placed a geometrically safe catch pan below the cut. No workers were contaminated or injured.

(b) Analysis

After the K-25 process was shut down in 1964, spare parts (piping, valves, fittings, etc.) were routinely cannibalized from the system. There were no effective controls in place that required resealing of the process system at the time of equipment removal. After shutdown of the remaining cascade in 1985, the controls for the facility were improved to reflect the change in facility use. With the change in controls (physical security and configuration control), a project was instituted to seal system breaches in 1989/1990. During the 25 years the auxiliary process line was potentially open, water accumulated in the sealed exhaust line. When the system was sealed, the accumulated water was trapped. The procedure for sealing the system did not require purging accumulations of water prior to sealing.

(c) Lessons learned

Systems and facilities that have been shut down and/or cannibalized may present hazards different from those that were present when the facility was operational. The longer a system or facility has been inactive, the more likely that the degradation will compromise the structure and systems. Consideration and evaluation of previously unlikely events may be justified [II–19].

II–20. MISCELLANEOUS EXPERIENCES, DODEWAARD NPP, THE NETHERLANDS

(a) Nuclear law and regulatory approach

(i) Problem encountered

After the decision was taken to shut down the Dodewaard NPP, it was impossible to start decommissioning activities immediately as Dutch nuclear law did not have any rules and regulations on decommissioning. The regulatory body was surprised that GKN decided to place the plant in safe enclosure as they expected that there would be no lack of funding for immediate dismantling.

(ii) Solution

The nuclear law was changed. A future NPP in the Netherlands will have to start full dismantling soon after final shutdown. A safe enclosure period will no longer be licensed. In practice, this will mean that after a short period of defuelling, active dismantling, work will start. In the Netherlands, nuclear plants are legally required to have enough money set aside in order to start active decommissioning immediately after final shutdown. For Dodewaard NPP an exception was made as there was no possibility of it collecting any more money; the plant was in safe enclosure already.

(iii) Lessons learned

A country needs to have rules and regulations in place for decommissioning, as a nuclear facility might be forced into shutdown and decommissioning at short notice.

(b) Insurance costs

(i) Problem encountered

The insurance premium was not lowered by the insurance company owing to the official plant status being defined as ‘in operation’, while the plant had actually been in safe enclosure for five years already.

(ii) Solution

Discuss the issue with the national safeguards regulatory body, and request the IAEA to reduce the status of the plant from operational to decommissioning as soon as possible after spent fuel is removed from site.

(i) Lessons learned

Early discussions with all parties involved could have led to a better understanding of the actual plant status. This could have led to an early status change and therefore a reduction of premiums shortly after the spent fuel removal.

(c) Cost studies

(i) Problem encountered

The first decommissioning cost study for Dodewaard NPP was not performed by engineers from the station but was made as a desk study by financial specialists from the head company assisted by an external company specializing in decommissioning cost calculations. Many issues to be dealt with during safe enclosure were, however, not considered. During PSE, this concern led to lengthy discussions between the engineering team and the financial specialists. After one year of safe enclosure it became clear that the costs for managing the safe enclosure had been underestimated by a factor of two.

(ii) Solution

After five years of safe enclosure, new cost calculations for final dismantling were executed. In this study the updated costs were included.

(iii) Lessons learned

When estimating decommissioning costs, competent people with experience in the field need to be consulted in order to obtain accurate figures. Simply relying on desk studies can easily lead to underestimating of certain costs.

II–21. HEAVY WATER COMPONENTS TEST REACTOR CLOSURE CAP — CONCRETE CURING LESSONS LEARNED FOR DESIGN ENGINEERING, SAVANNAH RIVER NUCLEAR SOLUTIONS[1], USA

(a) Problem encountered

On Monday 20 June 2011, surface cracks were discovered on the freshly poured concrete cap that had been placed over the footprint of the Heavy Water Components Test Reactor (HWCTR) facility located in B-Area at the Savannah River Site. The HWCTR facility had undergone decommissioning with the removal of the major components including the reactor vessel and steam generators, the grouting of all below grade spaces, and the demolition of all above grade structures. The placement of the concrete cap was the final activity of the decommissioning effort.

