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Dismantling of Contaminated Stacks at Nuclear Facilities

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DISMANTLING
OF CONTAMINATED STACKS
AT NUCLEAR FACILITIES

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FOREWORD

Nearly all nuclear installations utilize stacks to discharge ventilation air, as well as gases and fumes, from contaminated areas to the environment. Over a service lifetime that can span decades, stacks may become contaminated as a result of the deposition of radioactive substances, e.g. aerosols, on stack surfaces. In the longer term, this is a serious decommissioning issue. The contamination may be difficult to remove, depending on the operating conditions and the chemical and physical environment over time. In addition, the physical logistics of stack dismantling may be complex, for example the difficulty of severing concrete at height. Relevant aspects of stack dismantling include project planning and management, health and safety, and the management and disposal of the resulting waste. It should be noted that such issues are quite common in IAEA Member States, owing to the ubiquitous presence of these major components.

Although cases of stack decommissioning have been sporadically described in the technical literature, no comprehensive treatment of decontamination and dismantling strategies and technologies currently exists for contaminated stacks. Similarly, although more than forty IAEA publications have been issued in the field of decommissioning, none focuses on this subject. It can be assumed that generic decontamination/dismantling technologies would also apply to these bulky components, but such treatment disregards a number of specific physical and radiological characteristics that make stack decommissioning a unique project. With the growing experience in the decommissioning of nuclear installations, including the completion of some large scale decommissioning projects over the last few years, it is timely to review and consolidate the worldwide experience available on the technical and planning aspects of stack decommissioning in a dedicated report.

Following the preliminary drafting by the Scientific Secretary, M. Laraia of the Division of Nuclear Fuel Cycle and Waste Technology, a series of consultants meetings, which included the participation of a number of international experts, was held to review, amend and finalize this report.

CONTENTS

1. INTRODUCTION

As in the case of industrial sites, a feature of nuclear sites, such as nuclear power plants, nuclear fuel cycle facilities and research centres, is elevated ventilation stacks (Fig. 1). At nuclear facilities, the main purpose of stacks is to dilute and disperse authorized airborne discharges from active plant systems. Systems to monitor these discharges to the environment are typically located in the stack. As is also true for non-nuclear plants, stacks at nuclear facilities are required to be much higher than nearby buildings and the local topography. Therefore stacks are commonly constructed up to heights of 125 m, and in some cases even higher. Stack height depends on the prevailing weather conditions, heights and surfaces of nearby buildings, and radioactive discharge potential. From a structural perspective, stacks can be massive, with weights of up to 2000 t.

Stacks become contaminated over the operating lifetime of nuclear facilities through the accumulated deposition of radioactive particulates and the absorption of radioactive gases. This contamination may be difficult to remove, depending on the operating conditions and the chemical and physical characteristics of the contaminants over time. In addition, the physical logistics of stack dismantling may be complex, for example the difficulty of severing

FIG. 1. Nuclear Energy Corporation of South Africa Palindaba site.

concrete at heights. Thus alternative techniques, such as the use of explosives or one-piece removal, have been developed and successfully used. Dismantling radioactively contaminated stacks should therefore take into account both the radiological and the conventional hazards to the workforce and the public in general. Several options have been developed, including preliminary decontamination prior to dismantling and direct dismantling of contaminated structures. Relevant aspects include project planning and management, health and safety, and the management and disposal of waste resulting from dismantling.

Although dismantling of stacks is an important component of the decommissioning programme for nuclear facilities (Fig. 2), technical literature on dismantling of radioactively contaminated stacks is scarce or at best sporadic. Many IAEA publications dealing with decontamination and dismantling techniques for concrete or metals are expected to be applicable to the dismantling of stacks [1, 2]. However, none of these publications systematically addresses aspects specific to stack decommissioning. With growing experience in the decommissioning of nuclear facilities, it is timely to review worldwide experience available on this topic and provide a practical, consolidated guide for organizations responsible for decommissioning activities that include stack dismantling.

2. OBJECTIVE AND SCOPE

This Technical Report covers a broad range of ventilation stacks used at nuclear sites, focusing particularly on large contaminated structures. The report aims to identify the critical factors for developing cost efficient, safe and environmentally responsible strategies to dismantle such stacks. Ancillary systems, such as drains, air ducts and monitoring systems that are integral to the stack, are also addressed. The report highlights important issues in the planning and management of dismantling projects, including:

— Dismantling of stacks as part of broader decommissioning programmes;
— Physical, chemical and radiological characterization of the inner surfaces of stacks;
— Health, safety and environment;
— Stack dismantling strategy selection;
— Predecontamination;
— Waste management;

(a)

(b)

FIG. 2. Japan Power Demonstration Reactor. (a) View before decommissioning; (b) landscaping after building demolition.

— Management and organization;
— Public relations.

The information in this report is intended to give a consolidated review of experience and practical guidance to those planning, managing and implementing the dismantling of stacks located at nuclear facilities. The report 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 interested local communities.

3. STRUCTURE

The technical discussion in this report commences in Section 4, which deals with stack construction, the various types of stack and non-nuclear dismantling experience. Section 5 introduces the dismantling of stacks within the context of broader decommissioning programmes and strategies for nuclear sites, including immediate or deferred dismantling, site reuse and the hazards of taking no action. Section 6 deals with physical and radiological characterization as a precursor to project planning and selection of dismantling technologies. Section 7 addresses stack decontamination options prior to dismantling. Dismantling options, including methods and technologies, radiological factors and hazards, and remote operations, are discussed in Section 8. Section 9 addresses waste management issues. Section 10 focuses on the selection of an optimum dismantling strategy. Section 11 describes the dismantling of integral ancillary systems associated with stacks. Section 12 addresses organizational and managerial issues specific to stack dismantling. Section 13 discusses relevant cost factors. Conclusions are given in Section 14. The report also includes annexes on experience in various Member States and on lessons learned, documenting actual examples of stack dismantling projects.

4. CONSTRUCTION ASPECTS OF STACK DISMANTLING

4.1. TYPES OF STACK CONSTRUCTION

The design of industrial and nuclear stacks focuses on planned ventilation and discharge requirements, taking into account flow rates, corrosiveness, flammability and temperature. The design is influenced by two main factors: discharge characteristics and structural criteria. Discharge characteristics, including the ventilation flow rate and dispersion requirements, determine the stack height and diameter. Structural requirements must comply with building regulations and take into consideration wind, snow, seismic loading and the temperature of the discharge. Design requirements have evolved over the past century, and a broad range of stack types exist. Stacks can be summarized in four main categories.

4.1.1. Brick stacks

Brick stacks represent the oldest type of construction. Over time they have evolved to include improvements such as linings of firebrick, acid resistant brick and gunite cements. This type of stack is often equipped with ladders, inspection platforms and windows. Some include a historic symbol at the top of the stack and have been declared national monuments, which survive past their operational life. The height is typically less than 100 m but brick stacks generally require thicker bases. Construction requires bricklayers to work at high elevation on internal and external working platforms, which must be raised as the stack height increases. Modern construction methods make brick stacks uneconomical, and they are now only built for aesthetic reasons.

4.1.2. Steel stacks

Steel stacks can be classified in three main types depending on the complexity of the structure.

(a) *Single-wall, unlined — guyed and self-supporting.* These are the simplest stacks and are used for low temperature gases without condensation problems. When manufactured of stainless steel, they provide good resistance to acids. Guy cables can be used to support the stack, allowing cost effective construction using thinner material. Accordingly, guyed stacks are lighter and can be placed on a building roof, which then acts as the base for the guy lines. Guyed stacks typically have small diameters and no inspection ladder or access ports, and are quite flexible. Self-supporting stacks are more rigid and therefore can have inspection ladders and access ports, and they may include a walking platform at the top. Single-wall stacks can be flanged or welded and their height is often less than 80 m.

(b) *Lined with firebrick, acid resistant brick or gunite.* Where high temperatures and/or strong corrosion characteristics are prevalent, it is necessary to protect the steel with materials that are acid and heat resistant. Construction may be complicated by the need to allow for different coefficients of thermal expansion. Composite stacks may have an internal flue. Their height can exceed 125 m, and inspection ladders and platforms are often provided.

(c) *Dual-wall insulated and with interior steel lining.* This type of stack is used when it is essential to keep the discharges hot to avoid condensation in the stack and/or in the nearby area. The stack is constructed with two concentric tubes, with the gap filled with thermal insulation (most likely asbestos). Insulated steel stacks can have a large diameter and accommodate more than one flue. Prefabricated stacks, with dual walls or precast refractory lining, are commonly limited to 40 m in height. Installation and dismantling are easily carried out with a crane.

4.1.3. Reinforced concrete stacks

Reinforced concrete stacks are used in many plants, and like steel stacks, they can have various linings, include one or more flues, and have inspection ladders and access ports. Concrete stacks used in the nuclear industry represent the largest stacks, with internal diameters of up to 12 m, heights of up to 125 m and typical weights of up to 2000 t. Concrete stacks often present significant decommissioning challenges owing to their size and mass, and they may even include prestressed concrete construction.

4.1.4. Reinforced plastic stacks — guyed and self-supporting

Stacks of this type are small and very light, especially when guyed, and are easily assembled on a flanged base. They have good acid resistance and low thermal conductivity but offer only low heat resistance. Installation and dismantling are easily carried out with a crane.

4.2. STACK DISMANTLING EXPERIENCE AT NON-NUCLEAR SITES

Around the world many companies have considerable experience in stack dismantling utilizing a broad range of methods and technologies to meet customer needs. A competitive market exists, and access to basic information and experience is widely available. The demolition of non-nuclear stacks generally is less complex, is less expensive and can be accomplished in less time than is the case for nuclear stacks. The dismantling techniques used at non-nuclear sites include:

— Wrecking ball;
— Top-down breaking;
— Explosives.

Dismantling with a wrecking ball is one of the oldest demolition systems and the technique is still used.

Top-down breaking is shown in Fig. 3 for a concrete stack.

Explosive techniques are used in both open and urban areas, and skilled operators can direct a falling stack with an accuracy of 5°. The Kennecott Copper Smelter concrete stack was felled (Fig. 4) using this technique. This stack was exceptionally large, measuring 225 m in height and weighing 9300 t. Demolition work took less than one week.

The explosive demolition of one of two stacks at the Italsider Bagnoli plant near Naples, Italy, is shown in sequence in Fig. 5. Each stack was 102 m tall and weighed 1250 t. The duration of the project was very short, requiring only 10 person-days to demolish each stack.

An example of explosive demolition of a water tower structure, at the Fernald site in the United States of America, is given in Ref. [3]. It may be of relevance since it has several features in common with stack dismantling.

5. NUCLEAR DECOMMISSIONING STRATEGIES

Nuclear facilities require decommissioning at the end of their operating life. The end of the operating life is reached for a variety of reasons, such as completion of planned work programmes, obsolescence, loss of funding or competition. Decommissioning strategies for redundant nuclear facilities vary but generally involve either immediate or deferred decommissioning (entombment being a strategy applicable to special cases). Deferred

FIG. 3. Brick lined concrete stack at Corus Steelworks, Port Talbot, United Kingdom.

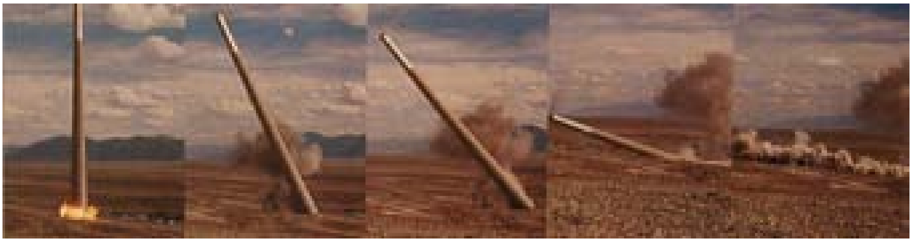

FIG. 4. Concrete stack (225 m high, 17 m dia., weight 9300 t) at Kenneccot Copper Smelter, Mcgill, Nevada, USA.

decommissioning normally involves at least some immediate decommissioning work, followed by one or more periods of institutional care and maintenance separating further decommissioning activities. Decommissioning strategies depend on several factors, such as:

— Plans for future use of the site;
— Funding priorities;
— Extent and levels of radioactive contamination/activation;
— Condition of the buildings and structures.

Decommissioning may be deferred to allow radioactive decay of dominant isotopes, which may in some cases make possible safer and more cost effective decommissioning at some future date. Immediate decommissioning is more appropriate where there are particular safety issues or where the care and maintenance costs outweigh deferred decommissioning savings. The ultimate objective of decommissioning is generally unrestricted release of the site (except where future use includes other nuclear applications). Safety guidance on the decommissioning of various nuclear facilities has been published by the IAEA in, for example, Refs [4, 5], and the principles given are fully applicable to stack decommissioning.

Dismantling of stacks is carried out within the overall decommissioning strategy for the facility or site. Stacks may no longer be required following shutdown of the facility, or they may remain either fully or partially operational in support of care and maintenance or decommissioning activities. Stack dismantling may form an integral part of the facility or site decommissioning strategy or may be carried out largely independently. Issues affecting how stack dismantling fits into the overall strategy may include the following:

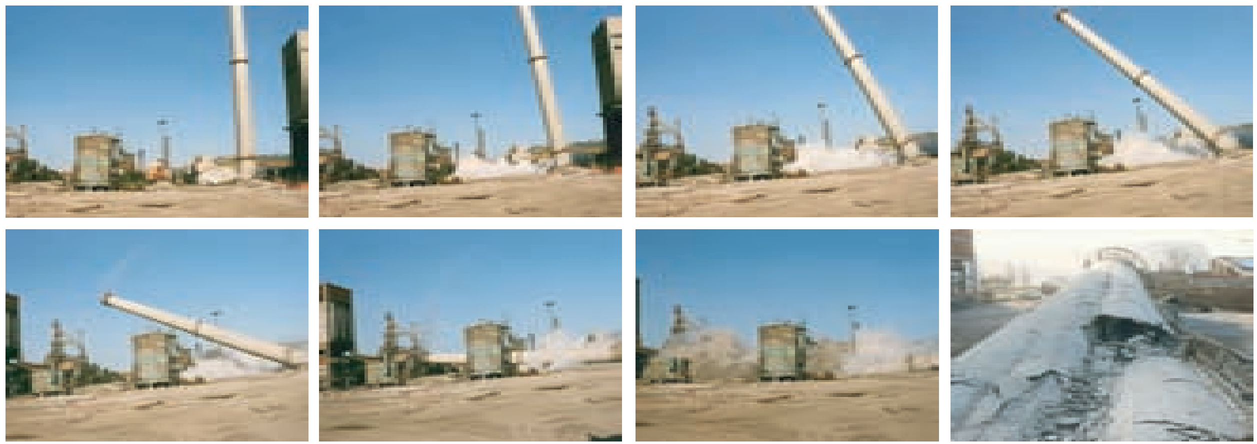

FIG. 5. Explosive dismantling sequence at the Italsider Bagnoli plant, Naples, Italy.

(a) The need for the ventilation system changes after shutdown of a facility and may decrease during decommissioning. The stack may be needed initially but ventilation requirements will cease at some stage. Ventilation needs during decommissioning are often provided for in situ (e.g. by ventilated tents) or by new ventilation systems with discharge points at building level.
(b) Stacks were designed to meet safety criteria at the time of construction that may be less stringent than those in use later on, leading to a decision for early dismantling. Modern standards are generally more demanding (e.g. seismic qualification) and may require assessment of events such as high winds, tornadoes or aircraft impact that may not have been previously considered.
(c) Stacks were usually designed for a defined lifetime appropriate to that of the nuclear facilities serviced. Decommissioning strategies may extend the life of the stack far beyond the original design lifetime.
(d) Deterioration of mechanical properties of the stack may result with ageing. Natural forces (high winds, rain, acid fumes, earthquakes and temperature variations) or mechanical vibration may reduce structural strength (through fatigue, erosion or corrosion) over extended lifetimes. Several publications have dealt with the long term deterioration of nuclear facilities [6–10] and may be usefully consulted, but they do not specifically address stacks. Ultimately a weakened stack presents an increasing collapse hazard.
(e) The safety benefit of removing potential stack collapse hazards should be compared with the disadvantage of not having the stack available for further care and maintenance or decommissioning activities.
(f) Planned reuse of the site for nuclear or non-nuclear activities may require a similar stack.
(g) Stakeholder perception can impact the stack decommissioning strategy, e.g. the end state and selection of dismantling methodology.

5.1. HAZARDS OF TAKING NO ACTION

Following the permanent shutdown of a nuclear facility, a hazardous situation can eventually arise if no action is taken. A comprehensive description of various risks associated with a no-action strategy is given in section 3.3 of Ref. [11]. A policy of no action is generally not approved by regulators and is not recommended by the IAEA. Decommissioning implies positive management action together with adequate resources and initiatives.

If stack dismantling is deferred, an appropriate level of refurbishment or upgrading may be required for longer term structural stability. Also, where deferred decommissioning of contaminated stacks is considered, some post-operational cleanup may be required. This may involve the removal of contamination from internal surfaces.

It should be noted that resistance against earthquakes and high winds is a serious issue even during plant operation. It was recently reported that following an inspection which revealed degradation in the stack's tie-rods at Cruas nuclear power plant (NPP), France, the French Nuclear Safety Authority issued an order to the operator to make the necessary backfits by a certain date [12].

5.2. TECHNOLOGICAL CHALLENGES IN STACK DISMANTLING

Stack dismantling strategies need to optimize technical, safety, environmental and economic requirements within the overall facility/site decommissioning strategy. This challenge has resulted in the application of innovative technology and techniques such as:

(a) Remote decontamination systems, e.g. a robotically operated high pressure water jet or scabbling equipment to remove internal surface layers.
(b) Contamination management, e.g. by wetting, painting and the use of strippable coatings.
(c) Containment systems, including filtered extract and liquid collection.
(d) Asbestos removal.
(e) Use of mobile hydraulic crushers. For example, crushers weighing less than 3 t can apply a force of up to 2000 kN to crush concrete up to 1 m thick.
(f) Combined cutting and lifting operations at elevated heights.
(g) Use of vibration analysis and impact limiters for stack demolition by explosive techniques. For example, sand or loose earth has been used as an impact limiter to reduce vibrations and detonation effects to a level allowing these techniques to be used adjacent to other buildings.

Stack demolition can only truly be optimized by incorporating decommissioning requirements at the design stage. The challenge to future stack designers is to maximize the ease of dismantling without sacrificing performance, economy or safety.

6. PRE-DISMANTLING CHARACTERIZATION

Accurate physical, chemical and radiological characterization is a key factor in the selection of stack dismantling strategies and technologies. However, the cost and risk of obtaining characterization data must be weighed against the risks resulting from the absence of this information. Physical characterization determines parameters such as stack size, design and materials; concrete thickness; and corrosion or deterioration of components. These are essential elements for estimating the residual mechanical properties of the stack and the length of time the stack can safely remain in place. Small fissures and cracks within the inner layers of a stack may indicate insufficient structural integrity to withstand decontamination procedures. It should also be noted that many old stacks may lack fully comprehensive design and as-built construction records, and pre-dismantling characterization can be useful in verifying the accuracy of records and filling any information gaps.

A significant consideration for stack decontamination is the finish of interior surfaces. For example, a coarse, porous surface will absorb contamination more readily and will be more difficult to decontaminate than a smooth, sealed surface.