The concrete cap was poured the previous Thursday, 16 June 2011, and allowed to cure over the weekend. Weather conditions during the pour were clear with the average ambient temperature ranging from 68 to 72 °F (20–22 °C). Immediately following the pour, the ambient temperature exceeded 90 °F (32.2 °C) and the weather remained very hot throughout the weekend. No measures were taken to minimize the evaporation rate during the initial curing period. For the final curing, a compound was applied immediately following the final finishing on Thursday. A curing compound conforming to ASTM C309 was specified on the engineering drawing and was installed upon completion of the concrete finishing. ACI 308, Standard Specification for Curing Concrete, was invoked by drawing notes and identified measures to be taken when curing concrete in hot weather. However, no precautions were taken by the subcontractor to keep the concrete wet for the initial curing period.

The forms were removed the following Monday and cracks were observed in the cap. Project management and area completion project management staff were notified of the condition. Design engineering staff members were notified and requested to provide assistance in determining the cause of the cracking and to provide an opinion on the acceptability of the as-built condition.

(b) Analysis

Design engineering staff reviewed the engineering documents, inspected the concrete cap, made a judgement as to the cause of the cracking and provided a recommendation to accept the condition with additional periodic surveillance of the cracks. Possible causes of the cracks were as follows:

- Improper initial curing of the concrete due to the hot weather experienced during the day of the pour and the subsequent days.
- The placement of the concrete in one continuous pour in lieu of two pours in order to meet schedule commitments. The engineering drawing required construction joints to be placed between the nine concrete segments. For the construction joints to be effective, the concrete needs to be allowed to harden before the adjacent segment is poured. A second pour would have allowed individual segments to shrink before the adjacent placement was made, thus minimizing plastic shrinkage that would cause cracking.
- Differential settling may have occurred between the HWCTR footprint and the surrounding native soil where the foundation had been placed.

Additional review of the engineering documents revealed the following:

- The modification traveller that identifies the functional requirements for the design specifies that the design minimizes any potential cracking of the concrete.

[1] Although this case history pertains to an entombment project (out of the scope of this publication), the experience is applicable to safe enclosure projects as well.

— The design drawing had the following deficiencies:

- The intent of the design was to make two pours in a chequerboard pattern to establish construction joints. This was identified on the drawing as ‘CJ’ in the plan view, the industry standard abbreviation for ‘construction joint’. Definition of CJ on the design drawing would have clarified the need for two separate pours.
- Note 14 on the drawing did not specifically mention hot weather curing requirements, which led the subcontractor to believe that water curing was not necessary and that the curing compound was all that was required for curing. Addition of water during the final cure may have reduced or eliminated the cracking.
- The drawing did not require any preparation or compaction testing of the native soil. No requirement was stated to test the soil ground pressure prior to installing the foundation.
- Differential settling has been identified as a possible cause of the cracking.
- A review of the field implementation identified a deficiency in curing the concrete pad by the subcontractor. The provisions for initial curing in hot weather per ACI 308 were not adhered to.
- Oversight of the subcontractor is the responsibility of the subcontract technical representative, who ensures that the subcontract scope is executed and completed as specified in the design documents. The subcontract technical representative is required to have a comprehensive understanding of the statement of work and/or consult with subject matter experts in order to confirm that the subcontractor is performing the work in accordance with the provisions of the engineering documents. The curing process, as stated in Note 14 of the drawing, led the subcontract technical representative and the subcontractor to believe that any additional curing was not required. Subject matter experts were not consulted to clarify the intent of the note.
- Communications between the various performing entities, including design engineering, deactivation and decommissioning engineering, project management and the subcontract technical representative, were unclear as to technical direction to the subcontractor regarding the concrete curing requirements. Schedule pressure based on the subcontractor’s commitment to perform during a specified time period took advantage of workarounds to save schedule time without fully understanding the impact of the decisions. This directly influenced the decision to make the final pour in only one pour in lieu of two pours.