Accessing a tall stack to obtain samples for physical or radiological characterization purposes requires careful consideration of industrial safety (for example with respect to scaffolding, cranes and confined spaces). Characterization activities in a contaminated environment will require radiological protection provisions. Practical applications of these to stack decommissioning are given in Refs [13, 14]. For example, most stacks are designed with an access port to provide entry to the interior. In order to minimize any potential release due to the opening of this port, a containment may be needed, e.g. a simple aluminium frame which supports a tent made of reinforced plastic sheeting [15]. It should also be noted that opening the access port in operating stacks might disturb and disperse contamination. In some cases remote operation techniques, such as videography [15] or even robots [14], have been proposed or deployed to overcome personnel access issues. Although remote or robotic characterization of stacks is often proposed, to date most stack characterization work has been done manually owing to the complexities of using these new technologies. It is expected that gamma cameras, i.e. systems for superimposing gamma radiation readings and spectrographic information onto visual images of an object, may be effective in radiological characterization of a stack [1, section 6.1.2]. Likewise, the use of the new In Situ Object Counting System isotopic identification device may prove useful in stack characterization, in particular at radioactivity concentrations near clearance levels, a situation that commonly occurs in stack decommissioning [16].

For radiological characterization, it should be noted that in most cases logbooks and reports regarding material released through a stack may be outdated, incomplete or non-existent. In addition, there is no reliable way to tell how much of the released material has been deposited and remains on stack walls. Stack characterization data provide information to determine whether a stack can be decontaminated in a cost effective manner. The degree of propagation of contaminants through the interior wall is another important piece of information, for example for assessing the amounts of radioactive and non-radioactive (below clearance levels) waste generated by decontamination or dismantling. While sampling the entire surface of a stack may be possible, it may be time consuming and is not necessarily economical. Through applying several assumptions and mathematical derivations, a good approximation of potentially contaminated areas can be achieved. By sampling or coring selected areas, the entire stack can be characterized in a cost effective manner [15] (Fig. 6). A number of publications describe radiological characterization techniques including statistical approaches, e.g. Refs [17–19]. Results of the radiological characterization of the stack at Garigliano NPP, Italy, are given in Refs [14, 20].

7. PRE-DISMANTLING DECONTAMINATION OPTIONS

Pre-dismantling decontamination is better considered within the context of the overall dismantling strategy. The cost and risk of in situ decontamination are typically evaluated relative to benefits of dismantling and decontamination at ground level. There are three main pre-dismantling decontamination options:

- Decontamination to unrestricted release levels or waste de-categorization in situ;
- Partial decontamination in situ;
- No in situ decontamination, i.e. decontamination at ground level after dismantling or direct disposal with no decontamination.

In situ decontamination may provide significant benefits by:

- Reducing occupational exposures;

FIG. 6. Mound facility, USA. Stack core drilling at 20 ft (6 m) level opposite ventilation entry port.

— Reducing the residual radiation source at the site to minimize any potential hazard to public health and safety (e.g. in preparation for safe enclosure);
— Achieving unrestricted release for the whole structure, simplifying subsequent dismantling and management of waste.

Conversely, one should consider that in situ decontamination may produce more secondary waste and may entail additional safety risks. A post-dismantling decontamination strategy may prove more cost effective and reduce overall worker exposure. A methodology for selecting between decontamination prior to dismantling or proceeding to direct dismantling is presented in Section 10.

7.1. DECONTAMINATION CRITERIA

Decontamination techniques are extensively dealt with in the technical literature [1, 18, 19]. For stacks, a typical problem is how to remove the surface layer where particulate contamination was deposited during operation. The thickness of the material to be removed is important, because some activity may have penetrated into deeper layers through cracks or fissures. Other selection criteria for stack decontamination technologies include:

- The requirement to preserve structural integrity, e.g. in the case of reinforcing bars close to the surface;
- Minimization of radiological and industrial safety hazards, e.g. by use of remote systems;
- Simplicity, including the possibility for equipment retrieval in the event of failure;
- Containment during decontamination;
- Containment of waste arisings;
- Market availability and costs.

7.2. DECONTAMINATION TECHNIQUES

Typical techniques for removal of contaminated surface layers include:

- Cleaning with abrasives;
- Use of high pressure water jets;
- Grinding/shaving;
- Scarifying/scabbling.

Abrasive cleaning uses a medium such as sand, plastic, glass or steel beads, or grit, e.g. garnet, soda, aluminium oxide or CO_2 ice pellets. Abrasive cleaning can be performed to remove fixed or loose contamination from metal and concrete surfaces. In the case of concrete surfaces, a significant amount of the base material is also removed. This process is most effective on flat surfaces but can also be used for areas that are difficult to reach. This process produces comparatively large amounts of secondary waste. It can be carried out wet or dry, with the abrasive medium being blasted against a surface using water or compressed air as the propellant [1, section 6.2.2.5]. A common application of this technology is sandblasting, which was carried out remotely to decontaminate a stack at a fuel reprocessing pilot plant in the USA. The rotary sand–air blast head was lowered down the stack with a winch. Reverse stack ventilation was employed to draw the dust created down the stack and into a large fibreglass and high efficiency particulate air (HEPA) filter system [21, 22].

High pressure water processes use a water jet to remove contamination from surfaces. Pressures and flow rates are optimized for individual requirements. Recirculation and treatment systems may be considered to reduce and handle secondary waste water production. Since the use of water can result in the concentration of contaminants, where fissile material is present, criticality issues may be significant. Typical applications include the cleaning of inaccessible or remote surfaces, making this technique generally applicable to stacks. In some cases grit is entrained in the water jet to enhance decontamination, making the process similar to the abrasive cleaning described above [1, section 6.2.2.11]. One application using this process to decontaminate a stack is given in Ref. [23]. This process can result in visibility problems in confined spaces.

Grinding and shaving processes use coarse grained abrasives in the form of water cooled or dry diamond grinding wheels, or multiple tungsten carbide surfacing discs. This process is recommended for use where only thin layers of contaminated material need to be removed. This type of decontamination has been demonstrated for general application at Hanford C in the USA [1, section 6.2.2.12] but is not proven for stack decontamination. An off-the-shelf asphalt road shaver adapted for use in the decontamination of the Windscale Pile stack in the United Kingdom is shown in Fig. 7.

Scarifying and scabbling are used primarily on concrete surfaces to abrade and remove a contamination layer. Scarifiers and scabblers include pneumatically operated impact tools, needle guns and flap wheel type tools. These processes are relatively effective for removing a contaminated layer from the surface of concrete and in some cases metals, and a broad range of industrial equipment is now available [1, section 6.2.2.13]. Examples of the use of scabblers on floors and walks at the Japan Power Demonstration Reactor (JPDR) decommissioning project are shown in Fig. 8.

The decontamination project at Garigliano NPP, Italy (Fig. 9), is a case where a selection process resulted in preference being given to scarifying internal surfaces [20]. The radiological characterization described in Refs [14, 20] concluded that:

— The activity concentration decreased with height.
— The surface contamination level was less than 1 Bq/cm^2 (the clearance level adopted) above 41 m of stack height and at depths of greater than 1 cm.
— The reinforcing bars were not contaminated.

FIG. 7. Windscale Pile, United Kingdom. Adapted asphalt shaver.

On the basis of these conclusions it was decided to scarify the surface to a depth of 2 cm to ensure that no residual contamination remained. In an initial phase of the project, preference had been given to high pressure water jets. However, one disadvantage of water jets is the generation of liquid waste (a typical range for the Garigliano NPP case was 0.11–0.25 m^3/min), making a collection and treatment system essential to minimize and manage secondary waste production.

In another example involving the Strontium Semiworks Complex at Hanford, USA, the main criterion for choosing sandblasting as the decontamination technique was that it could be deployed remotely, thereby reducing worker doses and the safety risks associated with working in enclosed spaces at high elevations [22].

Other technologies, such as drilling and spalling [1, section 6.2.2.15], jackhammering [1, section 6.2.2.17] and the use of foams and gels [1, 19], are also well developed and in some cases usable for surface decontamination. These technologies require manual handling. In general the adaptation of

(a)

(b)

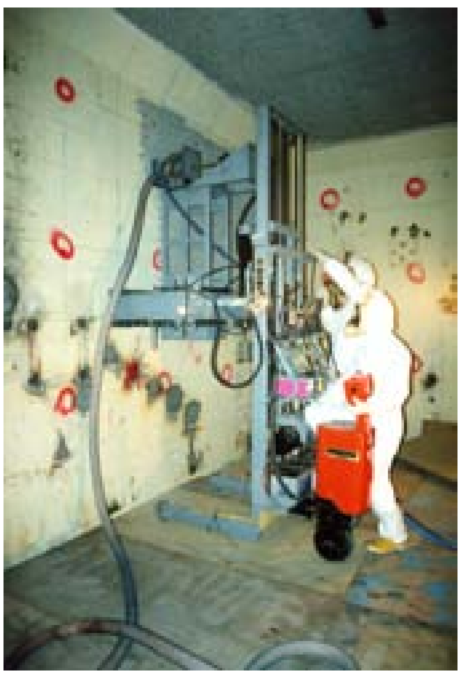

FIG. 8. JPDR decommissioning project. (a) Floor decontamination using a scabbler; (b) wall surface decontamination using a scabbler.

FIG. 9. Stack at Garigliano NPP, Italy.

existing, proven, commercially available technology to meet decontamination needs is efficient and economical.

Emerging technologies that require additional development before they could be considered as stack decontamination processes are listed below but are not given further treatment in this report.

- — Light ablation (lasers) [1, section 6.2.4.1];
- — Microwave heating [1, section 6.2.4.2];
- — Flame attack [1, section 6.2.4.3];
- — Biodecontamination (of concrete) [1, section 6.2.4.4; 24];
- — Electrokinetics [1, section 6.2.4.5].

8. DISMANTLING APPROACHES

8.1. DISMANTLING CRITERIA

In stack dismantling, the proximity of adjacent facilities is an important element to consider with respect to avoiding undue risk or disturbance. Containing waste materials and preventing the escape of contaminants are also vital. An important factor relevant to the selection of a dismantling strategy is residual contamination following any in situ decontamination. Additional factors include:

— Simplicity and ease of deployment of dismantling tools, taking into account the availability of working areas around the stack (to deploy cranes, scaffolding, lifts, etc.);
— Minimization of radioactive waste;
— Ease of handling, treatment, transport, storage and disposal of waste arisings (recycling of materials being a desirable option);
— Desirability of using remotely operated equipment or robots for reasons of radiological and industrial safety;
— Minimization of radiological and industrial hazards, for example through the use of remote systems;
— Demands of scheduling and the duration of the work;
— Availability of equipment, experience of the workforce, costs, etc.

8.2. DISMANTLING TECHNIQUES

Many established dismantling techniques are available, including:

— Top-down segmenting of the stack in horizontal slices or pieces;
— Top-down breaking;
— Controlled collapse;
— Intact removal.

8.2.1. Top-down segmenting

Top-down segmenting comprises cutting the stack into large but manageably sized sections and lifting and lowering these sections to ground level. Brick stacks are generally unsuitable for this approach (sections of brick structure are not stable for lifting), and different techniques are used for steel and concrete reinforced stacks. Top-down segmenting is particularly suitable for stacks requiring post-dismantling decontamination at ground level. This approach includes three main activities:

— Establishing safe working platforms;
— Cutting operations;
— Lifting operations.

Working platforms are required for workers to safely cut through the stack and to sling the section being released. Safe working platforms can be provided by several means, including scaffolding (Fig. 10), mobile platforms (independent or attached to or suspended from the stack) (Fig. 11) and crane suspended cages. One technique uses a special power shovel which climbs up to the stack top on cables [25].

Cutting operations are required to separate a section of the stack from the main structure. Appropriate techniques depend upon the type of stack construction. Cutting techniques generally use established construction industry methods, including:

FIG. 10. Scaffolding used during dismantling of the stack of the Steam Generating Heavy Water Reactor, United Kingdom.

FIG. 11. Stack at Windscale Pile 2, United Kingdom. External access platforms.

For steel stacks:

— Mechanical saws, shears, nibblers, etc.;
— Flame or plasma cutting.

For concrete stacks:

— Concrete fragmentation, e.g. drilling and spalling, use of rock splitters (hydraulic wedges, expanding grout), use of jackhammers;
— Diamond wire sawing;
— Circular diamond wheel sawing;
— Thermic lances.

Concrete fragmentation techniques result in an amount of broken concrete that needs to be managed. This material can be dropped inside the stack, but measures are often necessary to prevent this material falling outside the stack. Steel reinforcing used in concrete generally needs to be cut separately.

Diamond wire saws consist of diamond abrasives embedded in beads on a steel cable. Diamond wire sawing has been extensively used for cutting through concrete (including reinforcing bars) and masonry. Wire sawing was used to dismantle the stack at the National Research Experimental Reactor in Canada [26], at Humboldt Bay NPP in the USA [27], and at the stack of the Winfrith Steam Generating Heavy Water Reactor (SGHWR) in the United Kingdom, as described in Annex I.B. The technique has been applied to cut through heavily reinforced concrete. Figure 12 shows an application of this technique.

The use of circular saws is another established technique employed to cut reinforced concrete. The saw blade is a steel disc with diamond embedded teeth and can range in size up to 2 m in diameter. High reaction forces require the use of robust deployment equipment such as that shown in Fig. 13.

Both diamond wire and circular sawing are generally wet cutting processes resulting in potentially contaminated liquid waste. Diamond wire cutting can also be conducted using a dry approach, which eliminates the production of liquid waste [28].

Thermic lances consist of iron pipes packed with a combination of steel, aluminium and magnesium wires through which a flow of oxygen gas is maintained. Cutting is achieved by a thermite reaction at the tip of the lance, which consumes the lance as cutting progresses. Lances vary in length from about 0.5 m to more than 3 m and have a range of diameters. Ignition of the lance is normally performed using a flame or electric arc. This technique may be unsuitable in high contamination environments as a large amount of dust, aerosols and fumes can be created.

One interesting example of top-down segmenting was the work conducted in 2002 at the shut down Creys–Malville fast breeder reactor (Superphénix) [29]. This activity involved 48 stacks. Fourteen main stacks were in use for the cooling of sodium–air heat exchangers and 34 smaller stacks were used for building ventilation. These stacks were no longer required following plant shutdown and were dismantled in the early phases of decommissioning because of their high maintenance costs.

In total the project removed 950 t of steel, including:

— Fourteen main stacks ranging in weight from 3 to 25 t;
— Smaller stacks, each weighing less than 3 t;
— Piping located outside of the stack.

FIG. 12. Creating new cell entrances using a diamond cable cutting machine.

FIG. 13. Concrete cutting using a diamond tipped blade saw.

The length of the main stacks ranged between 23.5 and 35 m. They were segmented into two or three pieces having a maximum weight of 8 t. The length of the smaller stacks was between 1.5 and 4.5 m. The work was carried out at an elevation of between 75 and 95 m. The stacks were radiologically clean.

A crane capable of lifting 50 t at a height of 120 m was used for the dismantling of the stacks. The segmenting was carried out by specialized workers suspended by cables (Figs 14, 15). A maximum of 30 people worked on the stack removal at any given time. Another project utilizing top-down segmenting is detailed in Annex I.H. The backup approach for temporary removal of the stack at Gösgen NPP, Switzerland, was demonstrated by the removal of a non-nuclear stack of a local district heating power plant. The process utilized a climbing saw platform lowered into the stack to allow diamond cutting of the stack into segments (Fig. 16).

8.2.2. Top-down breaking

Whereas top-down segmenting releases large sections for controlled lifting to ground level, top-down breaking involves breaking the stack into smaller chunks of debris that are generally dropped inside the stack or down

FIG. 14. Creys–Malville, France. Removal of stack segments.

FIG. 15. Stack at Creys–Malville, France. Preparation for segmenting.

FIG. 16. Gösgen NPP, Switzerland. Climbing saw inserted into the stack.

external chutes. This approach is particularly suitable for brick stacks where explosive collapse is not appropriate. It is most suitable for stacks that have been fully decontaminated (down to or approaching unrestricted release levels) and is generally unsuitable for highly contaminated structures, for which radioactive waste minimization and contamination control pose significant difficulty.

Breaking can be carried out manually or by mechanical techniques. Manual methods require safe working platforms and use mortar fragmentation techniques to break up the stack structure, similar to the case of top-down segmenting.

Mechanical techniques can be deployed by excavator mounted and cable suspended systems, and include concrete pulverizers, rams, shears and grapples [18].

— Concrete pulverizers crush concrete and masonry, separating rebar and encased steelwork (using a range of interchangeable jaws).
— Rams demolish concrete structures (up to 2 m thick) using a chisel point.

— Shears sever concrete, metals, structural steel, etc.
— Grapples provide all-purpose demolition and materials handling.

Rams (air powered or hydraulic) are generally only deployed on excavator mounted mechanical arms. The ram is generally a resistance driven tool in that it begins operating as soon as the chisel point touches the workpiece and stops as soon as the chisel is lifted or has cut through the material. Air powered rams are used for lighter applications (e.g. concrete up to 0.7 m thick), and hydraulic rams are used for larger sections (e.g. concrete up to 2 m thick).

The British Experimental Pile 0 (BEPO) stack is an example of top-down breaking. The BEPO stack was removed in 2000 by specialist steeplejacks. A cage was erected around the top of the stack and four rows of bricks at a time were dismantled and dropped to the bottom of the stack. After decontamination and clearance monitoring, the bricks were crushed and used as backfill material at the Harwell site. Following the removal of the 6 m deep subfoundation, the land was backfilled and restored (Fig. 17). Dismantling of the stack was completed in four months [30]. Further examples of top-down breaking are shown in Figs 18 and 19.

A concrete pulverizer was used in the non-nuclear dismantling of three smokestacks from a former steam generating plant in Winnipeg, Canada [18]. The pulverizer was suspended from a 100 m crane and included stabilizing legs to provide safe, controlled demolition. The crew consisted of five people, and work was completed in 30 working days (not including time lost because of high winds).

8.2.3. Controlled collapse

Controlled collapse or felling of large stack structures is generally achieved using explosives, although smaller steel stacks can be pulled over after severing supports. Controlled collapse is often the quickest and least expensive method of stack dismantling, and minimizes the work required at elevated heights, but serious concerns exist in the case of high contamination levels and for stacks close to adjacent facilities.

Explosive felling of large concrete or brick stacks is achieved by inserting explosives into holes drilled at the stack base and detonating the charges in a predetermined sequence. At impact on the ground, a partial fragmentation of the stack takes place that may need to be completed with the use of jackhammers, shears, torches or other segmenting techniques. Figure 20 shows the insertion of explosives. Figure 5 (Section 4.2) shows the explosive demolition of a non-nuclear stack. Figure 21 shows the explosive demolition of

FIG. 17. BEPO stack dismantling, United Kingdom. (a) Stack before dismantling; (b) working 'cage'; (c) dismantling activity; (d) remediated site at the end of the dismantling project.

a nuclear stack at Hanford, USA. The stack was felled precisely into a previously excavated trench. The collapsed structure was then covered over with soil to natural grade level.

Systems for limiting impact to minimize flying debris hazards during collapse include vibration limiting structures (e.g. soil and sand heaps or 'pillows') and barriers.

FIG. 18. Mound facility, USA. Top-down breaking of a brick stack.

FIG. 19. Top-down breaking of a concrete stack, South Africa.

A large scale stack demolition operation using explosives to fell the Marcoule G1 stack, France, is detailed in Annex I.G. This project was unique in that it addressed a very large stack constructed of prestressed concrete. For this project, directional control of the fall of the stack was critical to avoid damage to adjacent facilities. Figure 22 shows a time sequence of the fall of the G1 stack.

8.2.4. Intact removal

Intact removal is often suitable for relatively short and/or light stacks. Such stacks are often constructed in sections, facilitating dismantling by reversing the construction sequence. This method may offer advantages in terms of reduced radiation exposures, short duration of the work, and simplicity, but may cause interference with surrounding buildings, involve extended work at height and require additional waste treatment for disposal.

The bolted sections in these stacks often used asbestos gaskets, and this hazard must be considered when dismantling them. The sections are normally sealed at both ends, cut or unbolted and lowered to the ground. In some cases they can be removed and lowered in one piece. Where necessary, the inner

FIG. 20. Initial Engine Test (IET) stack at Idaho National Engineering and Environmental Laboratory (INEEL), USA. Insertion of explosives.

FIG. 21. Felling of the 110-F stack at Hanford, USA, using explosives.

FIG. 22. Time sequence of the stack fall at Marcoule G1, France.

surface of the stack in the vicinity of cuts is decontaminated before cutting. Removed sections can sometimes be sealed at each end and transported as their own shipping container [31]. Intact removal of large components and related factors are described extensively in Ref. [32]. The 23 m tall exhaust stack of the Janus reactor, USA, was removed by this method using a boom lift and a crane [33]. Figure 23 shows the intact removal of a building exhaust stack at Los Alamos National Laboratory, USA.

FIG. 23. Exhaust stack intact removal at Los Alamos National Laboratory, USA.

9. WASTE MANAGEMENT

Waste management is a significant factor in stack dismantling. Waste is generated throughout the process and includes the structural material of the stack itself and integral ancillary systems, as well as secondary waste arising from decontamination, cutting and dismantling operations.

Stack structures can be massive and have the potential to generate significant amounts of radioactive waste during dismantling. Disposal of large volumes of radioactive waste can be difficult, and disposal costs can exceed dismantling costs. There are strong economic reasons to minimize radioactive waste and maximize the clearance of materials for reuse, recycling or conventional disposal. Planning for the management of this waste can be the dominant issue in deciding the dismantling strategy.

Stack dismantling can result in the generation of radioactive airborne discharges and of liquid and solid radioactive waste. Infrastructure and provisions should be available to collect, treat, condition, transport, dispose of and discharge this waste as required.

9.1. AIRBORNE RADIOACTIVE DISCHARGES

Airborne discharges typically include particulate contamination and radioactive gases released during dismantling activities. During controlled stack collapse, particulate contamination may be released when the stack hits the ground. The key feature of airborne discharges is the open working environment associated with stack dismantling, i.e. outside the controlled environment of a building. The potential for airborne discharges to result from stack dismantling can be minimized by predecontamination. However, where this is not practical, appropriate provisions such as water mist sprays [21, 22], fogging, tents or local ventilation systems should be used to control airborne releases and ensure that they are maintained within acceptable levels. These provisions can be supplemented by contamination fixants such as strippable coatings. Fogging was successfully used for a 75 m contaminated stack at Humboldt Bay NPP, USA [34]. Particular problems may exist for certain stacks, e.g. stacks contaminated with alpha emitters from nuclear fuel cycle facilities [21, 22]. Safety guidance on the control of radioactive discharges, including discharge authorizations, is given in Ref. [35]. In this connection, the potential for airborne releases to arise during stack dismantling that are different from those during normal operation (e.g. particulates as opposed to noble gases) may require ad hoc consideration.

9.2. LIQUID RADIOACTIVE WASTE

Liquid waste results from wet decontamination activities and cutting operations. In many cases stacks are not equipped for the collection, storage and treatment of liquid radioactive waste, and systems for these purposes should be procured and installed prior to stack dismantling work. Liquid waste treatment systems need to deal with suspended solids/slurries, contaminants and chemicals, as appropriate to the specific application and in accordance with established liquid waste disposal routes.

9.3. SOLID RADIOACTIVE WASTE

Solid radioactive waste resulting from stack dismantling is likely to be the largest radioactive waste stream. It includes structural materials and secondary decontamination, cutting and dismantling waste. The key waste management issue for stack dismantling is the optimization of solid waste disposal, using decontamination to minimize the volumes of solid radioactive waste and to maximize the clearance of materials [2]. An important issue is the treatment and processing of solid waste to meet transport and disposal requirements, including dimensional and weight constraints. Various options exist to size and package solid waste for disposal, for example in drums, boxes or custom containers.

Consideration of alternative waste management strategies can be a determining factor in the selection of the decommissioning approach. For example, where very low level waste disposal facilities exist (such as those in France), or where clearance criteria are in place, additional emphasis on waste segregation can provide considerable cost savings. The cost for management of waste in these cases can be much lower, providing a motivation for additional effort and resources to be expended on characterization and decontamination, leading to reduced overall project cost.

Information currently exists regarding the processing of large sections of metal and concrete waste from nuclear facilities. Work has included the development of custom containers [36] and the conditioning of concrete debris [37]. There is considerable experience available on concrete recycling [38], and R&D is still active in this field [39–41]. An example of guidance on this subject is included in Ref. [42].

10. SELECTION OF THE OPTIMUM DISMANTLING STRATEGY

To select the optimum dismantling strategy for a nuclear stack, factors relevant to decision making must be identified and evaluated. Key decision making factors are:

- Waste management;
- Radiological and industrial safety and environmental requirements;
- Regulatory requirements (acceptability of strategy, end state release requirements);
- Stack design, construction and physical condition;
- Operating history (e.g. routine contaminant deposition, accidental deposits);
- Access to stack, working environment (e.g. height, location, impacts on other facilities);
- Proximity to adjacent facilities;
- Resource and equipment cost and availability;
- Funding priorities;
- Public concerns.

In selecting a dismantling strategy, each of these factors is crucial in terms of its impact on the conduct of the project in a safe, timely and cost effective manner that meets regulatory requirements. The following paragraphs present a discussion of how individual factors may influence decision making.

Waste management can be a major factor in determining the dismantling approach and timing. For example, the availability of treatment and disposal facilities for contaminated waste may lead to an immediate dismantling strategy. Conversely, where waste cannot be readily accommodated, it may be practical to select a deferred strategy. The unavailability of waste disposal facilities can also drive a more comprehensive decontamination strategy in an attempt to reduce the amount of waste requiring interim storage where early dismantling is necessitated by other factors. On-site disposal of low level radioactive waste or cleared material may be an option on certain sites, depending on local and regulatory acceptance. On many sites this is not an option and more complex waste management issues may drive the dismantling strategy.

Radiological and industrial safety and environmental requirements can have a large influence on the selection of stack dismantling strategies. For example, dismantling stacks having high radiation fields or large amounts of loose contamination may require the adoption of special techniques and equipment selected to minimize worker doses. Industrial safety hazards often outweigh radiological risk in stack dismantling projects and require careful assessment.

Regulatory requirements can significantly affect the selection of the dismantling approach. Some strategies may be unacceptable and difficult to approve because of area safety and environmental concerns. For example, the selection of felling by explosives may raise concerns about impacts on adjacent buildings. End state requirements may also influence the strategy. An unrestricted release end state demands more rigorous decontamination to meet release criteria.

Stack design and construction also influence the selection of stack dismantling strategies. Large, massive concrete stacks will require a different set of technologies and equipment than small diameter metal stacks. The dismantling strategy should be selected to best match the physical and structural requirements of the stacks. For example, explosive, crushing and sawing techniques are better suited to concrete or brick stacks, while thermal (torch) cutting techniques work better for metal stacks.

The operating history of a stack can greatly influence the selection of dismantling strategies. For stacks where the operating history reveals little or no radioactive or chemical contamination, dismantling operations are straightforward, and strategies can be selected accordingly. However, for stacks with high levels of radioactive or chemical contamination, strategies may involve aggressive predecontamination or alternatively require remote operation and total containment. In such cases, much more rigid controls are appropriate in predecontamination and/or dismantling of the stack, in monitoring worker exposure and environmental releases, and in the packaging and disposal of waste. Where alpha contamination is present, more rigorous monitoring and contamination control are required.

Proximity to adjacent facilities can have a large impact on the selection of dismantling strategies, and stacks located near operational facilities are generally not candidates for explosive removal. These stacks must generally be removed from the top down. Conversely, isolated stacks, particularly those that are massive and easily decontaminated, are good candidates for explosive removal. As a general rule, dismantling activities should not interfere with ongoing operations at a facility and should not impact other workers or the environment.

Funding priorities, budgets, resource availability and equipment costs may influence the dismantling strategy and may eliminate some options. For example, the availability of certain resources, e.g. explosives experts or large cranes, may strongly influence the strategy selection.

Local community public relations may be of enhanced importance. The stack may have become a site landmark and community symbol, and there may be significant resistance to its removal. Additionally, the dismantling is a highly visible activity possibly involving innovative techniques (explosives) and the use of extremely large lifting equipment (cranes capable of hoisting large loads at significant heights). These factors can make necessary a comprehensive communications plan to address local sensitivities and safety concerns. An example of local use of a stack as a landmark is given in Ref. [43]. In this case an 80 m high stack had been used in the past to aid navigation into a local harbour on Lake Michigan in the USA.

To select the most appropriate strategy, the above considerations must be reviewed and a series of key variables defined. These variables can then be ranked according to their importance and due weighting can be given to each. One approach is to construct a quantitative scoring system for the factors pertinent to alternatives for a specific stack dismantling project, to identify the advantages and disadvantages of each alternative and rank the options to arrive at an optimum strategy. More formal quantitative evaluation methods, such as cost–benefit analysis and multiattribute analysis are available. A detailed presentation of such analysis techniques is given in Refs [32, 44, 45]. However, the value of such formal assessment techniques may be limited, considering the number of variable parameters present in any individual stack dismantling project.

Whichever approach is selected, careful analysis of the various parameters must be performed and documented. It should also be noted that no matter how carefully the analysis is done, overriding requirements such as regulatory criteria may supersede other considerations and dictate the actual strategy selected.

The following examples highlight the importance of the decision making process in the selection of a dismantling strategy.

The dismantling strategy initially selected for one case (Garigliano NPP, Italy) was controlled collapse using explosives [46]. The decision for this initial strategy selection was based on the following main factors:

— Available experience indicated that this strategy was reliable.
— The project implementation was of short duration.
— Dismantling activities were planned to be conducted at ground level, minimizing industrial risks compared with those involved in working at a height of about 100 m.

The strategy based on the use of explosives assumed that a few buildings adjacent to the stack would be removed prior to stack dismantling. Plans changed, and it appeared that new waste storage buildings would have to be constructed, thus further reducing the safe space available for stack collapse. Owing to these factors, the strategy was changed to top-down segmenting [14, 20].

Explosive collapse was also selected for the dismantling of a stack at Hanford, USA, as described in Refs [21, 22]. In this case the strategy withstood scrutiny and was implemented. Following decontamination, the stack interior was painted with a water based latex paint to stabilize any remaining contamination. Painting was accomplished remotely using a specially designed manifold from an airless pump attached to the same carriage used for sandblasting. The demolition work included chipping out sections of the stack to establish hinge joints; drilling holes in the stack for the placement of explosives; erecting a blast shield around the base of the stack; and loading, firing and detonating explosives. The stack was dropped into an area surrounded by 3 m high berms. These berms restricted flying debris caused by the impact of the stack landing. Prior to demolition, a temporary water spray system was designed and installed to minimize and control the dust generated when the stack hit the ground. Eventually the entire stack was covered with fill material and disposed of in situ. Similar projects are described in Refs [47–49]. Figure 21 shows the fall of a Hanford stack.

The decision making process followed to dismantle a stack at the Savannah River Site, USA, is described in Ref. [50]. Initially the preferred demolition method was mechanical disassembly using conventional tools and techniques. This required that personnel mechanically break the stack starting from the top while working from suspended or attached temporary working platforms. Initially explosive demolition was rejected in favour of mechanical disassembly because the former posed unmanageable safety risks. For example, proximity to a building where irradiated fuel was handled presented a major problem because parts of this building were located within the height range of the stack. A misdirected fall could have had serious consequences. One of the more significant arguments against explosive demolition was the lack of technical experience and familiarity of site personnel with this technique.

Ultimately the discovery of significant levels of tritium in the stack raised questions about using mechanical disassembly. Radiological protection controls were needed, including measures to prevent the spread of contamination beyond the worksite. This new requirement significantly increased the complexity of the work. For example, the use of protective clothing to mitigate contamination hazards introduced other safety concerns, such as limited vision, heat stress and decreased dexterity. This led to a re-evaluation and eventually to selection of the explosive dismantling technique. United States Department of Energy personnel and contractors assisted in solving associated issues such as ground vibration, air blast and flying debris. Further details of this project are given in Refs [50–53].

The criteria and factors in the decision making process for a dismantling strategy for the Windscale Pile stacks are described in Refs [54, 55]. In particular, Unit 1 was heavily contaminated as the result of a serious accident in 1957. Preliminary studies identified three constraints on selecting the dismantling strategy:

(a) The unacceptability of using cranes, owing to space constraints and height limitations, and because of the potential for damage to adjacent nuclear storage ponds and reprocessing plant from a dropped load or a crane toppling;
(b) The need to use remotely operated equipment to decontaminate some areas of the structure to reduce radiation and contamination levels prior to personnel access, in accordance with the ALARA principle;
(c) The need to use contamination control measures to prevent the spread of radioactive contamination from the working areas.

In the Windscale case it was necessary to construct primary and secondary containments at the base of the stack prior to the base access doorway being cut into the stack. Ventilation was installed at the stack base and top. The ventilation was introduced into the stack through diamond core drilled holes. After removal of the concentrator section from the top of the stack, the aperture was enclosed to complete the containment.

In the case of Gösgen NPP, Switzerland, the decision making process was impacted by the regulators, who could not accept an auxiliary stack for a longer period of continued full reactor operation during stack dismantling. The initial approach developed for top-down breaking was abandoned in favour of employing the latest technologies using diamond circular blade cutting to dismantle the stack by top-down segmenting. The project is described in Annex I.H.

Decision making for the Marcoule G1 stack in France also led to a change in the dismantling method. The original plan, to use conventional top-down segmenting, was not approved by the regulator. An alternative plan using explosives was developed and approved, and led to successful felling of the stack. The project is documented in Annex I.G.

11. DISMANTLING OF ANCILLARY SYSTEMS

There are a number of ancillary systems associated with stacks, including drains, ventilation ducts, monitoring systems, etc. Where these systems form an integral part of the stack, it is appropriate to dismantle them as part of the stack dismantling project. Ancillary systems that are outside the physical stack boundary are considered to be part of the overall facility or site decommissioning project.

The boundary and interfaces of the stack dismantling project need to be clearly identified and managed to ensure that ancillary systems and services are appropriately isolated and terminated prior to and following the dismantling work.

Temporary systems required for the dismantling work need to be appropriately installed and connected to adjacent ancillary systems and services. Temporary systems also need to be removed at the end of the work with appropriate terminations.

Some ancillary systems may need to be maintained during the stack dismantling project, e.g. navigation lights. Temporary arrangements and controls may be needed as the height of the stack is reduced.

12. ORGANIZATIONAL AND MANAGERIAL ISSUES

In general the organizational and managerial aspects associated with a stack dismantling project are not markedly different from those connected with carrying out other nuclear decommissioning projects, and the documentation requirements are essentially the same. Organization, planning and management aspects of nuclear decommissioning projects are well documented [56, 57]. However, there are a number of considerations specific to a stack dismantling project that require attention, in particular the following:

(a) Although an organization may have considerable experience in nuclear decommissioning work, stack dismantling may represent a ‘first of its kind’ task. This may require seeking specialized expertise to manage work in an exposed environment at great heights.
(b) The safety review system for a nuclear facility or site often focuses heavily on nuclear safety. For stack dismantling, the conventional hazards often outweigh the nuclear hazards, and the safety assessment processes may

have to be adapted to properly evaluate those hazards. An example of the hazards of working at extreme heights is documented in Ref. [58].

(c) The combination of skills needed for working at height with radioactive materials will have to be addressed and may require specific training.

(d) Public relations may be important where a stack has become part of the local landscape, heightening sensitivity about its removal. The public may also have safety concerns about the actual removal project.

13. COSTS

Budgetary constraints are a significant factor in developing overall facility decommissioning strategies. These constraints extend to the development of stack dismantling strategies. Stack dismantling costs are often dominated by site specific issues that require evaluation before a clear project cost can be established. Because of this, cost comparisons between stack decommissioning projects can be misleading. The elements of cost for stack dismantling projects are broadly similar to those for decommissioning projects in general (see, for example, Ref. [59]). The key factors influencing stack dismantling project costs include:

Site factors:

— Structure, size, height and type of stack;
— Physical condition of stack;
— Nature and level of contaminants;
— Location of facility;
— Proximity to adjacent facilities.

Management interfaces:

— Regulatory framework;
— Safety and environmental requirements;
— Availability of resources and suitable expertise;
— End state criteria;
— Stakeholder management issues.

Waste management:

— Availability of disposal/recycling routes;
— Treatment, packaging and transport requirements;
— Interim storage issues.

Site factors influence cost largely on the basis of safety issues. For example, where explosive dismantling can be used, it often provides the quickest and least expensive dismantling option. However, if there is a risk to adjacent facilities, this method is not appropriate and an alternative approach must be selected. For remote locations the access to large equipment (cranes) may significantly increase cost.

Management cost influences are predominantly risk based. For example, failure to obtain the required regulatory approval can result in significant rework.

Waste management factors may dominate project cost where large amounts of radioactive waste are unavoidable. Good waste management practice minimizes waste generation, maximizes reuse and recycling, avoids mixed waste production, and minimizes the overall cost of radioactive waste treatment and disposal. In general, where established radioactive waste treatment and disposal routes exist, project costs can be accurately estimated. Where these routes are not available, waste management costs are more difficult to predict, may have a greater influence and may dominate project cost.

14. CONCLUSIONS

For this report an evaluation was made of the factors to be considered in planning and implementing a dismantling project for nuclear facility stacks. A number of conclusions can be drawn from the evaluation, as follows:

(a) Virtually all nuclear facilities have ventilation stacks which must be dismantled as part of broad site and facility decommissioning programmes.
(b) Although contamination levels and contaminants vary, stacks subjected to accidental releases may have high contamination levels.
(c) Dismantling experience with nuclear stacks is not extensive, but equipment and technologies are readily available from experience with industrial stack projects (e.g. use of explosives, very large cranes) and

have been easily adapted and used in a number of countries to complete nuclear stack dismantling projects.

(d) Industrial safety considerations usually outweigh the risks associated with radioactive contamination.

(e) Waste management, including release criteria, is an important factor in developing a nuclear stack dismantling project and is often a critical factor in the timing and cost of a project.

(f) Stack dismantling is a highly visible activity that can create a need for a well developed stakeholder communications programme in order to achieve public confidence, which in turn can also influence regulatory requirements.

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Annex I

EXAMPLES OF NATIONAL EXPERIENCE

The examples provided in this annex address a wide range of technical and organizational aspects of stack decommissioning. This information is intended to provide practical guidance based on how stack decommissioning projects are planned and managed in various countries. The examples given are not necessarily best practices; rather they reflect a wide range of national legislation and infrastructure, site conditions and nuclear programmes. Although the information presented is not intended to be exhaustive, the reader is encouraged to evaluate the applicability of these schemes to a specific stack decommissioning project.

Annex I.A

CANADIAN EXPERIENCE OF STACK DISMANTLING

I.A–1. INTRODUCTION

Since 1990, Atomic Energy of Canada Ltd (AECL), a Government of Canada Crown Corporation, has completed two nuclear facility ventilation stack decommissioning projects to meet facility and/or laboratory operating needs for reactors in the initial phases of decommissioning. The first project was conducted in 1991, addressing the complete removal of the redundant NRX reactor ventilation stack that had been isolated from the reactor in the 1950s following an accidental contamination incident.

The second project, also carried out in 1991, involved the height reduction of the Whiteshell Reactor 1 (WR-1) stack, which consisted of a ventilation stack combined with an emergency cooling water supply tank located at the top of the structure. The project activities are outlined separately for each project in the following sections.

I.A–2. NRX VENTILATION STACK REMOVAL

The NRX reactor ventilation stack was removed from service in 1952 following a contamination release incident which resulted in deposition of fission products on the inside surface of the stack. The stack was isolated from the reactor and sealed at the top with a steel cap, and it remained in that state until decommissioning was undertaken in 1991.

The stack was 60 m in height and was constructed of reinforced concrete erected on a 1.7 m thick base slab approximately 8.5 m wide. The outside diameter was 3.4 m at the base, with a wall thickness of 0.4 m, tapering to an outside diameter of 1.5 m at the top, with a wall thickness of 0.1 m.