(c) Analysis. Immediate actions taken:

— Notified area completion project management staff;
— Requested design engineering to evaluate the cracks and provide a recommendation;
— Initiated water flow on the concrete pad in an attempt to anneal the cracks.

(d) Description of apparent cause.

The most likely causes of the concrete cracking were:

— Improper initial curing of the concrete during a period of very hot weather;
— Pouring the concrete in one pour in lieu of two pours;
— Using a curing compound in lieu of a multiday wet cure for the final cure.

(e) Actions. Corrective actions implemented to correct the situation and prevent recurrence:

— Periodic surveillance of the HWCTR concrete has been initiated to monitor the cracks and identify any change in the condition of the pad;
— Design engineers/personnel review the operating experience report and the recommendations below for design engineering applicability;
— Recommend that key requirements pertaining to concrete curing be stated clearly in future engineering documents in lieu of relying on the subcontract technical representative or subcontractor to interpret a referenced standard;
— Update the concrete curing general notes for future concrete designs and drawings to adhere to the requirements of the latest revision of ACI 308. Specifically, identify the concrete elements that are to be cured and identify the method and duration required to cure those elements.

(f) Lessons learned

Engineering ensures that design documents are sufficiently detailed such that construction of the design does not deviate from the requirements of the design or national standards. Thorough communications between the design agency and the implementing organization are necessary to ensure the construction is in accordance with the design [II–20, II–21].

References to Annex II

[II–1] US DEPARTMENT OF ENERGY, ORPS Rep. EM-ID-CWI-BIC-2009-0001, CPP-621, Water Leak from Freeze Damage, CWI-ICP-2009-004, US DOE, Washington, DC (2009) (available per authorized access to DOE database).

[II–2] US DEPARTMENT OF ENERGY, 2006-RL-HNF-0050, US DOE, Washington, DC (2006) (available per authorized access to DOE database).

[II–3] US DEPARTMENT OF ENERGY, 2005-RL-HNF-0030, US DOE, Washington, DC (2005) (available per authorized access to DOE database).

[II–4] US DEPARTMENT OF ENERGY, 2010-ORNL-SEC-0001, US DOE, Washington, DC (2010) (available per authorized access to DOE database).

[II–5] INTERNATIONAL ATOMIC ENERGY AGENCY, Planning, Managing and Organizing the Decommissioning of Nuclear Facilities: Lessons Learned, IAEA-TECDOC-1394, IAEA, Vienna (2004).

[II–6] US DEPARTMENT OF ENERGY, Occurrence Report ORO-LMES-K25ENVRES-1997-0005, Y-1997-OR-LMESETTP-1201, US DOE, Washington, DC (1997) (available per authorized access to DOE database).

[II–7] US NUCLEAR REGULATORY COMMISSION, Fermi, Unit 1, US NRC, Washington, DC (2017), http://www.nrc.gov/info-finder/decommissioning/power-reactor/enrico-fermi-atomic-power-plant-unit-1.html.

[II–8] SWINDLE, D.R., "Scheduling Hurdles at Fermi 1 and Successes to Date" (Int. Conf. on Nuclear and Hazardous Waste Management, Reno, NV, 4–8 August 2002), American Nuclear Society (2002) CD-ROM.

[II–9] US DEPARTMENT OF ENERGY, 2003-RL-HNF-0040, Occurrence Report RL-PHMC-327FAC-2003-0001, US DOE, Washington, DC (2003) (available per authorized access to DOE database).

[II–10] INTERNATIONAL ATOMIC ENERGY AGENCY, "Lessons Learned from the Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities" (Proc. Int. Conf., Athens, 11–15 December 2006), IAEA, Vienna (2007).

[II–11] US DEPARTMENT OF ENERGY, Y-2002-OR-BJCX10-1202, US DOE, Washington, DC (2002) (available per authorized access to DOE database).

[II–12] US DEPARTMENT OF ENERGY, Accident Investigation Report — Plutonium Contamination in the Zero Power Physics Reactor Facility at the Idaho National Laboratory, November 8, 2011, US DOE, Washington, DC (2012), https://energy.gov/sites/prod/files/2014/04/f14/INL_AI_Report_11-08-2011.pdf

[II–13] US DEPARTMENT OF ENERGY, 2005-CH-BNL-RCD-001, US DOE, Washington, DC (2005) (available per authorized access to DOE database).

[II–14] INTERNATIONAL ATOMIC ENERGY AGENCY, Design Lessons Drawn from the Decommissioning of Nuclear Facilities, IAEA-TECDOC-1657, IAEA, Vienna (2011).

[II–15] US DEPARTMENT OF ENERGY, L-1998-INEEL-97410, US DOE, Washington, DC (1998) (available per authorized access to DOE database).

[II–16] US DEPARTMENT OF ENERGY, B-2005-OR-BJCK25/K27-0301, Occurrence Reports ORO-BJC-K25GENLAN-2004-0013 and ORO-BJC-K25GENLAN-2004-0018, US DOE, Washington, DC (2004) (available per authorized access to DOE database).

[II–17] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Small Medical, Industrial and Research Facilities: A Simplified Stepwise Approach, Nuclear Energy Series No. NW-T-2.3, IAEA, Vienna (2011).

[II–18] US DEPARTMENT OF ENERGY, USER-3 2005-NV-NLVBN-057, US DOE, Washington, DC (2005) (available per authorized access to DOE database).

[II–19] US DEPARTMENT OF ENERGY, L-2001-OR-BJCETTP-0201, Occurrence Report ORO-BJC-K25GENLAN-2000-0010, US DOE, Washington, DC (2000) (available per authorized access to DOE database).

[II–20] OAK RIDGE NATIONAL LABORATORY, Primer on Durability of Nuclear Power Plant Reinforced Concrete Structures — A Review of Pertinent Factors, NUREG/CR-6927, ORNL/TM-2006/529, Oak Ridge Natl Lab., Washington, DC (2007).

[II–21] US DEPARTMENT OF ENERGY, 2011-SR-SRNS-0016, US DOE, Washington, DC (2011) (available per authorized access to DOE database).

Annex III

INTERNATIONAL WORKSHOP ON LESSONS LEARNED FROM PLANNING AND IMPLEMENTATION OF THE DEFERRED DISMANTLING STRATEGY FOR DECOMMISSIONING

23–26 June 2014
St Ermin's Hotel, 2 Caxton Street, London SW1H 0QW, United Kingdom

Meeting outcomes

The last major international review of the decommissioning strategy of deferred dismantling was documented in Safe Enclosure of Nuclear Facilities during Deferred Dismantling, IAEA Safety Reports Series No. 26 (2002). This was based on the limited decommissioning experience of some 15 years ago. Globally, much has happened since that time and this international workshop set about a review of recent developments.

In general, the main driver for decommissioning of nuclear facilities is to reduce the radiological hazard and the associated risk to people and the environment, which these facilities represent. A significant reduction in the hazard is achieved by the removal of the spent fuel from the reactor and its placement in a secure storage facility; however, the remaining activated and contaminated components continue to represent an important risk, for which protective measures need to be maintained.

Deferred dismantling represents an interim end state, with the final end state generally being achieved a number of decades later, following a period in which entry to the facility is severely restricted and controlled, and the facility is subject to ongoing monitoring and maintenance. Experience suggests that the main technical reasons for selecting a deferred dismantling strategy are as follows:

— The lack of waste disposal routes would result in the plant being to some extent modified and used as temporary storage facilities awaiting a later decision on conditioning and packaging needs for final disposal;
— The ability to use hands on (as opposed to remotely operated) technologies for final dismantling work, due to reduced workforce doses following the decay of short lived radionuclides.

An overarching consideration for many programmes is the need to allow additional time to collect adequate funds to proceed with final dismantling and demolition or to optimize the use of available funding, particularly in cases where the costs are covered directly from State budgets.

In the past, the potential for decay of short lived radionuclides was often considered to be an important benefit of deferred dismantling, but improvements in the technologies required for undertaking full system decontamination (of the primary circuit) after shutdown mean that dose levels in the facility may be significantly reduced even without the benefit of radioactive decay, particularly in the case of PWRs. For the specific case of facilities containing long lived contamination, as in many research and fuel cycle facilities, there is no benefit to be gained in terms of reduced dose from a deferred dismantling strategy.