A radiation survey conducted prior to dismantling confirmed the results of an earlier survey indicating ^{137}Cs to be the primary contaminant (in concrete), in the range of 50 000 Bq/g. The surveys also indicated alpha contamination, mainly from plutonium, at a level of 100 Bq/g, and beta contamination at a level of 18 000 Bq/g.

I.A–2.1. Selection of removal method

Pre-decommissioning planning placed emphasis on the health and safety of the workers and the public, as well as on protection of the environment, throughout the dismantling project, incorporating the following principles:

- Compliance with the ALARA principle;
- Minimization of exposure to radiological and industrial hazards;
- Achievement of a safe end state for any remaining structure or systems at the end of the project.

Three approaches to dismantling were evaluated in the removal method selection process, namely:

- Rubble the stack in an as-is condition;
- Decontaminate in situ and then rubble;
- Dismantle in sections and remove from the site for decontamination.

The sectioning followed by removal to a work location for decontamination was selected since this approach resulted in the earliest unrestricted release of the site for other uses and provided better control over, and more time for, the decontamination process.

The key work packages identified were:

- Painting of the bottom 3 m of the stack interior surface;
- Assembling access scaffolding;
- Removing the stack cover seal; inspecting, monitoring and removing loose contamination from the interior surface;
- Painting the interior surface at the cut locations;
- Setting up crane operations;
- Cutting stack sections and transporting them to the waste management area;
- Sectioning and removal of the foundation pad;
- Clearing the site for turnover to the site owner.

A work plan was prepared for each work package, detailing the individual work steps and the personnel and qualifications required. Safety requirements were also detailed in each work plan. The work was carried out by a contractor.

I.A–2.2. Removal

The contractor was given full responsibility for the crane, high rigging and painting operations, and for transport of the stack sections. Bracket cable scaffolding was used to provide suspended work platforms approximately 0.3 m below each cut location. Five platforms were rigged initially and then removed from the cut sections lowered to the ground and reused for subsequent cuts.

The interior surface of the stack was painted at each cut location to minimize the release of contamination during cutting. A negative pressure was maintained in the stack during all operations through the use of a 1000 cfm (28 m^3/min) HEPA filtration unit installed at the base of the stack. The open upper end of the stack was fitted with a plywood cover overlaid by polyethylene taped to the concrete sides of the stack section to further control contamination release during cutting. On completion of each cut, the bottom end of the section was also sealed with polyethylene sheeting to minimize contamination release during lowering and transport.

A diamond wire saw was used for the cutting operation. The wire was driven by a variable speed, reversible hydraulic motor, which provided ample control over the cut depth to avoid cutting through the inner surface. The cutting progressed to within 25 mm of the inner surface. At that point, the crane tension was applied to break the section being removed free of the remaining stack. The section being removed was secured by two chains to the stack below to restrict motion during the final cut and breaking-off process.

I.A–2.3. Waste handling

The diamond wire cutting operation required water for lubrication. A recycling water supply system was used to minimize the amount of secondary waste produced. In total, 800 L of water and 400 L of sludge were generated. The water was free of contamination and was processed through the site active drainage system. The sludge was solidified and placed in waste storage.

The stack sections were transferred to an on-site waste storage area for decontamination. The intention was to decontaminate the concrete surface of each section to allow disposal of most of the concrete as non-radioactive waste. Initial attempts at decontamination using shot blasting and scabbling methods indicated that over 90% of the contamination was contained in 1.5 mm of the superficial layer. However, there was deeper penetration around joints and around construction hanger bars, creating uncertainty that the sections could in fact be decontaminated to levels that would allow landfill disposal of most of the concrete volume. The sections have been secured in storage at the waste management site pending future evaluation and possible additional decontamination before final disposition.

I.A–3. WR-1 STACK HEIGHT REDUCTION

The second project involved the WR-1 stack, which was a combined ventilation stack and emergency cooling water storage tank. It consisted of a 45.7 m high by 2 m diameter ventilation column with an 8.4 m spherical water storage tank (263 000 L capacity) surrounding the upper section of the structure. The stack was constructed from carbon steel plate, insulated with rigid non-asbestos insulation and covered with an aluminium outer jacket. The inside of the stack column contained three water supply lines routed to and from the water storage tank.

With the shutdown of WR-1 in 1985, the emergency cooling water tank was no longer required. Although the ventilation stack component must remain in operation to meet the decommissioning plans for the reactor, removal of the stored water was carried out following reactor shutdown to reduce operating costs. The stored water required heating during the winter, adding a substantial burden to the decommissioning cost.

Following draining of the tank, it became apparent that the stack became unstable in high winds owing to vortex shedding under reduced mass conditions. Stability was re-established by refilling the tank with water, which again entailed a high annual operating cost. Ultimately the decision was reached to remove the upper tank portion of the stack to eliminate the water storage cost. Studies concluded that the height reduction from 45.7 to 30.4 m was acceptable for meeting the operational ventilation needs for WR-1 during decommissioning and planned deferment periods.

I.A–3.1. Tank removal plan

The work steps to remove the upper tank section of the stack consisted of:

- Recalculation of the stack release limits to confirm that environmental release limits were not impacted by the reduced height;
- Guying the tower to maintain stability during removal operations;
- Removal of aluminium cladding and insulation at all cutting locations;
- Cutting off internal water pipes and electrical cables to the stack aircraft obstruction lights;
- Removal of the tank and stack sections and lowering them to the ground;

— Salvaging the top 2 m of the stack (outlet pipe section) for capping the stack at the reduced height;
— Restoring the aluminium cladding to its original condition for the remaining stack;
— Reconnecting the aircraft obstruction lights at the top of the stack;
— Decontamination and disposal of the stack and tank components.

A radiation survey of the interior stack surfaces revealed very low levels of contamination, indicating that lowering the stack sections to an adjacent lay-down area was adequate to control any possibility of contamination dispersion. The removal work was contracted out to Dominion Bridge, a crane company, with work carried out under AECL project management. A schematic of the height reduction plan is given in Fig. I.A–1.

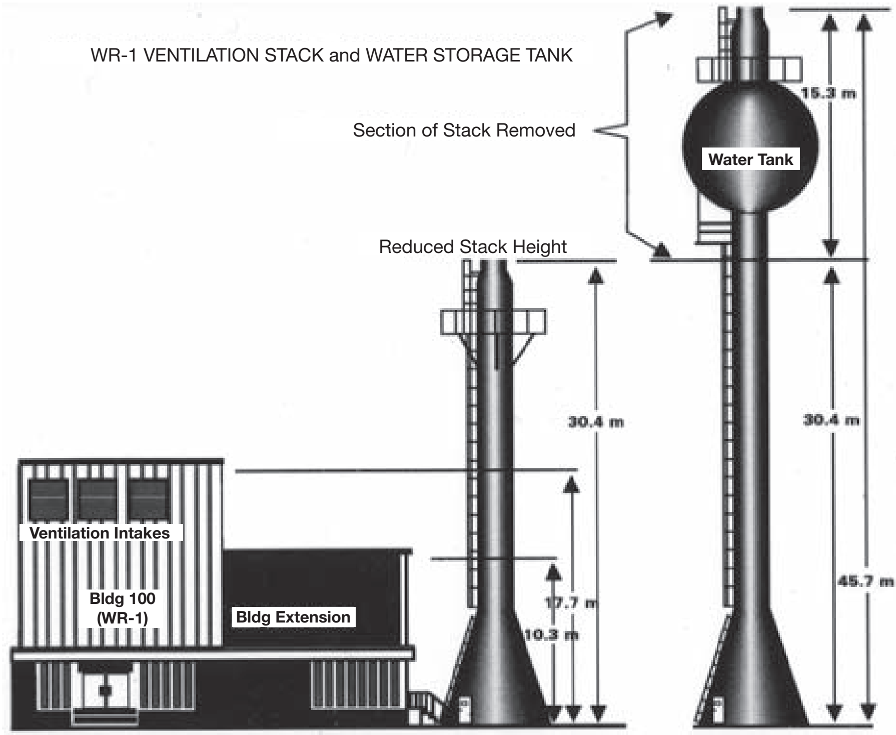

FIG. I.A–1. *Schematic of the WR-1 stack height reduction plan.*

I.A–3.2. Height reduction

The height reduction operation was a specialized large scale dismantling activity accomplished by the contractor through the use of two cranes: a 30 t crane to raise and lower person-lifts to allow access to the tank for segmenting, and an 80 t crane to lower cut segments to the ground. The tank was removed in four sections as follows:

- The upper ventilation stack section, including an access platform at the top, was cut off immediately above the water tank.
- The upper half of the water tank was torch cut from the lower portion and removed (Fig. I.A–2).
- The internal ventilation pipe section was removed.
- The lower half of the tank was cut free and removed along with a section of the lower ventilation stack (Fig. I.A–3).
- The upper ventilation stack section, including the access platform, removed as the first step, was then reattached to the top of the remaining stack column to provide a remaining stack operating height of 30.4 m.

The ventilation stack was returned to normal operation to meet the needs of the WR-1 reactor decommissioning programme; it is to remain in operation during a planned deferment period which is expected to extend to about 2040.

I.A–3.3. Waste handling

The sections of the water tank and the stack column were collected in a local lay-down area for survey and decontamination as the project progressed. The water tank material was free of contamination and was shipped off-site for recycling. The stack sections revealed some low level contamination during the radiation survey. These sections were decontaminated to clearance criteria and were then disposed of in an on-site non-radioactive landfill.

I.A–4. CONCLUSIONS

These ventilation stack projects were both completed successfully to meet ongoing AECL laboratory site requirements. The NRX stack removal met site needs by releasing space required for a new development project. The WR-1 stack height reduction met the continued need for a facility stack during the reactor decommissioning programme while significantly reducing the cost of continuing operation.

FIG. I.A–2. *Removal of the upper half of the water tank.*

FIG. I.A–3. Removal of the lower half of the water tank.

Annex I.B

DECOMMISSIONING THE SGHWR STACK

I.B–1. INTRODUCTION

The Steam Generating Heavy Water Reactor (SGHWR) was a 300 MW(th) prototype power reactor operated at Winfrith in the United Kingdom between 1967 and 1990. The SGHWR stack was used to discharge filtered air from the reactor secondary containment from the mid-1960s until 1999.

The SGHWR stack was decommissioned to reduce the visual impact of the SGHWR facility. The stack was the highest structure on the facility, indeed on the Winfrith site. A schematic of the stack is shown in Fig. I.B–1, and views of the SGHWR facility are included as Fig. I.B–2. Views of the stack during construction are included as Fig. I.B–3, and views of the stack prior to decommissioning are shown in Fig. I.B–4.

I.B–2. DESCRIPTION

The SGHWR stack was constructed from reinforced concrete with a central stainless steel flue. The stack was 120 ft (36.6 m) high and extended a further 24 ft (7.3 m) below ground. The internal diameter was 6 ft 6 in (2.0 m), and the wall thickness was 1 ft 2 in (0.35 m) at the base (up to 10 ft (3.0 m) above ground level) and 9 in (0.23 m) for the remainder.

The stainless steel flue was 1 ft 9 in (0.53 m) in diameter and was centralized by six steel spiders. A steel soot and access chamber for the flue was located at ground level and was supported by a profiled reinforced concrete support beam.

The stack was internally contaminated with radioactive surface contamination, and in addition tritium was absorbed into the bulk concrete. Surface contamination resulted from any particulate contaminants that were not captured by the HEPA filters and carbon beds. Tritium contamination absorbed into the concrete resulted from the legal discharge of tritium over the life of the reactor. The HEPA filters and carbon beds did not capture tritium.

The stack was internally monitored for surface contamination, and readings of up to 34 Bq/cm^2 were recorded. The predominant isotopes of the surface contamination were ^{137}Cs and ^{60}Co. A sample of concrete chipped off the inside surface of the concrete at the base of the stack was analysed for

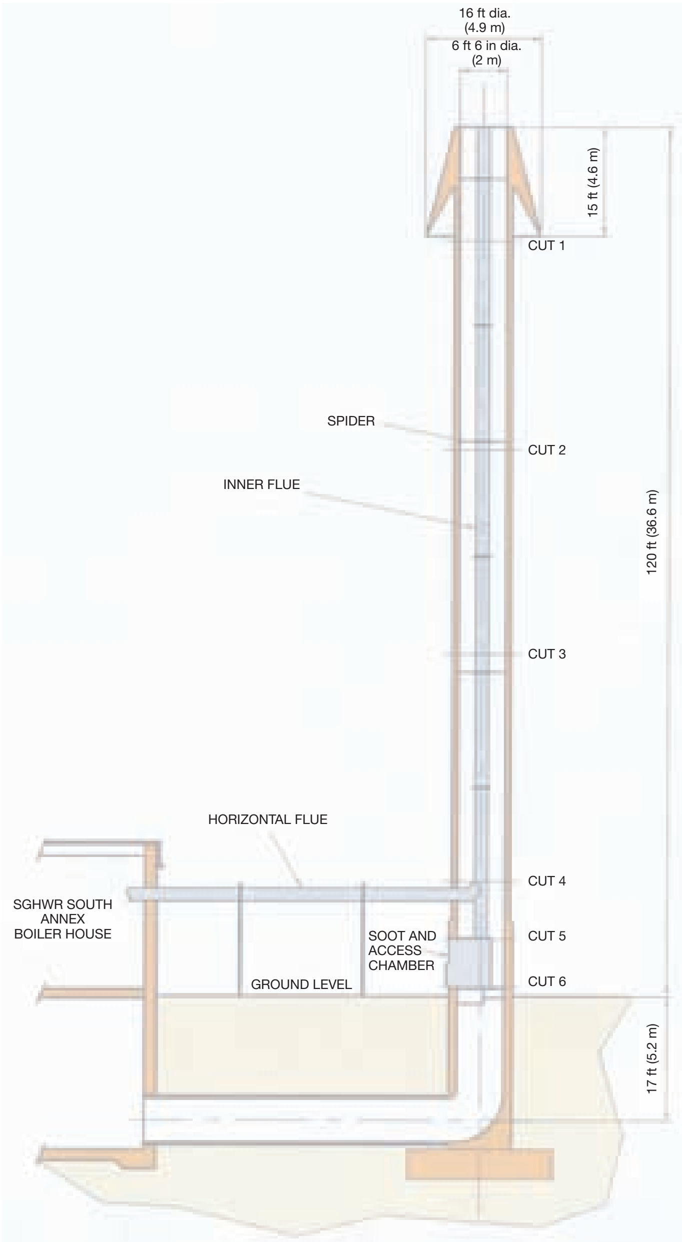

FIG. I.B–1. Diagram of the SGHWR stack.

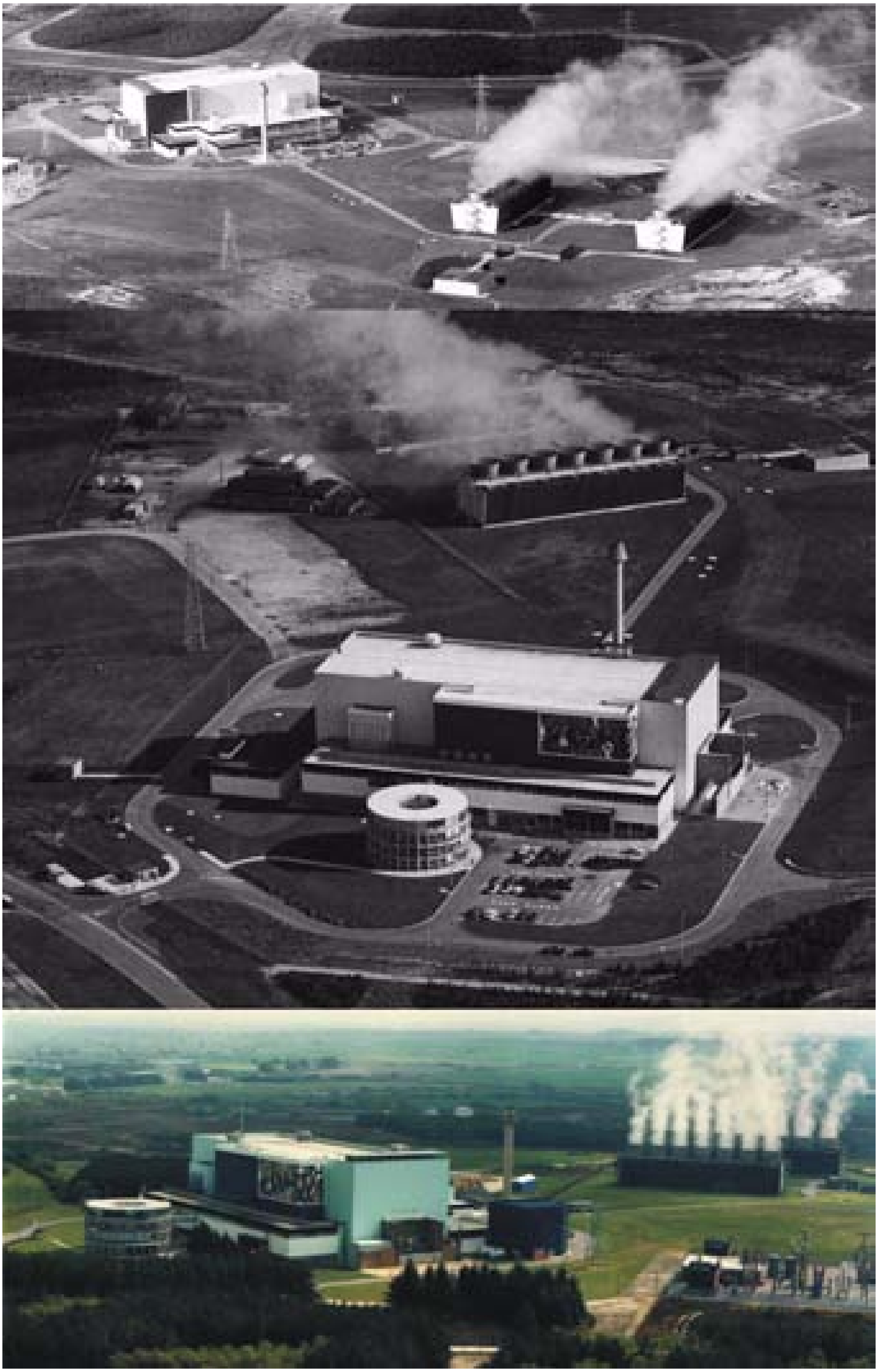

FIG. I.B–2. Views of SGHWR.