There are various interpretations of deferred dismantling, ranging from a plant state, which is passively safe, (i.e. no active systems are required to maintain safety), to a range of situations for which active maintenance is needed. Achieving a passively safe state generally entails the removal of:

— Plant equipment from all areas except the area adjacent to the reactor;
— All waste and loose material, including asbestos and other hazardous materials;
— The original electrical, water, heating, ventilation and fire suppression systems, and installation of minimal essential security systems to control entry, with plant ventilation being based on natural convection.

Regardless of whether an active or passive option is followed, a period of safe enclosure is envisaged during which access to the facility is significantly restricted in comparison to the period after shutdown; for the passive option, no access is expected except for inspections/measurements taken at intervals that can be separated by periods of five years or even longer.

Key learning points from the workshop were concerned with the following issues:

— Passive deferred dismantling achieves the reduction of radiological hazards and associated risks due to the facility being placed in a state that is passively safe. In the case of active deferred dismantling, an equivalent reduction in hazard is achieved only during the final phase of dismantling; this option has therefore been time limited (by the onset of deterioration of systems, components or structures) to a greater extent than the passive option, which is limited only by the stability of the main structures. For both situations, it is important that a periodic review of safety is undertaken and presented to the regulatory authorities.
— The lack of a generally accepted disposal route for irradiated graphite waste is a significant constraint to proceeding with the decommissioning of reactors where graphite was used as a reflector or moderator. More international attention should be brought to this challenge and a future workshop focusing on waste management solutions that could be implemented over a short or medium time frame would be a good means to share experience.
— Achieving consensus both on interim and final end states presents a challenge for most programmes. In some countries, the required end states are established by government policy; but, more generally, these are proposed by the operator and need to be agreed with stakeholders and with regulators. Sharing of experience through a future international workshop would provide a good means to elaborate upon this important aspect of decommissioning.
— An argument often used against the selection of deferred dismantling is that direct knowledge of the plant operating history is unlikely to still be available during final dismantling and there may then also be a lack of persons with appropriate knowledge. Also, even if records are still available, they may not be trusted and a future decommissioning operator may feel obliged to recharacterize the plant. This argument is less relevant for passive deferrals, as the relevant contamination situations are likely to already have been addressed and therefore direct knowledge of plant operations is no longer required (little knowledge transfer is needed for empty spaces). The importance of documenting, adequately, operational experience relevant to decommissioning was emphasized, as was the need to undertake, in advance of shutdown, a systematic evaluation of systems that may be needed during the safe store period to inform decisions about which systems could remain following shutdown.
— There is little data to support a comparison of costs and other criteria for deferred versus immediate dismantling; similarly, there is a lack of information on life cycle costs providing comparative cost data for the passive versus active options of deferred dismantling. The levels of uncertainty in costs associated with long deferral periods may be significantly higher, as anticipated end states may prove more difficult to achieve (e.g. due to changes in government policy or regulatory standards). This important dimension of strategy selection is another topic that could be elaborated upon through international cooperation.
— The development of strategies for decommissioning requires intensive interaction with a range of stakeholders, which may include government, regulators, the facility workforce and the interested public. Good communication strategies, recognizing that different decommissioning strategies will be optimal in different situations, and will be helpful in achieving a commonality of purpose between different stakeholders.

The international workshop provided participants with a good opportunity for exchange of knowledge and experience on the deferred dismantling strategy for decommissioning. It featured presentations from 13 countries that covered policy, regulatory, planning and implementation aspects of decommissioning. The Magnox decommissioning programme is well under way and served as an excellent platform to demonstrate deferred dismantling. The opportunity to learn first-hand about the evolution of the Magnox decommissioning programme — from a collection of sites operating somewhat independently of one another to a company-wide and programmatic approach — was of great value for participants. The visits to Bradwell and Berkeley were most informative; contrasting a site being made ready for SAFSTOR (Bradwell) with a reactor that has already entered SAFSTOR (Berkeley). This made tangible what was presented and discussed during the proceedings. The conference facilities and logistical arrangements for the international workshop provided by the UK hosts were excellent. The Magnox team and their UK partners are to be congratulated for being such generous and gracious hosts.

GLOSSARY

Unless otherwise noted, definitions are extracted from the IAEA Safety Glossary[1].

accident. Any unintended event, including operating errors, equipment failures and other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

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.

ageing management. Engineering, operations and maintenance actions to control within acceptable limits the ageing degradation of structures, systems and components.

barrier. A physical obstruction that prevents or inhibits the movement of people, radionuclides or some other phenomenon (e.g. fire), or provides shielding against radiation.

contamination. Radioactive substances on surfaces, or within solids, liquids or gases (including the human body), 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.

immediate dismantling is the strategy by which the equipment, structures and parts of a facility containing radioactive contaminants are removed or decontaminated to a level that permits the facility to be released for unrestricted use, or with restrictions imposed by the regulatory body. In this case decommissioning implementation activities begin shortly after the permanent cessation of operations. This strategy implies prompt completion of the decommissioning project and involves the removal of all radioactive material from the facility to another new or existing licensed facility and its processing for either long term storage or disposal[2].

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[2].

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, 2018 Edition, IAEA, Vienna (in preparation).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities, IAEA Safety Standards Series No. GSR Part 6, IAEA, Vienna (2014).

decommissioning phase. Well defined and discrete set of activities within the decommissioning process[3].

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.

defence in depth. A hierarchical deployment of different levels of diverse equipment and procedures to prevent the escalation of anticipated operational occurrences and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, in accident conditions.

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[3].

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

emergency. A non-routine situation that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human health and safety, quality of life, property or the environment. This includes nuclear and radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes. It includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard.

emergency plan. A description of the objectives, policy and concept of operations for the response to an emergency and of the structure, authorities and responsibilities for a systematic, coordinated and effective response. The emergency plan serves as the basis for the development of other plans, procedures and checklists. Emergency plans are prepared at several different levels: national, local and facility.

emergency preparedness. The capability to take actions that will effectively mitigate the consequences of an emergency for human health and safety, quality of life, property and the environment.

emergency response. The performance of actions to mitigate the consequences of an emergency for human health and safety, quality of life, property and the environment. It may also provide a basis for the resumption of normal social and economic activity.

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.

entombment. Entombment is the strategy by which radioactive contaminants are encased in a structurally long lived material until radioactivity decays to a level permitting the unrestricted release of the facility, or release with restrictions imposed by the regulatory body[4].

graded approach. 1. For a system of control, such as a regulatory system or a safety system, a process or method in which the stringency of the control measures and conditions to be applied is commensurate, to the extent practicable, with the likelihood and possible consequences of, and the level of risk associated with, a loss of control. An example of a graded approach in general would be a structured method by means of which the stringency of application of requirements is varied in accordance with the circumstances, the regulatory systems used, the management systems used, etc. For example, a method in which: (1) The significance and

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[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Radioactive Waste Management Glossary, IAEA, Vienna (2003).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities, IAEA Safety Standards Series No. GSR Part 6, IAEA, Vienna (2014).

complexity of a product or service are determined; (2) The potential impacts of the product or service on health, safety, security, the environment, and the achieving of quality and the organization's objectives are determined; [and] (3) The consequences if a product fails or if a service is carried out incorrectly are taken into account. 2. An application of safety requirements that is commensurate with the characteristics of the practice or source and with the magnitude and likelihood of the exposures.

incident. Any unintended event, including operating errors, equipment failures, initiating events, accident precursors, near misses or other mishaps, or unauthorized act, malicious or non-malicious, the consequences or potential consequences of which are not negligible from the point of view of protection or safety. The word incident is often used, in [this report] and elsewhere, to describe events that are, in effect, minor accidents, i.e. that are distinguished from accidents only in terms of being less severe.