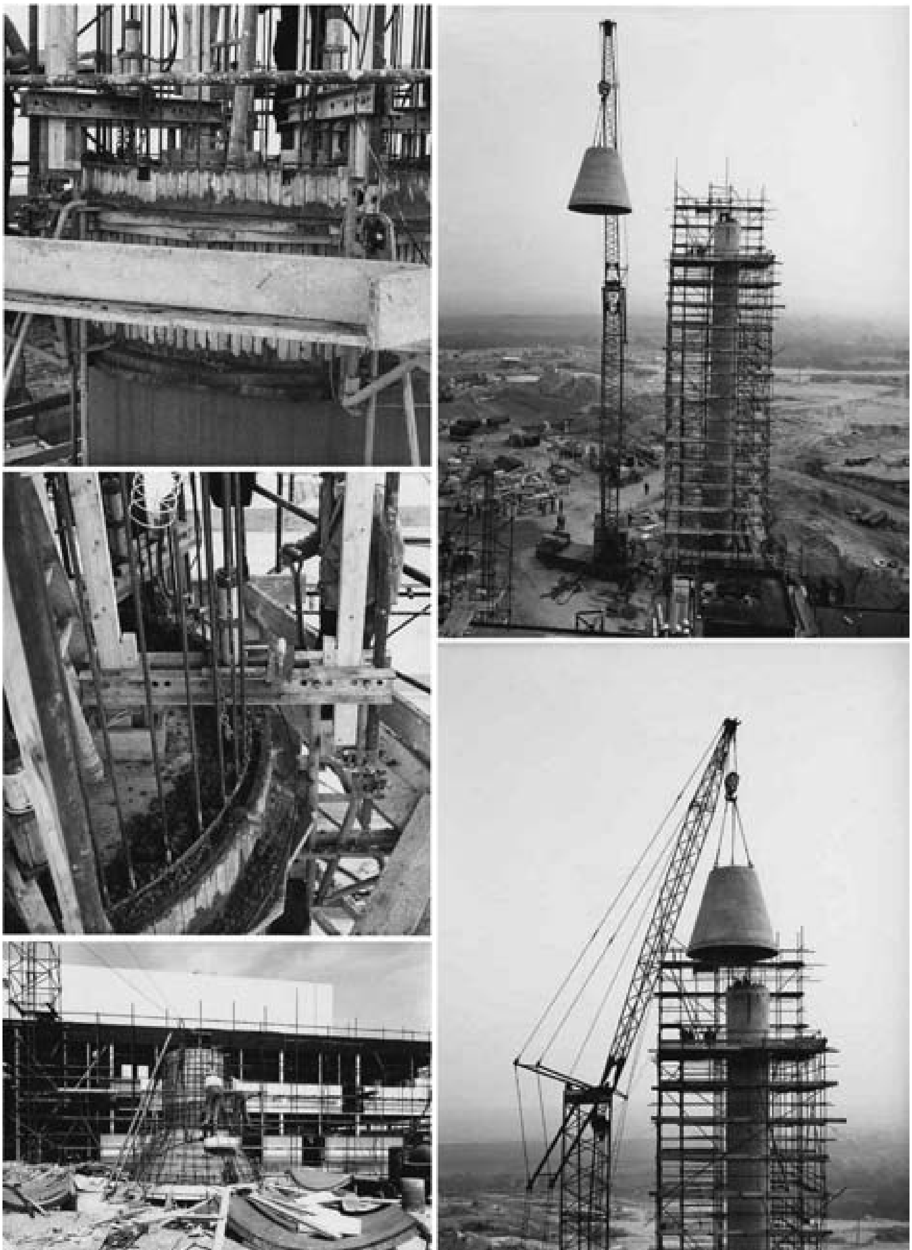

FIG. I.B–3. SGHWR stack during construction.

FIG. I.B–4. SGHWR stack before decommissioning.

tritium. A reading of 5.79 Bq/g was recorded. Tritium analysis of cores taken at ground level gave maximum readings of 15.9 Bq/g, with peak readings located about 2 in (0.05 m) from the inside surface.

Asbestos gaskets and joinings were present between connections on the inner steel flue and soot box on the stack.

I.B–3. PROJECT STRATEGY

I.B–3.1. Project definition

The SGHWR stack decommissioning project was defined as:

— Dismantling of the reinforced concrete structure of the stack to ground level in large undisturbed sections;
— Surface decontamination of the concrete sections to clearance levels for on-site storage;
— Dismantling of the soot box and flue, and packaging for disposal as low level radioactive waste (LLW) or cleared waste;
— Capping and weatherproofing of the underground parts of the stack.

The project was defined in this way predominantly to address waste management issues. The main issue was how to deal with surface and absorbed tritium contamination without creating a large radioactive waste disposal liability.

It was recognized that surface decontamination of the stack would be required to minimize radioactive waste disposal volumes and for any subsequent storage of concrete sections. Decontamination of the surface was only considered feasible in situ, i.e. before the stack was dismantled, or by first dismantling the stack into sections and then decontaminating on the ground. Decontamination in situ would have involved extended working at height, in confined spaces and wearing respiratory protection, and was therefore dismissed on safety grounds. Thus it was decided to dismantle the stack in sections for surface decontamination on the ground.

Decontamination of the absorbed tritium in the concrete was not considered feasible. It was therefore concluded that while the stack could be decontaminated with respect to surface contaminants, the bulk concrete could not be completely decontaminated for disposal as cleared waste. The volume of concrete in the stack is of the order of 125 m^3, and allowing for packing fractions, this volume could double for disposal. The cost and practicalities of disposing of a bulk volume in the region as LLW were prohibitive. Tritium contamination of concrete is a wider issue affecting the decommissioning of SGHWR as a whole, and thus it was decided to store the stack sections locally pending further processing and disposal.

The main objective of the project was to decommission the stack to reduce the visual impact of the SGHWR facility. In addition, there are numerous underground structures and services in the vicinity, and it was not practical to excavate and remove the underground parts of the stack. It was therefore decided to decommission only the above ground structures.

I.B–3.2. Contract strategy

An implementation contractor under United Kingdom Atomic Energy Authority (UKAEA) control carried out the decommissioning of the stack. The implementation contract was tendered as a fixed price package of work using the New Engineering Contract, Engineering and Construction Contract Option A: Fixed Price with Activity Schedule. The contract covered the scope of work as defined in the project definition above. Following competitive tender, the contract was awarded to Hertel Services (UK) Ltd. Features of the contract included:

- The contract requirements were written as a performance specification — what, not how.
- UKAEA was responsible for monitoring and controlling safety and project delivery.
- The contractor was responsible for the methodology and the planning, management and implementation of the work.
- UKAEA was responsible for the safety case (based on the accepted methodology).
- Weather risks were shared. The contractor bore the first three days; thereafter UKAEA owned the risk.
- Decontamination risks were shared. The contractor's risk was limited to removing an average of 5 mm from each surface to meet decontamination requirements.
- UKAEA was responsible for the disposal of radioactive waste.
- UKAEA was responsible for providing health physics support to the work.
- This project showed the importance of a cooperative, partnering relationship between the nuclear operator and the contractor.

I.B–4. PROJECT IMPLEMENTATION

I.B–4.1. Preparation

The contractor's outline methodology was included in its tender and was accepted by UKAEA during contract award. The accepted outline methodology comprised:

— Erecting scaffolding to the full height of the stack;
— From the top, cutting through the stack (by diamond wire sawing) and lifting the released sections to the ground;
— Progressive lowering of the scaffold, and cutting and lifting the released sections to the ground;
— Surface decontamination of the sections on the ground;
— Capping and weatherproofing the base of the stack at ground level.

UKAEA prepared the safety case for the work on the basis of the accepted outline methodology and obtained approval from the Site Safety Committee. The safety case included a full hazard assessment supported by a Hazard and Operability (HAZOP) study.

Detailed controlling documentation, including method statements supported by specific risk assessments, crane lifting and berthing plans, manual handling assessments, etc., was produced by the contractor for each detailed task or phase of the work. This documentation was assessed and approved locally by UKAEA (provided it remained within the bounds of the safety case). UKAEA used specialist advice to support assessment and approval, including the following:

— The Senior Appointed Person Electrical was consulted for temporary power supplies to the diamond wire saw cutting equipment.
— The Senior Appointed Person Lifting was consulted for all lifting operations and approved lifting and berthing plans.
— Radiation Protection Advisors were consulted for any work with ionizing radiation, particularly cutting and decontamination work.
— Civil engineering consultants checked scaffolding calculations, and crane positioning and ground bearing calculations.

Several technical issues were addressed during the detailed work planning. These issues were resolved by the contractor and UKAEA working closely together, while recognizing contract responsibilities. The technical issues and solutions are outlined as below.

Size of sections

The contractor proposed to cut the stack into as few sections as possible. This was based on the size of crane required to lift the top cowl section. The cowl was estimated to weigh 55 t and would require a 500 t crane to lift and lower it to the ground. The contractor proposed cutting the remainder of the 9 in (0.23 m) thick section of the stack into three sections nominally 9 m long and weighing approximately 35 t, and to lift and lower the sections to the ground with the same crane. The 9 m long sections would be tilted to the horizontal during the lowering operation. The final lower section would be cut in two and lifted by a smaller crane. UKAEA accepted this proposal, noting the following:

- The proposal increased the commercial risk of weather delays. Large capacity cranes are more expensive, and the inherent weather delay risk (i.e. over three days) is owned by UKAEA.
- The proposal improved safety by minimizing the number of operations and the amount of work required at height (particularly cutting and lifting operations).

The cowl was found actually to weigh only 40 t as it was constructed of lightweight concrete, and a 1000 t capacity crane was used because a 500 t crane was not available.

Strength of concrete

The contractor proposed to sling the sections of the stack for lifting using chain slings through holes cut in the stack. UKAEA required the contractor to demonstrate the strength of the concrete to bear the slings. The lifting points were predrilled at the start of the work by core drilling and the resulting cores were sent for strength testing. The analysis results confirmed the predicted concrete strength, thus confirming the acceptability of the slinging arrangement. The analysis of the cowl cores also revealed the lightweight concrete construction of the cowl.

Sequencing of cutting and lifting operations

The cutting and lifting operations were carefully sequenced to ensure that an unsupported section could not fall from the stack, that the scaffolding was not damaged during lifting, and that a section was not left overnight under support by the crane. The detailed sequencing was developed by the contractor and was extensively reviewed and assessed by UKAEA before acceptance. The accepted sequencing was as follows:

(a) Set up working platform and wire saw at cutting position.
(b) Sling inner steel flue to crane.
(c) Cut 80% through the stack to release the inner flue section and stop cutting. A detailed assessment confirmed the stability of cutting 80% through the stack unsupported by the crane. T-section pieces were inserted into the cut to prevent the cut closing on itself as the cut progressed.
(d) Lift the released inner flue section out of the stack and lower it to the ground. Process and package the flue section for disposal.
(e) Sling the stack section for lifting.
(f) Dismantle the scaffolding to the working platform level at the cutting position.
(g) Complete the cut and lift the released section to the ground (tilt to the horizontal for the 9 m long sections).

Steps (e) to (g) were required to be completed within a single working day so that the section was not left overnight under support by the crane.

Contamination control during cutting

Diamond wire sawing through concrete is a wet cutting operation and the potential to spread contamination via the water used for cutting was recognized. Gullies were attached and sealed to the outside of the stack to collect the water and cut concrete and to channel it to drums at ground level. A dam was set up at the inside base of the stack to collect any water inside the stack. Solids in the water were allowed to settle and the water was siphoned off the top. Settled solids were disposed of as LLW, and the water was monitored and discharged to the drainage system. In the event, no contamination was detected in the water.

Decontamination

The sections were enclosed and ventilated on the ground for surface decontamination by operators in air suits. However, surface decontamination proved much more difficult than expected. Proven mechanical concrete decontamination methods that have been successful on flat surfaces were not as effective on the inside curved surfaces of the stack sections. Water jetting was attempted, but in the relatively enclosed space of the stack sections, loss of visibility because of the water spray became a problem. The only successful method was working by hand with needle guns and similar tools. This was a slow process and it was made more so by the low trigger rates necessary with such tooling to avoid hand and arm vibration problems. Thus it took considerably longer than planned to decontaminate the inside surfaces of the sections.

I.B–4.2. IMPLEMENTATION

The SGHWR stack was dismantled between 15 February and 19 March 2002. Dismantling activities went very well, were carried out according to the plan and were successfully completed without incident. Dismantling work was delayed for a total of eight days during this period owing to adverse weather (high winds). Stack dismantling operations are shown in Fig. I.B–5 and diamond wire sawing is shown in Fig. I.B–6.

Decontamination of the stack sections took considerably longer than planned. The intended decontamination method, scabbling with rotary flap wheel type tools, was not effective. Scabbling with needle gun type tools was more effective but progress was slow and it was made more so by the low trigger times. UKAEA allowed the contractor time to explore alternative decontamination methods, but a more effective method was not identified. Decontamination work continued with needle gun type tools and was finally completed in mid-September 2002. The decontaminated stack sections are shown in Fig. I.B–7.

The contractor managed the working areas for the project under UKAEA control. The contractor maintained the working documentation, including method statements, risk assessments, plant records, training records, etc. UKAEA monitored the documentation and checked that it was correct and that work was carried out in accordance with the accepted documentation. UKAEA organized regular (unannounced) safety walkrounds of the working areas by industrial safety specialists. No significant safety issues were raised. This was a project with significant safety risks and it was completed without any safety problems or issues.

The contract was completed at 110% of the original contract price, and the 10% increase was entirely due to UKAEA's share of weather delay costs. The dismantling work was carried out to the accepted contract programme, but the decontamination problems resulted in late overall contract completion.

FIG. I.B–5. SGHWR stack decommissioning: lifting operations.

FIG. I.B–6. SGHWR stack decommissioning: wire sawing.

FIG. I.B–7. Views of decontaminated SGHWR stack sections after decommissioning.

I.B–5. PROJECT REVIEW

A project review was held on completion of the stack decommissioning. The main points raised were the following:

(a) All parties considered the project a success. The key factors contributing to this were:
   (i) Good project planning and definition with clear contract requirements, responsibilities and interfaces.
   (ii) Good work planning with concise and appropriate controlling documentation.
   (iii) Good teamwork and cooperation between UKAEA and the contractor.
   (iv) Good safety management. There were significant safety risks with this project and the work was properly managed such that no safety problems occurred.

(b) The decommissioning problems and delays were noted but did not significantly detract from the overall success of the project.

The SGHWR stack was successfully decommissioned in 2002 to reduce the visual impact of the SGHWR facility.

BIBLIOGRAPHY TO ANNEX I.B

SGHWR Ventilation Stack Factsheet, UKAEA web site, April 2002, www.ukaea.org.uk/reports/generaldpf/Ventilation_Stack.pdf

Annex I.C

UNITED STATES EXPERIENCE OF STACK DISMANTLING: STACK DISMANTLING AT THE IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

I.C–1. INTRODUCTION

Since its establishment in the late 1940s, the Idaho National Engineering and Environmental Laboratory (INEEL) has built and operated 52 nuclear reactors. Since most of these were built to support reactor safety research for various types of electrical power generating nuclear systems, most were operated for only relatively short periods of time before being shut down and decommissioned. Many of these reactor facilities contained their own exhaust systems including a dedicated exhaust stack. The size and complexity of these stacks ranged from relatively short and simple to tall and complex. In general, heights ranged from slightly less than 30 m to greater than 60 m. Construction ranged from simple, small diameter metal piping supported on a concrete base with anchoring cables, to massive brick lined concrete structures of more than 10 m diameter. Contamination within these stacks consisted primarily of mixed fission products (^{137}Cs, ^{60}Co and ^{90}Sr). Very low levels of ^{235}U existed in some of the stacks. The following sections describe the decontamination and decommissioning (D&D) efforts associated with two types of stack located at the INEEL.

I.C–2. INITIAL ENGINE TEST FACILITY

The Initial Engine Test (IET) facility was built in the 1950s to support testing of the Aircraft Nuclear Propulsion reactors which were being developed and tested at the INEEL. The reactors themselves were located on double-wide railroad cars and were thus mobile between a large hot shop and the IET facility where the tests were conducted. An aerial photograph showing the IET stack and test facility, the connecting railroad tracks and the supporting hot cells is given in Fig. I.C–1.

The IET facility was decommissioned as a series of small individual tasks or projects. That is, the duct, stack, underground control centre and support buildings were all treated as separate projects and decommissioned individually. Of these portions of the overall facility, the stack contained the most radioactive contamination and presented the greatest challenge.

FIG. I.C–1. IET facility with exhaust stack.

The stack presented a challenge because it was large (53 m tall, 10 m in diameter at the base and 5 m in diameter at the top), contained loose contamination and represented a large waste volume (660 m^3) to be disposed of at the Radioactive Waste Management Complex. The risk of industrial type accidents is also very high when performing conventional dismantling of large stacks such as this. For these reasons, non-conventional dismantling techniques were considered for the IET stack.

Conventional dismantling techniques for stacks such as this usually involve large platforms which are placed at the top of the stack and which allow manual removal of pieces of the stack as the platform is lowered. Pieces are removed from the top of the work area on the stack either by using jackhammers or by using concrete saws to cut through the stack wall. Removed pieces are usually dropped or lowered into the interior of the stack and then packaged at the stack base before being removed and disposed of. Conducting these activities at great heights, accompanied by lowering or dropping large pieces of concrete, often puts the workers at risk. The chance of environmental problems through release of contaminated dust is also increased. Decommissioning a stack in this manner not only presents unnecessary risk to the workers, but is also time consuming and costly.

Because of the problems associated with conventional stack removal techniques, a new approach was investigated for D&D of the IET stack. In this case it was desired to improve worker safety, decrease the amount of waste generated and reduce the cost of decommissioning the stack. On-site disposal of the stack was desired since it would reduce the amount of waste going to the radioactive waste disposal site.

A decision was made to decontaminate the stack in place, and then use high explosives to fell it into a prepared trench at the IET site. The plan was to decontaminate the stack to a level such that the contamination left in the rubbleized and buried stack would decay to agreed upon release levels (1 mSv/a to a maximally exposed individual) within an institutional control period of 100 years. Following decontamination of the stack interior and confirmation of the amount and types of contamination remaining, a trench would be dug out from the base of the stack, and high explosives would be used to drop the stack into the trench. The felled stack would then be rubbleized as necessary and buried in place. A permanent marker would be installed and the area monitored as necessary to prevent intrusion until the radionuclides decayed to release levels. Thus plans were made for the partial decontamination and explosive demolition of the IET stack.

Decontamination of the stack was accomplished by first shovelling loose debris and a sludge-like material from the bottom of the stack. This material consisted mostly of dirt, which had settled to the concrete base of the stack over the years. The material was lightly contaminated (about 0.12 mSv/h) with Co, Cs and Sr. The next step in the decontamination process was to vacuum the base and interior walls of the stack to remove further loose material. Following this, a pressurized sandblasting unit was used to clean the interior of the stack. Following sandblasting, the interior of the stack was again vacuumed to remove sand and loose contamination. Surface radiation surveys were then conducted to determine if spots or areas of contamination had been missed during the decontamination operation. Samples of concrete from the interior of the stack were then removed and analysed in a laboratory to determine residual isotopes and their concentrations. When it was determined that any isotopes remaining in the wall of the stack would decay to release levels within the defined time period (see above), permission was given to proceed with explosive demolition of the stack. It should be noted that almost all of the original contamination existed within the bottom 5 m of the stack. This made decontamination relatively easy since only the bottom 5 m needed to be cleaned.

An explosives demolition contractor (Blasting and Vibration Consultants) was then hired to perform the actual stack dismantling. Soil was excavated from around approximately half of the stack foundation and a large trench was dug out radially from this part of the foundation. The stack, exposed foundation and trench can be seen in Fig. I.C–2.

Holes were then drilled into the stack base and supporting concrete piles, as shown in Fig. 20 in the main text. The explosive charges were placed within

FIG. I.C–2. IET stack, exposed foundation and trench.

these holes and detonated in such a fashion as to cause the stack to fall directly into the trench that extended out from its base. The stack can be seen on its way down in Figs I.C–3(a) and (b). Somewhat surprising was the complete collapse of the stack when it hit the bottom of the trench. This can be seen in Fig. I.C–4. It was expected that manual or explosive actions might be necessary to completely collapse the stack once it was in the trench. However, its massive weight and the force with which it hit the trench bottom caused it to completely collapse. The surrounding area was checked for radiation. In particular, a grid pattern for 10 m on each side of the trench was marked out and each grid element was carefully surveyed with a handheld (pancake probe type) radiation detector. Also, soil samples were collected from randomly selected grid elements and were sent to a laboratory for analysis. Since no radiation above the background was found either from the handheld survey or from the samples analysed in the laboratory, the trench was filled with soil, thus completing burial of the rubbleized stack.

This proved to be a very safe and cost effective solution for decommissioning of the IET stack. The total cost of the entire operation was less than US $50 000, and the generation of over 660 m^3 of waste was avoided. Although the industrial risk to workers avoided by not performing a manual demolition of the stack is not quantifiable, it is certainly significant. Annual environmental monitoring of the area where the stack is buried has shown no adverse impact on the site. This has proven to be a very satisfactory way of decommissioning stacks of this type. More details on the IET decommissioning project are given in Ref. [I.C–1].

I.C–3. AUXILIARY REACTOR AREA III FACILITY

Another very common type of stack that exists at the INEEL includes one which was decommissioned at the Auxiliary Reactor Area (ARA) facility. These stacks are simple, thin walled metal pipes or tubes mounted on a concrete base and supported by cables attached at varying elevations and anchored to metal or concrete objects at some distance from the base. Since air emission standards do not permit the release of large amounts of radioactivity, these stacks are also only very lightly contaminated, usually with mixed fission products as in the IET stack. Where space exists, these stacks are simply pulled over by heavy equipment and are then cut up and disposed of once they are on the ground.

The 50 m stack at ARA-III can be seen being pulled over in Figs I.C–5 and I.C–6. In this case the base bolts which attached the stack to its concrete pad or base were removed and its supporting cables cut. A preattached cable

(a)

(b)

FIG. I.C–3. IET stack fall.

FIG. I.C–4. IET stack collapse after fall into trench.

FIG. I.C–5. ARA-715 stack at start of fall.

FIG. I.C–6. ARA-715 stack during fall.

was connected to a large end loader/excavator and pulled down. Once the stack was on the ground, its internals were surveyed for radioactive contamination. Since very little was found, the metal stack was torch cut and disposed of as mildly contaminated material.

Again, this method of disposing of stacks is very safe and cost effective, in most cases entailing a total cost of only a few thousand dollars. If the stacks are contaminated, waste disposal costs often exceed the demolition costs. Given proper precautions to avoid pulling the stack onto other buildings or equipment, this option can be performed very safely. More details on the ARA decommissioning project are given in Ref. [I.C–2].

REFERENCES TO ANNEX I.C

[I.C–1] STOLL, F.E., Final Report of the Decontamination and Decommissioning of the Initial Engine Test Facility and the IET Two-Inch Hot-Waste Line, Rep. EGG-2468, INEEL, Idaho Falls, ID (1987).

[I.C–2] LABUY, S.A., Final Report — Decontamination and Decommissioning of Auxiliary Reactor Area III, Rep. EGG-ER-114093, INEEL, Idaho Falls, ID (1994).

Annex I.D

UNITED STATES EXPERIENCE OF STACK DISMANTLING: DECOMMISSIONING OF A BRICK STACK AT THE MOUND SITE

I.D–1. INTRODUCTION

The stack was located at the Mound site in Miamisburg, Ohio. The site has been involved with radioactive materials since 1948. It is currently being decommissioned and remediated by CH2M Hill for the US Department of Energy.

The stack was built in the mid-1960s (Fig. I.D–1) and supported the exhaust system of a ^{238}Pu processing building. The building had three separate exhaust systems (single HEPA banks) which were directed to an air plenum and stack fan located on a raised platform adjacent to the brick stack. During a filter change, the duct, the plenum, the fan and the stack became contaminated with ^{238}Pu (weak gamma radiation of little radiation concern but also high energy alpha radiation of considerable radiation concern). A new plutonium processing facility was built in the early 1970s. Its ventilation system was connected to the original plenum, fan and stack. The original processing

FIG. I.D–1. Mound facility stack and its surroundings.

building was decontaminated and decommissioned (D&D) in the late 1980s and early 1990s. It was during this time that plans started to be formulated concerning the disposition of the brick stack.

I.D–2. DESCRIPTION

The stack was 200 ft (61 m) tall with an outer diameter of approximately 16 ft (4.9 m) at the base tapering to approximately 7 ft (2.1 m) at the top. The wall thickness was 18 in (0.5 m) at the base and 8 in (0.2 m) at the top. The stack was constructed of bricks and mortar, and its inside surface was coated with gilsonite (a natural form of asphalt).

There were four openings in the stack: a 2 ft (0.61 m) × 3 ft (0.91 m) 'manway' at the base, an 8 ft (2.4 m) × 4 ft (1.22 m) air inlet duct opening at the 16 ft (4.88 m) to 24 ft (7.3 m) elevation, and two air monitoring probe holes at the 104 ft (31.7 m) elevation.

Two structural steel platforms were located on the stack, one at the 100 ft (30.5 m) elevation and the other at approximately 192 ft (58.5 m). Both were accessible from the ground by means of a ladder with safety cage and safety tie-on. In addition, aircraft lights were located on the platforms, and a lightning arrester system with four lightning rods and a ground wire were attached to the stack.

A reinforced concrete base pad 8 ft (2.4 m) deep in three steps — 4 ft (1.22 m), 2 ft (0.61 m) and 2 ft (0.61 m) — supported the stack.

The remaining portions of the stack system included the 4 ft (1.22 m) diameter exhaust duct and associated support structure from the building to the plenum, the exhaust plenum with support platform and the stack exhaust fan. The ductwork was generally welded 1/8 in (3.1 mm) thick carbon steel, and the plenum was fabricated from 18 gauge carbon steel.

I.D–3. PLANNING

The stack had to be characterized to determine the extent of the contamination problem and at the same time still support an active nuclear facility. The characterization included: (a) radiological background, (b) loose alpha contamination, (c) fixed alpha contamination, (d) depth of penetration of contaminants into the walls and floor, (e) a video recording of the stack interior for visual inspection, and (f) nature and extent of the radiological and other hazardous contamination within the stack.

I.D–4. CHARACTERIZATION

The stack was characterized in 1990 after 25 years of operation. The stack was visually inspected, and data were collected from direct measurements, smear samples, debris and core samples. Subsections of core samples and debris were analysed for TCLP (toxicity characteristic leachate protocol) analytes and radioisotopes of Th, U, Pu and Am. Core samples were taken at 1.0 ft (0.3 m), 20.0 ft (6.1 m) and 60.0 ft (18.3 m) above the stack base (see Fig. 6 in the main text). A core was taken from the concrete base. The core samples were cut into prescribed sections. The results for the innermost ¼ in (6.2 mm) and next ¼ in (6.2 mm) depth are presented as first cut and second cut below. Smear samples were taken from areas inside the stack at 2.0 ft (0.61 m), 6.0 ft (1.8 m), 20.0 ft (6.1 m) and 200 ft (61 m).

A US Environmental Protection Agency approved lab performed the TCLP sample analyses. The TCLP protocol requires testing for metals (inorganics), herbicides, pesticides, and volatile and semivolatile organics. The TCLP protocol does not include asbestos.

None of the TCLP results were above maximum permissible contaminant levels, hence the stack would not require waste categorization as chemically hazardous or mixed waste. To determine the levels and constituents within the stack, an isotopic analysis using alpha spectrometry and liquid scintillation spectrometry was completed for the innermost cut of the 20 ft (6.1 m) wall core sample directly across from the inlet (impingement point).

The single sample isotopic results are presented in Table I.D–1. To minimize cost, this sample was used to normalize data from other samples and calculate estimated activities based on the comparison of ^{238}Pu results.

Isotopic activity ratios indicate that the combined radioactivity from the tested isotopes of Th, U, Pu and Am totals approximately 2.2 times the ^{238}Pu activity.

An assumption was made that isotopic ratios would be constant throughout the sampling matrix. The ratio was used to calculate total activity values for waste quantification purposes. Table I.D–2 lists the measured ^{238}Pu results along with the estimated total activities.

The first and second cut figures refer to ¼ in (6.35 mm) slices from the core sample. The first cut is the inner surface; the second cut is the next ¼ in (6.35 mm) slice.

Sample sites were chosen where hazardous materials would be detected and that would provide a worst case indication of radiological contamination. It was originally assumed that the impingement point from the incoming duct would result in the highest contamination site. However, this assumption proved to be incorrect. The point of impingement was probably kept dry by the

TABLE I.D–1. ISOTOPIC ANALYSIS OF STACK CORE SAMPLE

Isotope	Activity concentration		Error		Activity (%)	Specific activity		Mass (g)	Mass (%)
	(pCi/g)	(Bq/g)	(pCi/g)	(Bq/g)		(Ci/g)	(Bq/g)		
Th-228	6.8	0.252	2.8	0.104	1.03	8.20E+2	3.04E+13	8.29E–15	1.26E–8
Th-230	4.7	0.174	5.4	0.200	7.11	2.06E–2	9.65E+8	2.28E–9	3.47E–3
Th-232	2.5	0.093	1.2	0.044	0.38	1.10E–7	4.08E+3	2.27E–5	34.5
U-234	16.0	0.593	4.0	0.148	2.42	6.23E–3	2.31E+8	2.57E–9	3.90E–3
U-235	1.2	0.044	0.9	0.033	0.18	1.92E–6	7.12E+4	6.25E–7	0.95
U-238	14.0	0.519	3.0	0.111	2.12	3.30E–7	1.22E+4	4.24E–5	64.5
Pu-238	300.0	11.11	34.0	1.259	45.41	1.71E+1	6.34E+11	1.75E–11	2.67E–5
Pu-239/240	0.51	0.019	0.5	0.019	0.08	6.20E–2/ 2.27E–1	2.30E+9/ 8.42E+9	3.53E–12	5.36E–6
Pu-241	270.0	10.0	135.0	5.00	40.87	1.03E+2	3.82E+12	2.62E–12	3.98E–6
Pu-242	<1.4	<0.052	Negligible		0.21	3.93E–3	1.46E+8	3.56E–10	5.42E–4
Am-241	1.3	0.048	1.7	0.063	0.20	3.43E+0	1.27E+11	3.79E–13	5.76E–7
Total	618.4	22.92	NA	NA	100	NA	NA	4.39E–5	100

Note: NA: not applicable.

Table I.D–2. STACK RESULTS FOR PLUTONIUM

Sample type	Sample location	Pu-238 activity				Total calculated activity	
		First cut		Second cut			
		(pCi/g)	(Bq/g)	(pCi/g)	(Bq/g)	(pCi/g)	(Bq/g)
Core	Floor	3 300	122.22	82	3.04	7 300	270.37 (1st)
Core	1 ft (0.3 m) inner wall	1 700	62.96	67	2.48	3 700	137.04 (1st)
Core	20 ft (6.0 m) inner wall	300	11.11	4.7	0.17	660	24.44 (1st)
Core	60 ft (18.0 m) inner wall	4 200	155.56	62	2.30	9 300	344.44 (1st)
Debris	Floor under inlet	280 000	10 370	Negligible		617 000	22 852
Debris	Floor centre	140 000	5 185.2	Negligible		308 000	11 407
Debris	Floor opposite inlet	620 000	22 963	Negligible		1 370 000	50 741
Smear	2 ft 6 in (0.75 m) interior	120 000	4 444.4	Negligible		264 000	9 777.8
Smear	20 ft (6.0 m) interior	7 200	266.67	Negligible		16 000	592.59
Smear	200 ft (60 m) interior	12	0.44	Negligible		26	0.96

blast of dry conditioned air from the building, which would account for the results being significantly lower than expected.

In addition to the lab data above, field data for surface alpha emissions are listed in Table I.D–3.

A video survey (Fig. I.D–2) of the interior of the stack indicated that the gilsonite coating had failed at the mortar joints but appeared intact on the brick surfaces. The debris at the base of the stack was primarily the coating material, dirt and mortar.

Of greater concern was the quantity and activity level of contaminated material at the base of the stack — over 500 lb (227 kg) of debris and one sample with an activity of over 100 nCi/g (3700 Bq/g).

I.D–5. DECONTAMINATION AND DEBRIS REMOVAL

Originally this project was to be carried out with an inflatable plug being inserted into the stack to seal it while the material was removed. Airlocks with HEPA exhausts were fabricated and installed at the stack manway. Before starting the fieldwork, the Environmental Monitoring Group did not want the stack to be plugged, considering that having the natural draft from the stack during debris cleanup would be preferable to plugging (better to have any emissions at 200 ft (61 m) above the ground rather than any possibility of emissions at ground level).

TABLE I.D–3. STACK FIELD DATA

Location	Smear		Direct	
	(dis · min^{-1} · (100 cm^2)$^{-1}$)	(Bq/cm^2)	(dis · min^{-1} · (100 cm^2)$^{-1}$)	(Bq/cm^2)
N 2 ft	500	0.083	16 000	2.67
E 2 ft	1 200	0.20	50 000	8.33
S 2 ft	600	0.10	35 000	5.83
W 2 ft	3 000	0.50	130 000	21.67
N 6 ft	1 000	0.17	24 000	4.0
E 6 ft	1 500	0.25	45 000	7.50
S 6 ft	1 500	0.25	35 000	5.83
W 6 ft	2 000	0.33	110 000	18.33
Inlet 20 ft	1 000	0.17	18 000	3.0

FIG. I.D–2. Two hundred foot (61 m) crane placing camera platform on stack.

Fifteen drums of waste material were generated, and disposal of this material became a concern. Characterization data proved that mixed waste was not an issue, but because one sample showed an activity of greater than 100 nCi/g (3700 Bq/g), a complete statistical analysis had to be performed for the waste to be shipped to the Nevada Test Site to meet the low level waste acceptance criteria. It was considered undesirable to reopen the drums for more sampling or for the waste to be classified as transuranic waste. The answer, in hindsight, would have been to take more ‘in-process’ samples.

All the debris was removed in 1995.

I.D–6. DEMOLITION

Several studies and alternatives concerning stack demolition were reviewed. A value engineering study showed implosion as the most cost effective means of stack demolition; however, the cost of using explosives was only US \$15 000 less than that of normal crane and clamshell demolition methods.

These stack demolition plans required approval by regulatory agency personnel from the US and Ohio environmental protection agencies. It was considered that the effort and cost involved in producing the level of documentation required to support the implosion method and ensure public safety would exceed the \$15 000 cost difference. This situation was exacerbated by the fact that the stack was within 100 yd (91 m) of a public golf course and a public road.

The decision was made to contract the demolition of the stack and the adjacent production building (operations in the building had ceased), and the use of explosives was prohibited.

The prime contractor selected was URS, Oak Ridge, Tennessee, and subcontractors included the Cleveland Wrecking Company and International Chimney Corporation. The contractor was responsible for developing the specific demolition plan and a ‘fenceline’ dose calculation, and for responding to Environmental Protection Agency comments until approval was achieved. The essential elements of the approved plan were:

(a) The masonry stack was removed after engineered controls were applied. The stack was removed by trained workers who specialize in demolishing stacks and are considered experts in this field. The stack was maintained under negative pressure while demolition was in progress. Demolition debris was dropped inside the stack and collected at the interior base. Waste was removed using a skid steer loader.

(b) An airlock measuring 75 ft (22.9 m) long, 14 ft (4.3 m) wide and 10 ft (3.0 m) high was installed and sealed around the access hatch of the stack (Fig. I.D–3). It was manufactured by installing a scaffold frame and attaching two heavy duty plastic layers. The airlock consisted of three rooms separated by double-layered plastic doors. Four HEPA ventilation units at 2100 ft^3/min (1 m^3/s) per unit were attached to provide negative pressure — two units servicing the chamber nearest to the stack and one unit each in the intermediate and outer chambers. The chamber nearest to the stack (room 1) contained the skid steer loader. The loader periodically removed debris from the base of the stack and placed debris into waste boxes in room 1. The boxes were staged in room 2. Debris was only

FIG. I.D–3. Fabrication of airlock.

removed from the stack base when overhead work/demolition was halted. When the waste boxes were full, they were sampled and closed, gross contamination was removed and then the boxes were moved into room 3. Radiological surveys were performed on the closed boxes in room 3 before removal from the airlock.

(c) A fixative fog was placed on the interior of the 48 in (1.22 m) duct from the building to the plenum, the plenum and the stack fan. The ductwork was cut or unbolted, removed in sections and placed in waste containers. The plenum, stack fan blower and motor were removed and placed in waste containers (Fig. I.D–4).

(d) A bracket and cable scaffold was installed on the stack to allow stack workers to break up the brick from the top, pushing the brick into the stack interior (Figs I.D–5 and I.D–6).

(e) The access hatch at the bottom of the stack was enlarged to approximately 8 ft (2.4 m) high × 4.5 ft (1.37 m) wide to allow access for debris removal. An engineering study was performed to evaluate enlarging the hatch. A new lintel was bolted into place and saw cuts were made to

FIG. I.D–4. Lowering 'fogged' exhaust duct.

accommodate new side jambs. The hatch and remaining brick were removed to create the larger opening.

(f) The octagon shaped stack platforms at 100 ft (30.5 m) and 192 ft (58.5 m) were disassembled and removed in sections.

(g) The stack monitoring sample lines, the lightning arrester system and the associated ground wire were removed.

(h) The original aircraft lights were removed. Temporary warning lights were installed in accordance with US Federal Aviation Administration (FAA) regulations, and the FAA was notified on a daily basis until the stack height was reduced to less than 150 ft (45.7 m).

(i) Two 2100 ft^3/min (1 m^3/s) HEPA ventilation units were attached to a prefabricated cover where the existing ducting penetration originally entered the stack.

(j) The four 2100 ft^3/min (1 m^3/s) HEPA ventilation units attached to the airlock and the two 2100 ft^3/min (1 m^3/s) HEPA ventilation units attached to the stack were started up. Negative pressure with respect to atmosphere was verified on a daily basis.

FIG. I.D–5. Bracket and cable scaffold.

The stack workers were trained to collect routine radiological samples and to verify ventilation flows using smoke tubes. All stack workers wore personal air samplers to record exposure.

FIG. I.D–6. Stack platforms gone, less than 100 ft (30.5 m) of stack remaining.

Various encapsulants and water misting were used throughout the project, particularly when the stack height was reduced to the 25 ft (7.6 m) level where the two HEPA exhausters became ineffective. Below this level, standard excavators with hydraulic grapple attachments were used for the remaining demolition.

Stack debris totalling 7500 ft^3 (215 m^3) was packaged into intermodal containers, which were loaded on railcars for low level radioactive waste disposal at the burial site at Envirocare in Utah. No on-site burial is allowed at the Mound site. The stack removal project was successfully completed in the summer of 2003.

I.D–7. SITE RESTORATION/TRANSITION

Plans are currently being made for the partial removal of the remaining stack foundation.

Annex I.E

WINDSCALE PILE STACK DECOMMISSIONING, UNITED KINGDOM

I.E–1. INTRODUCTION

The Windscale Pile stacks served to discharge cooling air from the reactors constructed to produce nuclear material for the United Kingdom's first atomic weapons. The stacks have formed a distinctive part of the Cumbrian skyline for some 55 years. Initially seen as visible progress towards a nuclear future, they were later to become associated with the worst nuclear accident in the United Kingdom and internationally known as landmarks of the Sellafield site.

The Windscale Pile stacks, shown in Fig. I.E–1, form a distinctive landmark of the Sellafield site. They are curiously shaped, massive reinforced concrete structures standing 130 m above ground level and visible for many miles around west Cumbria.

The outward simplicity of each stack belies a complex engineering structure which allowed their connection to a nuclear pile designed to produce plutonium for atomic weapons during the early 1950s. The reactors were cooled by forcing air over the pile and passing the heated air directly to atmosphere via the stacks. The weapons programme was considered a matter of national priority, and speed was of the utmost importance. Many aspects of the work associated with the project progressed in parallel, and a shortage of materials and human resources added to the challenges faced during construction. Despite these challenges the stacks were constructed on time, and the whole project (including the other process plants) associated with the weapons programme was delivered on schedule.

I.E–2. CONSTRUCTION

The stacks were intended to be conventional circular structures, but problems were envisaged with potential release of radioactive contamination from the core to atmosphere. As a consequence, the stacks were redesigned to incorporate filtration systems. However, as construction of the first stack had progressed to a height of 30 m, the filters were placed at the top of the stack instead of at the bottom where they conventionally would have been located. The redesign resulted in the distinctive square section at the top of each stack (Fig. I.E–2).

FIG. I.E–1. Windscale Pile stacks.

Although the stacks appear simple from the outside, they hide a complex civil structure utilizing novel materials and construction techniques. The structure is a composite of reinforced concrete and structural steelwork. A

FIG. I.E–2. Detail of top of Windscale Pile stack.

total of 20 000 t of concrete and bricks and 1000 t of structural steelwork were used in the construction. The interior contained aluminium, steel and asbestos cement boxes filled with fibreglass to insulate the stack structure from the hot exhaust gases (1 t of air per second at 180°C). The filter gallery housed multiple filters which had to be taken to the top of the stack and the contaminated filters returned to the base in massive steel flasks; these were handled on trolleys which ran on rails at the top of the stack.