licence. 1. A legal document issued by the regulatory body granting authorization to perform specified activities related to a facility or activity. The holder of a current licence is termed a **licensee**. The licensee is the person or organization having overall responsibility for a facility or activity (the **responsible legal person**) [also called the **operator** in this publication.]
2. Any authorization granted by the regulatory body to the applicant to have the responsibility for the siting, design, construction, commissioning, operation or decommissioning of a nuclear installation.[5]

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.

corrective maintenance. Actions that restore, by repair, overhaul or replacement, the capability of a failed structure, system or component to function within acceptance criteria.

predictive maintenance. Form of preventive maintenance performed continuously or at intervals governed by observed condition to monitor, diagnose or trend a structure, system or component's condition indicators; results indicate present and future functional ability, or the nature of and schedule for planned maintenance.

preventive maintenance. Actions that detect, preclude or mitigate degradation of a functional structure, system or component to sustain or extend its useful life by controlling degradation and failures to an acceptable level.

mixed waste. Radioactive waste that also contains non-radioactive toxic or hazardous substances.

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.

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 to closure and decommissioning. Records are an essential part of quality assurance[6].

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[5] Convention on Nuclear Safety, INFCIRC/449, IAEA, Vienna (1994).
[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Radioactive Waste Management Glossary, IAEA, VIENNA (2003).

regulatory body. 1. 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.

2. For each Contracting Party any body or bodies given the legal authority by that Contracting Party to grant licences and to regulate the siting, design, construction, commissioning, operation or decommissioning of nuclear installations.[7]

stakeholder. Interested party; concerned party.

storage. The holding of radioactive sources, spent fuel or radioactive waste in a facility that provides for their/its containment, with the intention of retrieval.

surveillance. Activities performed to maintain and improve equipment availability, to confirm compliance with operational limits and conditions, and to detect and correct any abnormal condition before it can give rise to significant consequences for safety[8].

transport. The deliberate physical movement of radioactive material (other than that forming part of the means of propulsion) from one place to another.

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

vital area. An area inside a protected area containing equipment, systems or devices or nuclear material, the sabotage of which could directly or indirectly lead to high radiological consequence[9].

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

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[7] Convention on Nuclear Safety, INFCIRC/449, IAEA, Vienna (1994).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Surveillance and In-service Inspection in Nuclear Power Plants, IAEA Safety Standards Series NS-G-2.6, IAEA, Vienna (2002).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Identification of Vital Areas at Nuclear Facilities, Nuclear Security Series No. 16, IAEA, Vienna (2012).

ABBREVIATIONS

AECL	Atomic Energy Canada Limited
APAT	Agency for Environmental Protection and Technical Services
BEA	Battelle Energy Alliance
CEA	Atomic Energy Commission, France
CJ	construction joint
COVRA	Central Organization for Radioactive Waste, Netherlands
CSB	Canister Storage Building
DOE	Department of Energy
DSA	Documented Safety Analysis
ENEL	Italian National Electricity Company
ENRESA	National Company for Radioactive Waste, Spain
EPP	emergency planning and preparedness
GKN	Gemeenschappelijke Kernenergiecentrale Nederland
HEPA	high efficient particulate air (filter)
HFBR	High Flux Beam Reactor
HIFAR	High Flux Australian Reactor
HIFRENSA	Hispano Francesa de Energía Nuclear, S.A.
HVAC	heating, ventilation and air-conditioning
HWCTR	Heavy Water Components Test Reactor
IAEA	International Atomic Energy Agency
ICOD	increased cost of decommissioning
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Centre
ISDC	International Structure for Decommissioning Costing
LED	light-emitting diode

MT	Modification Traveller
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
ONR	Office for Nuclear Regulation
OSR	operations safety requirement
PSE	preparation for safe enclosure
PWR	pressurized water reactor
SAFSTOR	safe storage
QA	quality assurance
RCD	Radiological Controls Division
RCT	radiological control technician
SOGIN	Nuclear Plant Management Company, Italy
STF	security training facility
TRF	technical requisition file
VOC	volatile organic compounds
ZPPR	Zero Power Physics Reactor