The haste in the construction of the stacks challenged conventional design. Forced changes during construction, such as the filter galleries at the top of the stack, had to be accommodated through application of sound engineering, cleverly applied in difficult circumstances.

I.E–3. OPERATION

The Pile reactors performed well in operation and very little contamination was released from the core. This meant that the filters did not have to remove large quantities of contamination. The filters were constructed from mineral wool covered in oil, but in the hot air stream from the reactor the oil evaporated rapidly. This meant that a lot of effort was put into the filter changing process and developing new designs to mitigate the problem. This problem, coupled with the fact that the reactors worked so well, led to an argument that the filters were not necessary. Fortunately the filters were retained, and the accident of 1957 validated this decision.

In October 1957 a fire in the core of Pile 1 led to significant quantities of contamination being released. Some of this contamination travelled in the cooling air stream, up the stacks to the filters. The filters removed approximately 65% of the radioactivity that passed up the stack, and played a significant role in reducing the impact of the accident to the public. This meant that the filters and the interior of the stack became contaminated, making the later job of cleanup more challenging.

I.E–4. DECOMMISSIONING

The Piles were permanently shut down following the fire, and the stacks were placed into a state of care and maintenance. Over time, the structures at the top of the stacks began to deteriorate, and structural assessments carried out as part of the care and maintenance work showed that it would be sensible to remove the filter galleries (the square section) before deterioration progressed to a point that they were rendered unsafe.

Once the decision was taken to dismantle the filter galleries, an approach had to be developed to address the unique aspects which prevented conventional techniques being employed. Dismantling of such large contaminated civil structures was not typical of the nuclear industry. The challenges included:

(a) *Height*. The top of the stacks was 130 m above ground level. Access to the top was via an installed ladder system. A new access system was needed to allow civil dismantling work and waste handling on a routine basis.
(b) *Contamination and radiation*. The fire led to significant quantities of radioactivity being released and deposited in the Pile 1 stack and on the filters. This contamination gave rise to high radiation levels in the structure that restricted access. Radiological conditions in Pile 2 were less restrictive. The contaminants were largely fission products, with predominantly ^{137}Cs remaining.
(c) *Poor records*. The haste with which the stacks were built meant that drawing records for the structures were sometimes inconsistent. Data had to be gathered to substantiate designs to ensure that a proposed solution was safe before it was implemented.
(d) *No examples to follow*. The Pile stack design and restrictions because of the fire were unique. No other structure in the world provided an example to follow. The solutions adopted would have to match the problem at hand and the team would have to learn from their own experiences.
(e) *Sensitive structures around the base*. A number of buildings that contained personnel, process equipment and nuclear fuel storage facilities were at the base of each stack. These structures had to be protected from hazards posed by dismantling operations. In addition, it had to be demonstrated that occupancy of the buildings at the base of the stacks could continue during dismantling work.

I.E–4.1. Decommissioning strategy

The approach adopted by the project team to deal with the challenges was to assess each element of the work as a unique package and to devise solutions for each specific problem.

The general strategy was to demonstrate solutions on the Pile 2 stack, which had lower levels of contamination and radiation. The experience gained from operating the equipment on Pile 2 was applied to the Pile 1 stack, where radiation and contamination levels were much higher.

I.E–4.2. Implementation of the strategy

The application of solutions to the stacks identified a number of important issues:

(a) The stacks were inconsistent with drawing records, which led to a requirement for flexible solutions.
(b) Radiological conditions could only be fully assessed as work progressed, owing to the difficulty in gaining access prior to implementing solutions.
(c) Some of the best solutions came from outside the management team. This fact was recognized early on with civil contractors extensively employed on the project. Working relationships were developed to integrate best practice in the nuclear industry with practices in relevant areas from outside the industry.

Experience led to the recognition that standard off-the-shelf equipment was preferable to bespoke, custom solutions. The value of this approach was enhanced by incorporating non-nuclear experience into the solution development process, although conventional approaches had to be challenged to deliver cost effective solutions. Figure I.E–3 shows an example of how an

FIG. I.E–3. Asphalt shaver.

off-the-shelf road asphalt shaver was adapted to carry out the decontamination of the stack interior.

I.E–5. EXPERIENCE GAINED

1.E–5.1. Civil dismantling

Civil dismantling involved the removal of large quantities of concrete and reinforcement steel once the complex internal structures of the stack had been removed. This required careful removal of the concrete at the top of the stack and transport of all material to the stack base.

The principal problem with civil dismantling was the quantity of material to be removed (for example 3500 t of concrete and 300 t of steel for the filter gallery alone). Without decontamination, all of the dismantling debris would have required disposal as low level radioactive waste, making the cost of disposal prohibitive. In addition, the disposal of such a large volume as low level radioactive waste would not be an effective use of a limited capacity national disposal site. Stack decontamination led to significant reductions in the waste disposal costs, and this was the first major example of gaining approval for the clearance of concrete from the controlled area of the Sellafield site.

Preparatory work for dismantling included:

(a) Protecting the buildings around the base of the stack from falling debris so that they could remain occupied for the duration. This was done by installing wood decking over the roofs and limiting impact load potential to 25 kg.
(b) Extensive contractor involvement and cross-fertilization of ideas between British Nuclear Fuels (BNFL) and contract staff. Throughout, the contract personnel were regarded as an integral part of the project team and worked in partnership to achieve results.
(c) Adaption of standard tools to provide solutions to problems. For example, a standard quarry concrete/stone crusher was used in order to allow thorough monitoring to demonstrate clearance levels. Standard concrete scabbling equipment was used to remove contaminated material. Standard equipment was used to clean steelwork to clearance levels.

1.E–5.2. BROKK application

The BROKK is a small scale multipurpose excavator type vehicle used to deploy a wide variety of equipment. It is a standard item of equipment widely used and proven in the harsh environment of the construction industry (Fig. I.E–4).

The BROKK can be used to deploy a number of standard and modified standard tools to the workface. These include percussive breaking tools, reciprocating and circular saws, and clamping, lifting and shearing tools. The equipment provides a high pressure hydraulic supply to ensure that the necessary power can be obtained for a wide variety of tasks. It was used by the stack project for a number of applications, such as lining box removal, remote concrete breaking operations, cutting of rolled steel sections and other operations where personnel access was restricted owing to dose or for safety reasons.

The usefulness of the equipment can be measured by the number of decommissioning projects that now employ BROKKs. This proliferation of their use could be considered as a direct consequence of the success achieved by their use on the Pile stack decommissioning project.

FIG. I.E–4. BROKK excavator.

I.E–5.3. Filter dismantling

Owing to the high levels of contamination and radiation in the Pile 1 stack, working times were restricted and innovative solutions for filter dismantling were necessary. The solution demonstrated on Pile 2 for removal of the filter gallery section could not be directly applied to Pile 1.

The approach to the problem was to review alternatives that addressed the specific concerns raised by implementing the solution adopted on Pile 2. The solution developed utilized a simple shearing tool deployed from chain blocks, and involved letting the cut sections of the filter gallery fall to the floor of the stack to be recovered later. The solution was simple and highly effective, significantly reducing cost and dose uptake.

The principal area of concern relating to adopting the proposed solution was the issue of aerial release of contamination when sectioned items of gallery dropped to the base of the stack. This issue required the project to challenge conventional thinking to demonstrate that the approach could be implemented safely. Theoretical calculations backed up by close initial scrutiny of operations demonstrated that the approach was safe.

I.E–6. CONCLUSION

Removal of the Pile stacks has proven a tremendous learning experience for both BNFL and contractors who have worked in partnership with the project over many years. It has visibly demonstrated the effect of combining expertise across industries to cost effectively realize practical solutions to complex problems.

The key aspects of the decommissioning project were to provide flexible solutions built upon standard, proven technology to ensure that they coped well with the unexpected, and furthermore to challenge conventional thinking to ensure that simple solutions were not allowed to become complex and unworkable.

Annex I.F

Z-PLANT URANIUM ENRICHMENT FACILITY OF SOUTH AFRICA: STRATEGY FOR THE DECOMMISSIONING OF THE VENTILATION STACKS

I.F–1. INTRODUCTION

The purpose of this annex is to present the information and factors relevant to decommissioning as well as the derivation of a conceptual strategy for decommissioning the stacks of the Z-plant in South Africa. In addition, regulatory requirements and criteria, as well as the information obtained from preliminary characterization, are presented. The information interfaces and options are evaluated in terms of key factors (e.g. cost, waste class and quantities) in order to derive a proposed conceptual decommissioning strategy.

Construction of the semicommercial Z-plant started in 1978. The plant was commissioned in the early 1980s. By 1994 it had become clear that the Z-plant would not be able to compete cost effectively with international producers of enriched uranium for South Africa's needs. The decision was consequently taken to shut down on 31 March 1995 and to immediately commence with decommissioning of the plant. Decommissioning up to the removal of process equipment was completed in 1999.

In its lifetime the plant produced 225 t of enriched uranium at concentration levels of between 3.25% and 3.90%. The total quantity of uranium released via the four stacks of the plant was approximately 1900 kg U-nat equivalent. The plant has a design ventilation rate of 1000 m^3/s.

Except for the removal of the emergency oil feed systems that were installed on the stacks and the removal of the off-gas line, no decommissioning activities were performed on the stacks.

Since 2000 the plant has been used as a temporary waste store, for which the natural ventilation through the stacks is sufficient. In view of the current application of the plant, decommissioning of the stacks is not foreseen for the immediate future. The development of a stack decommissioning strategy is nonetheless required for the ongoing liability assessment of the site.

I.F–2. STACK CHARACTERIZATION

Stack description

A single stack is considered for the characterization (Fig. I.F–1). The stack includes the concrete structure and the steel plenum connecting the fan house with the stack. The fan house is an integral part of the building.

Physical characterization

The stack is 80 m in height and is erected on a foundation 12 m in diameter and 2.5 m thick. The stack outer diameter is nominally 5.6 m, with an inner diameter of 5 m.

The stack is constructed of reinforced concrete. The outer surface of the stack has a smooth finish while the inner surface is rough. The plenum is constructed of epoxy coated carbon steel (Fig. I.F–2).

The stack has the following design features that are of importance to characterization and decommissioning:

(a) The stack is sealed from its base at the plenum connection point.
(b) A water drain point is located at the plenum connection point with draining facilities to the base of the stack (Fig. I.F–3).
(c) A sump for water collection is also installed in the fan house.
(d) The plenum and internal surface of the stack are accessible through a bolted panel in the fan house. No other access points to the internal surface exist, although the top of the stack can be reached by ladder and via a number of platforms at various heights (Fig. I.F–4).
(e) The stack is equipped with an off-gas discharge point approximately 17 m from the base into the plenum of the stack. The discharge point is not accessible and the off-gas line has been removed as part of the phase 2 decommissioning project (Fig. I.F–5).
(f) A stack sampling point is installed at approximately 65 m from the base of the stack. The sampler is still functional.

A visual inspection of the stack showed that the stack components are still in a good condition, without evidence of corrosion or deterioration of components or any indication of poor structural integrity. This probably results from the short operational period of the plant.

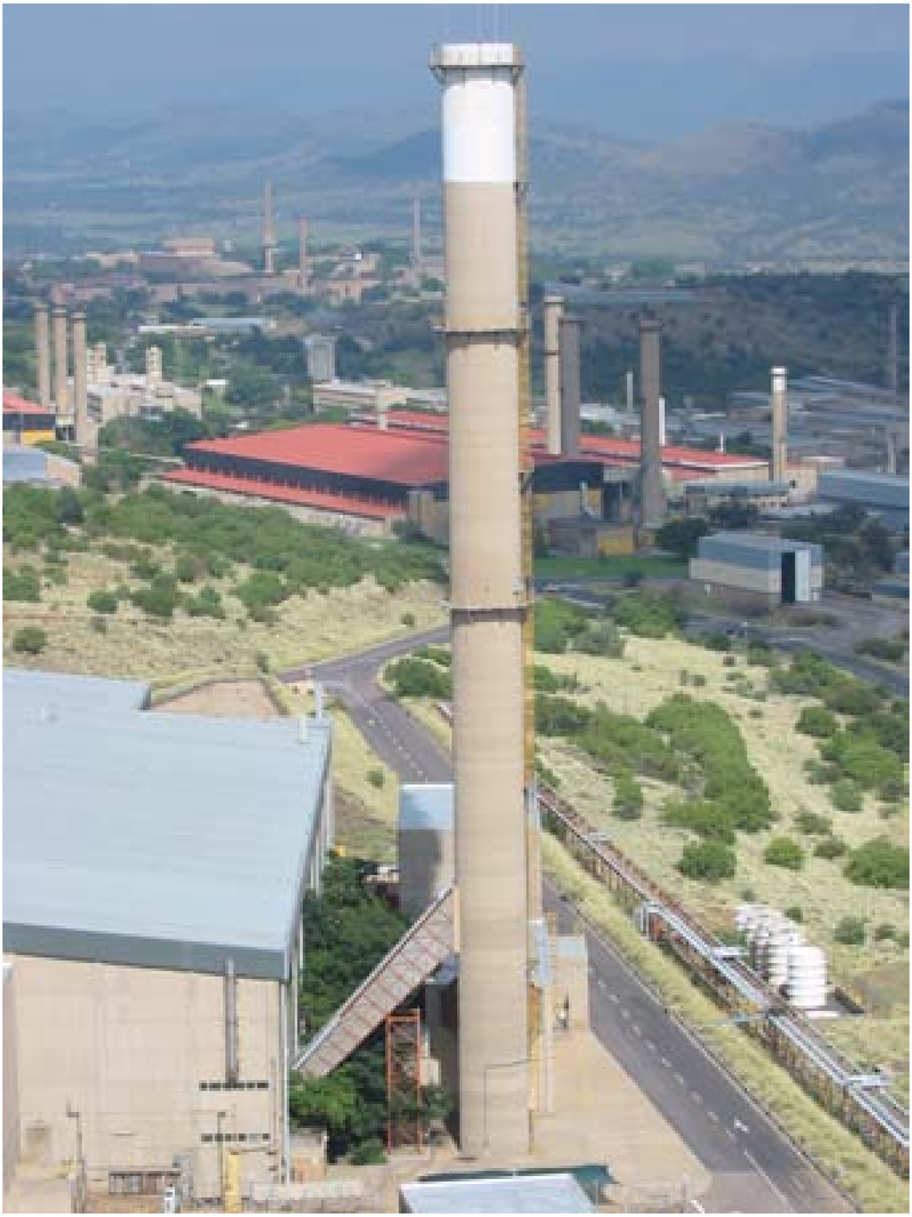

FIG. I.F–1. Stack considered for characterization.

FIG. I.F–2. Epoxy coated plenum.

FIG. I.F–3. Water drain point.

FIG. I.F–4. Platforms.

FIG. I.F–5. Off-gas discharge point.

The stack material quantities are as follows:

- Concrete: foundation: 280 m^3; stack: 350 m^3. (These quantities are in situ volumes per stack and may increase by up to 60% for concrete in rubble form.)
- Reinforcing steel: approximately 50 t.
- Sheet steel: approximately 200 m^2 and 11 t.

Radiological characterization

A radiological survey was performed to obtain information regarding the prevailing radiological condition of the inner surface of the stack. Owing to accessibility limitations, most of the measurements, as well as the decontamination tests, were performed where the plenum enters the stack. Since the off-gas line also enters at this point, it is assumed that the highest contamination levels occur in this region. Nonetheless the stack was also surveyed at its top and approximately 15 m below the top.

Source material

The plant was designed for operation with fresh uranium in the form of UF_6. Recycled uranium was not used as feed material. The contaminants are therefore uranium that is slightly enriched in the ^{235}U isotope in secular equilibrium with its short lived daughter products.

Emissions occurred mainly as UO_2F_2 aerosols due to UF_6 releases. The emission of uranium was also associated with the discharge of HF vapour.

Stack contamination

The level of contamination of the stack was evaluated in terms of surface contamination and activity concentration in the top 8 mm of the inner surface of the stack. Surface contamination is evaluated in terms of removable and total contamination levels. Owing to the rough inner surface of the concrete sections of the stack, swipe sampling results provided only a qualitative indication of the removability of the contamination.

Surface contamination levels were obtained on the various sections and are indicated in Table I.F–1. (The results are background (BG) corrected but are not statistically evaluated, in view of the purpose of the study.)

The following can be derived from the contamination evaluation:

(1) Internal steel sections are contaminated (mainly removable contamination) to levels that require decontamination for clearance consideration.
(2) The two steel platforms at the top of the stack are contaminated (mainly fixed contamination) to levels that require decontamination.
(3) The inner concrete surface of the stack is contaminated, with propagation of contamination into the top layer of concrete as indicated by the high beta to alpha ratio.
(4) The highest contamination levels occur at the plenum inlet point, with a gradual decrease at higher stack elevations.
(5) The stack base floor has localized contamination due to water that spilled from the water collection point (Fig. I.F–6).
(6) The gravel surrounding the water drain point outside the stack base is contaminated.

Activity concentration levels in concrete were obtained in the zone where the highest surface contamination levels were indicated.

The radioactivity concentration levels were analytically determined for two inner layer thicknesses, i.e. 2–3 mm and 6–8 mm, as well as for the

TABLE I.F–1. RADIOLOGICAL CHARACTERIZATION OF THE Z-PLANT STACK (LOOSE AND TOTAL CONTAMINATION)

Section	Average smear sample results (Bq/cm^2)		Average total contamination results (Bq/cm^2)	
	Alpha	Beta	Alpha	Beta
Plenum (steel)				
Floor	0.74[a]	0.66	0.44	0.85
Sides	0.80[a]	0.71[a]	0.25	0.64
Stack concrete				
Water collection point	1.20[b]	1.30[b]	1.03	195.00[c]
Plenum entry point 1	0.19[b]	0.12[b]	1.48	80.80[c]
Plenum entry point 2	0.08[b]	0.05[b]	2.78	166.90[c]
Top of stack				
Inside — concrete	Negligible	Negligible	0.26	6.89[c]
Top — concrete	Negligible	Negligible	0.14	1.06
Outside — concrete	Negligible	Negligible	0.03	0.42
Platform 1 — steel (top)	0.18	Negligible	1.48	5.72
Platform 2 — steel	Negligible	Negligible	0.58	1.86
Platform 3 — steel	Negligible	Negligible	0.17	0.39
Platform 4 — steel	Negligible	Negligible	0.08	0.19
Platform 7 — steel	Negligible	Negligible	0.16	0.42
15 m from top of stack				
Inside — concrete	Negligible	Negligible	0.35	23.85
Stack base				
Floor — concrete	Negligible	Negligible	6.97	160.45
Sides — concrete	Negligible	Negligible	BG	BG
Area surrounding stack				
Gravel	Negligible	Negligible	0.18	12.98

[a] Higher than the total surface contamination level owing to pick-up greater than the assumed factor of 10%.

[b] Inefficient smear sampling owing to rough concrete surfaces.

[c] High beta to alpha ratio owing to penetration into concrete (layer thickness) and absorption of alpha particles.

FIG. I.F–6. Localized contamination.

uncontaminated remainder of the outer wall of the stack (core sample). The activity concentration of the uncontaminated core is regarded as the 'background' activity concentration level. The activity concentration levels are indicated in Table I.F–2.

The following can be derived from the activity concentration evaluation:

(i) The concrete layers are contaminated to activity concentration levels that would require management as radioactive waste.
(ii) If it is assumed that the total inner surface of the stack is contaminated to the same extent up to a depth of 8 mm (no contamination was detectable below the removed layer), the homogenized activity concentration level of the concrete of the stack without any decontamination will be approximately 6 Bq/g.