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Consultants Meetings

Vienna, Austria: 8–12 October 2012; 4–8 November 2013; 6–10 October 2014

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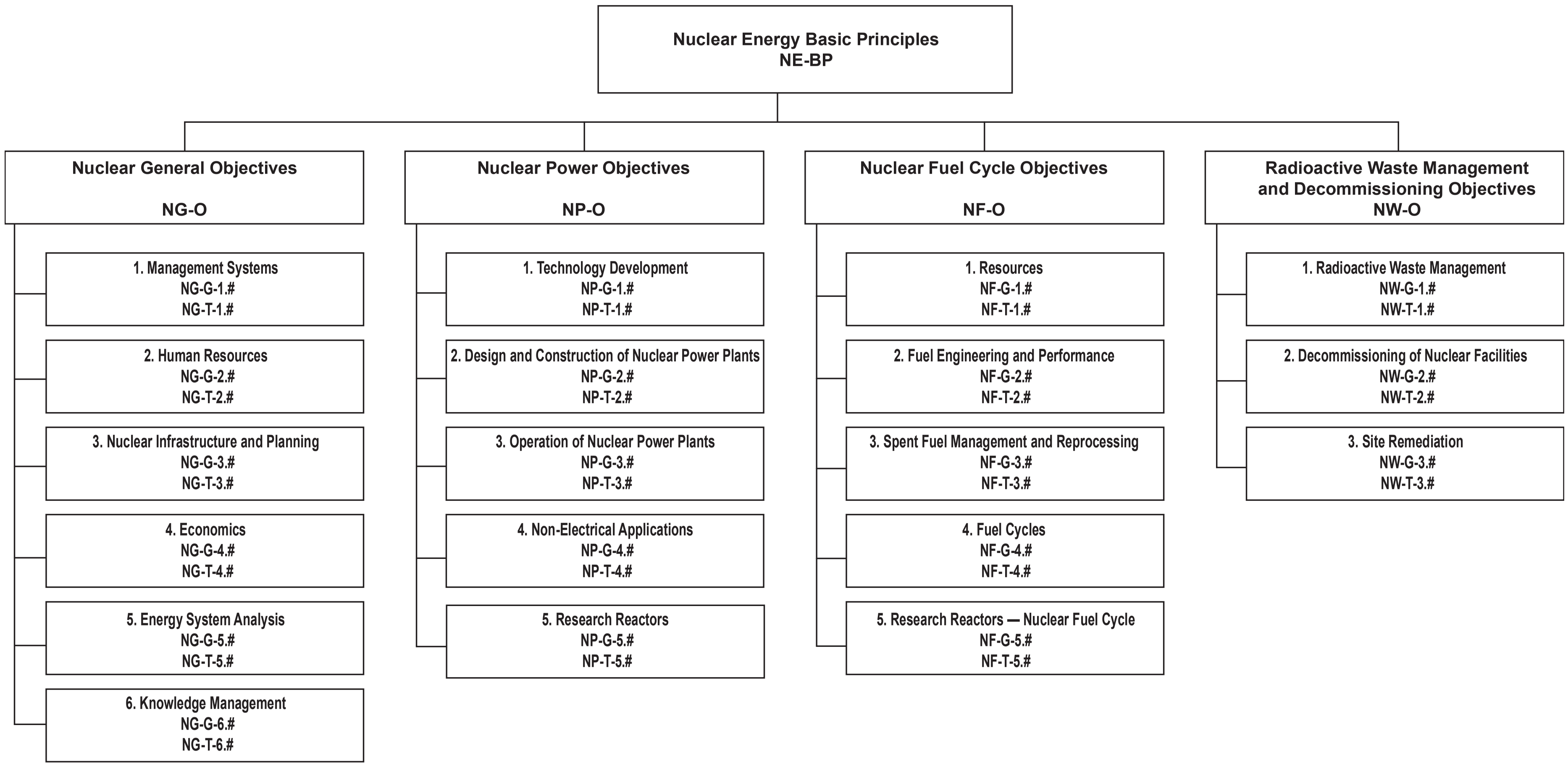

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18-03341

INTERNATIONAL ATOMIC ENERGY AGENCY
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ISBN 978–92–0–100418–5
ISSN 1995–7807