TABLE I.F–2. RADIOLOGICAL CHARACTERIZATION OF Z-PLANT STACK (AVERAGE CONTAMINATION (Bq/g) AT VARIOUS DEPTHS)

Section	Alpha	Beta
Plenum grinding — 3 mm	210.13 ± 6.57	577.85 ± 2.85
Plenum solid — 8 mm	118.51 ± 4.87	269.37 ± 1.96
'Background'	4.07 ± 0.26	13.59 ± 0.12

I.F–3. DECONTAMINATION EVALUATION

The preliminary radiological characterization exercise included decontamination tests and measurements to indicate the propagation of contamination into the inner surface of the stack. Contamination measurements of the undisturbed surface were followed by a pressure water and decontamination detergent cleaning exercise and resurveillance of measurement points. The undisturbed surface was also skimmed by grinding, and a composite sample was taken from the upper 3 mm of the inner surface. A sample of the top 8 mm and a core sample of the uncontaminated outer surface were also analysed. The locations were resurveyed after the removal of the layers. The results obtained for the surface decontamination evaluation are shown in Table I.F–3.

The following can be derived from the decontamination evaluation:

(a) The epoxy coated steel of the plenum is only slightly contaminated on the surface (as a result of frequent cleaning during operation). A pressure water wash is sufficient as a decontamination step to reach clearance levels.
(b) Pressure water washing of the concrete reduces contamination on average by 38% and 14% in terms of alpha and beta contamination levels, respectively. The higher percentage for alpha and lower percentage for beta are indicative of the propagation of contamination into the concrete. (Beta particles have a longer range.)

TABLE I.F–3. SURFACE DECONTAMINATION TESTS (AVERAGE TOTAL CONTAMINATION RESULTS (Bq/cm^2))

Section	No decontamination		Pressure water wash		Pressure water wash and use of detergent	
	Alpha	Beta	Alpha	Beta	Alpha	Beta
Plenum (steel)						
Floor	0.44	0.85	0.03	0.03	Negligible	Negligible
Sides	0.25	0.64	0.04	0.06	Negligible	Negligible
Stack concrete						
Water collection point	1.03	195.00	0.50	203.28	0.63	139.78
Plenum entry point 1	1.48	80.80	1.02	70.75	0.42	55.92
Plenum entry point 2	2.78	166.90	1.87	123.08	0.90	94.76

(c) The addition of a decontamination detergent further reduces the contamination levels by 55% and 34% in terms of alpha and beta contamination levels, respectively.
(d) Pre-dismantling decontamination using the tested techniques will reduce surface contamination levels significantly and will be beneficial to radiation protection and further handling of the concrete.

The results obtained for the surface skimming evaluation are shown in Table I.F–4.

The following can be derived from the surface skimming evaluation:

(1) Most of the contamination is located in the top 3 mm of concrete.
(2) Propagation of contamination levels that are still higher than clearance levels for surface contamination occurs to beyond 3 mm.
(3) Residual uranium contamination is not distinguishable from the natural levels measured on concrete when the top 6–8 mm of concrete is removed from the inner surface of the stack.

I.F–4. DECOMMISSIONING RELATED INFORMATION AND CONSIDERATIONS

Clearance criteria

The clearance levels approved by the National Nuclear Regulator (NNR) for the clearance of uranium contaminated materials are given in Table I.F–5.

TABLE I.F–4. SURFACE SKIMMING DECONTAMINATION TESTS (AVERAGE TOTAL CONTAMINATION RESULTS (Bq/cm^2))

Section	Before skimming		Skimming 2–3 mm		Skimming 6–8 mm	
	Alpha	Beta	Alpha	Beta	Alpha	Beta
Plenum connection point						
Zone 1	1.23	70.23	0.44	0.66	0.02	0.27
Zone 2	1.96	154.12	0.36	2.30	0.01	0.33
Zone 3	2.42	103.36	0.48	3.05	0.03	0.16
Zone 4	3.67	225.28	0.83	14.58	0.02	0.34

TABLE I.F–5. CLEARANCE LEVELS FOR URANIUM CONTAMINATED MATERIALS

	Surface contamination	Activity concentration
Steel	0.4 Bq/cm^2 (for alpha and beta)	1 Bq/g
Concrete	0.4 Bq/cm^2 (for alpha and beta)	1 Bq/g[a]

[a] An activity concentration level of 1 Bq/g for concrete is envisaged. The level is subject to verification and final approval by the NNR.

Waste management

The current waste management system does not provide a disposal option for long lived waste. Waste with a long lived alpha concentration below an average of 400 Bq/g could be managed as short lived waste, for which a disposal option exists (near surface disposal).

Waste quantities should be minimized but not concentrated to average activity concentration levels higher than 400 Bq/g, to allow near surface disposal.

Conventional safety

Work that involves personnel activities at elevated heights and specifically on the inner surface of the stack should be minimized. Work at elevated heights, for example dismantling of the stack from the top, will result in a hazard of falling objects in and around the stack. The construction regulations of the Occupational Health and Safety Act will apply.

Radiological safety

The critical pathway for the source material involved is inhalation. Actions that result in dust generation and dispersion where operators are involved are regarded as the focus area for radiological safety. These actions should either be minimized or be well managed to ensure compliance with radiological protection standards and the ALARA principle.

Authorization

In terms of the National Nuclear Regulator Act and the Nuclear Energy Corporation of South Africa (NECSA) site authorization, the decommissioning of the stacks would be regarded as a project that requires specific authorization. Authorization is based on a submitted decommissioning plan of which the main points include the following:

— Project organization and schedule;
— Decommissioning objective and strategy;
— Prospective hazard assessment;
— Radiation protection programme;
— Non-radiological safety and environmental control;
— Material and radioactive waste management;
— Quality assurance and close-out.

I.F–5. FACTORS FOR THE SELECTION OF A DECOMMISSIONING STRATEGY

Clearance of material

Clearance of the bulk of material is essential for the decommissioning project owing to the following:

— The vast quantity of material and the inability of the current waste management system to handle bulk radioactively contaminated waste;
— The low average activity concentration of the concrete, which does not justify handling as radioactive waste;
— The cost associated with handling as radioactive waste.

The cost of decommissioning a stack is to a large extent optimized if clearance of material is achieved.

Factor 1

Pre-dismantling decontamination is necessary, ideally to the extent that clearance levels for surface contamination are reached prior to demolition.

In general, homogenization of material to achieve compliance with clearance criteria is a questionable practice. In any case, verification of compliance with clearance levels after demolition remains problematic and a significant cost factor.

Radioactive waste management

Factor 2

Waste should be minimized by applying decontamination actions and techniques that focus on areas which will result in the generation of secondary waste that is on average not concentrated beyond 400 Bq/g.

Factor 3

The stack structure must be dismantled to the stack foundation, which is slightly below ground level. The stack foundation will remain in situ.

Decontamination and decontamination techniques

A significant reduction in surface contamination is obtained by pressure water and decontamination detergent washing of the contaminated surfaces. Less surface contamination would be an advantage for subsequent decontamination, for radiation protection and for achieving clearance. Efforts should at least include reduction in the contamination levels of the inner surfaces to levels that will ensure clearance of the bulk material after demolition and homogenization.

Factor 4

A pressure water wash should be performed as a preliminary decontamination step prior to the application of more aggressive decontamination techniques.

Factor 5

The steel plenum is cleanable to clearance levels but should remain intact until after the pre-dismantling stage for effluent handling purposes.

Decontamination can be achieved by removal of the first 6–8 mm of the inner surface of the zone with the highest contamination. The propagation of contamination at higher stack elevations is expected to be significantly less (2–3 mm).

Factor 6

After preliminary decontamination, a further radiological survey of the inner surface of the stack should be performed to determine the zones and extent of contamination and contamination propagation.

The inner concrete surface of the stack is rough and can easily be removed by aggressive decontamination techniques such as diamond disc grinding.

Factor 7

Aggressive decontamination of the inner surface of the stack is necessary, preferably with the aim of achieving and verifying compliance with surface contamination clearance levels prior to demolition. Further investigation regarding an aggressive decontamination technique is required for the preparation of the final decommissioning strategy. Potential advantages related to such a technique include the following:

— Limited operator involvement;
— Small amount of dust generation;
— High level of consistency;
— Modest costs.

Decontamination and dismantling techniques

Other facilities, including sensitive and operational facilities such as the hydrogen plant shown in Fig. I.F–7, are located in the vicinity of the stacks.

Factor 8

The selected dismantling techniques should not impact on adjacent facilities. Dismantling by explosion was considered but was eliminated as an option because of the adjacent hydrogen plant.

Top-down crushing dismantling techniques have been applied in South Africa for dismantling of chemical industry stacks (Fig. 19 in the main text). Concrete rubble and reinforcing steel will drop in and around the stack and will only affect the close vicinity of the stack base. Further dismantling to separate the reinforcing steel and concrete will be necessary. Limited clearance verification will be required if inner surfaces have been decontaminated to clearance

FIG. I.F–7. Operational hydrogen plant.

levels for surface contamination. Limited operator involvement is required and the dismantling work for each stack can be completed in approximately one week.

A summary of the envisaged decommissioning strategy for the Z-plant stack is given in Table I.F–6.

TABLE I.F–6. DECOMMISSIONING STRATEGY

Actions and sequence of work	Techniques/options	Further developments
1 In situ decontamination of inner surface and stack base	Pressure water and detergent washing	Development of suitable equipment and techniques for safe and efficient work inside stacks
2 Radiological surveillance of internal surfaces for zoning purposes; radiological characterization to optimize the aggressive decontamination actions	(i) Surface contamination surveillance (ii) Contamination depth profiling	Development of suitable equipment and techniques for safe and efficient surveillance work inside stacks
3 Aggressive decontamination of zones of inner surfaces; removal of up to 8 mm of the top layer of screed; collection and management of removed material as radioactive waste in accordance with NECSA waste management procedures	Options: (i) Diamond disc grinding (ii) High pressure water (iii) Scabbling (iv) Others	Evaluation of options, including others, in terms of set criteria
4 Radiological surveillance of internal surfaces to verify compliance with clearance levels for surface contamination or to obtain sufficient information to justify compliance with activity concentration clearance levels. Additional decontamination actions and resurveillance if required	(i) Surface contamination surveillance (ii) Activity concentration surveillance	Derivation and NNR approval of activity concentration levels and applicable conditions for clearance
5 Area preparation for dismantling		(i) Determination of extent of affected zone and consideration of options for physical barriers to keep personnel out (ii) Familiarization with the new construction requirements of the OHS Act

TABLE I.F–6. DECOMMISSIONING STRATEGY (cont.)

Actions and sequence of work	Techniques/options	Further developments
6 Stack dismantling	Existing top-down crushing	Consideration of new developments in the field of dismantling
7 Further crushing/material handling and clearance verification Note: 6 and 7 can be done in parallel		(i) Evaluation of concrete handling options (ii) Evaluation of additional clearance verification requirements and techniques
8 Unrestricted release of site and close-out		Determination of the requirements for unrestricted release of site and close-out of the projects

Annex I.G

DEMOLITION OF THE G1 STACK AT MARCOULE BY TOPPLING

I.G–1. CHARACTERISTICS OF THE G1 STACK

The G1 stack at Marcoule was constructed during the first half of 1956 as a ventilation outlet for the G1 reactor, which is cooled by air. After the G1 reactor was decommissioned, the G1 stack served as a ventilation outlet for two new nuclear facilities on the site. Being no longer in compliance with regulations and having many inadequacies and uncertainties in terms of the prestressed concrete, the stack posed a potential damage risk in extreme wind or in the event of an earthquake. In 1994 it was decided that a new stack would be built to act as an outlet for the existing nuclear facilities, and that the old one would be demolished.

The G1 stack was 100 m in height, 10 m in diameter and constructed with 24 vertically stacked concrete rings consisting of nine prefabricated sections, each 3.6 m in height. It was capped by a metal deflector (about 6 m in height and weighing 50 t). The inside consisted of nine semicircular tubes constructed of steel sheet metal weighing 120 t (Fig. I.G–1).

The base of the stack consisted of the foundation, a plate and a base plate which were constructed at the site. The barrel sections were prefabricated. Construction lasted from January 1956 to June 1956.

At the base, the cylindrical portion of the stack widened to form three feet extending to a depth of 7.5 m. The base plate of the stack was formed on-site to the height of 16.7 m and then prestressed using cables. A repair carried out in 1964 included adding a concrete lining of the initial rings of the cylinder up to a level of 22.1 m. Additional prestressing with the base plate and repair of the horizontal and vertical prestressing of the barrel were also carried out, leaving only 22 rings and 43 visible cables.

The total mass of the stack was 2170 t, including:

— Concrete: cylinder 800 t, base plate 1200 t;
— Steel: internal structures 120 t, deflector 50 t.

The main radiological risk was the presence of traces of tritium. The radioactive inventory for the entire stack was estimated in 2000 to be 0.2 TBq. Samples were taken during the project and calculations confirmed lower values of the order of 0.1 TBq as a realistic inventory.

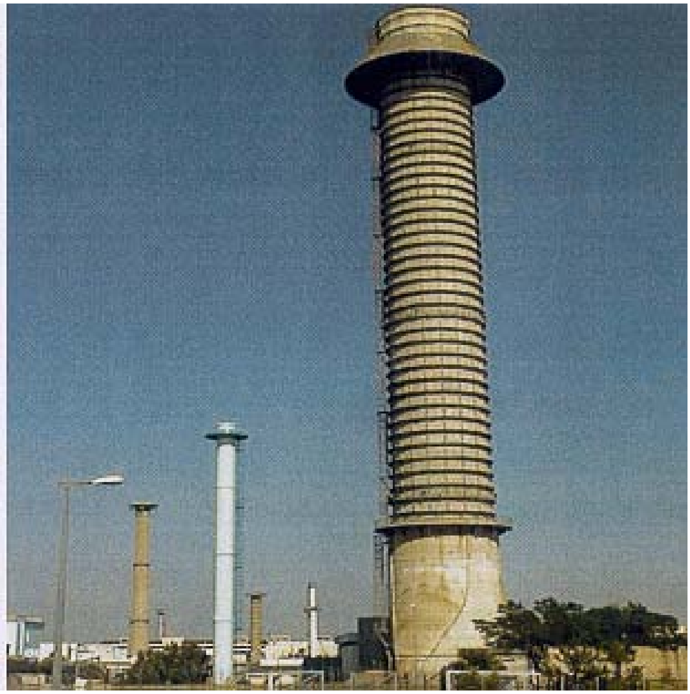

FIG. I.G–1. The G1 stack and its surroundings.

I.G–2. SCENARIO EVOLUTION AND PROJECT DEVELOPMENT

I.G–2.1. Scenario evolution

An authorization for demolition was requested in 1995. Permission was expected at the end of 1999. The initial demolition method proposed was based on a classic dismantling advancing ring by ring. The scenario presented to the Autorité de sûreté nucléaire (ASN) envisioned a crane being placed inside the cylinder with platforms including masts being set up around the stack in order to disassemble each concrete ring by removal of the nine individual sections. Demolition was planned to start in September 1999, assuming that the precondition of the active startup of the new stack had been met. However, the demolition approach was rejected by the ASN owing to the concern that the removal of the prestress by cutting the cables could cause a weakening of the stack.

At the end of 2000, the Commissariat à l'énergie atomique (CEA) questioned the demolition approach and suggested an alternative demolition solution using explosives to topple the stack, allowing a shorter work period. On 26 April 2001 the document incorporating the safety options for this new demolition method was sent to the ASN. An additional revision to the demolition approach proposed, and ultimately chosen, consisted of toppling the stack by rotation around a hinge placed under the south foot of the tripod base. The toppling plan consisted of the sawing of the south foot of the stack base and the destruction of the other two feet by explosives.

The advantages of the classic deconstruction method were:

— Little dust generation;
— Immediate removal of waste products;
— A known and tested method.

The disadvantages of the classic deconstruction method were:

— Need for working at heights;
— Use of tools at heights, with the risk of their being dropped;
— Difficulties in releasing the barrel prestress;
— Long work period;
— Implementation of the work activities in proximity to operational facilities;
— Risk of uncontrolled fall.

The advantages of the toppling method were:

— No need for working at heights;
— Absence of tools at heights;
— Short work period (except for waste management).

The disadvantages of the toppling method were:

— Risk of stack falling in the wrong direction;
— Risk of projectiles from concrete during the toppling;
— Generation of 1 t of dust;
— Need for waste management at the end of the toppling;
— Generation of vibrations;
— More media coverage.

I.G–2.2. Project development

The demolition of the G1 stack by explosives was initiated with the ANS, on 26 April 2001, on the basis of the presentation of the safety options document.

The G1 stack project progressed as follows:

- Completion of safety studies made explicit in the safety options document concerning the environmental impact (dust contamination and vibrations), modelling of the toppling, management of generated wastes, and interfaces with facilities and service networks;
- Completion of a project risk analysis;
- Securing work (foot of the stack and flues);
- Establishment of an operational command unit;
- Preparatory work for the toppling;
- Bringing the stack down;
- Management of the waste produced.

I.G–3. RELATIONS WITH THE NUCLEAR SAFETY AUTHORITIES

The qualified authority for nuclear safety for the Marcoule site is the director for the safety and radioprotection of nuclear facilities concerned with national defence. The Institut de radioprotection et de sûreté nucléaire (IRSN) provides technical support and advice.

I.G–3.1. Milestones

The main activities leading to securing of the permission for demolition are listed in Table I.G–1.

I.G–3.2. Safety principles

I.G–3.2.1. Normal design basis

The normal design basis corresponded to the stack falling along a south–north axis passing over the two north feet and impacting along this axis on the ground. Indeed, this normal condition corresponded to the stack being brought down intact until an inclination angle equal to or greater than 20° compared with the vertical was attained. Precision of the order of ±5° for the axis of the fall was planned.

TABLE I.G–1. SEQUENCE OF ACTIONS LEADING TO SECURING OF PERMISSION FOR DEMOLITION

26 April 2001	Request for approval of the safety options document for the demolition of the G1 stack by toppling
11 July 2001	Approval in principle of the safety options document for the demolition of the G1 stack by toppling given by the Commission for the Safety of Laboratories and Factories
30 April 2002	Request issued for authorization to carry out preliminary work
29 July 2002	Authorization received from the Commission for the Safety of Laboratories and Factories to carry out preparatory work for the toppling of the G1 stack
9 August 2002	Request issued for authorization to carry out demolition operations by toppling the G1 stack
13 May 2003	Authorization for demolition of the G1 stack by toppling

Within the framework of defence in depth, a stack in the vicinity (less than 10 m away) was protected by a temporary wall. The two nuclear facilities originally connected to the stack had a provisional ventilation outlet in place during the demolition operation. These facilities were also brought to a safe state through removal of nuclear materials.

In order to remain within the normal design basis condition, it was necessary to:

(a) Keep the stack intact throughout the entire work period;
(b) Limit the effects on the site of dust contamination, general contamination and vibrations resulting from the impact of the stack fall;
(c) Limit the effects on neighbouring facilities and the various services and utilities located in the vicinity from the concrete projectiles resulting from the explosion, the impact of the stack falling to the ground, the blast from the explosion, the vibrations and dust contamination due to the impact on the ground, and potential fires induced by the explosives.

I.G–3.2.2. Outside-of-design situation

The outside-of-design situation corresponded to a deviation from the plan of the intended fall of the stack to the extent that, if it fell to the south-east or to the south-west, it would impact on other facilities located in its proximity. This situation could have been caused by an unforeseen wind arising after the countdown, and the start of sawing of the south foot. Sawing of the south foot could not commence in the event of a wind speed of greater than 10 m/s.

I.G–4. MAIN WORK PHASES

The demolition project of the G1 stack was broken down into several distinct phases as follows:

— Preliminary work;
— Preparatory work;
— Preconditioning work for the demolition;
— Pre-demolition actions;
— Execution of the demolition;
— Post-demolition actions.

I.G–4.1. Preliminary work

Preliminary work consisted of preparing the logistics and securing the future worksites as well as carrying out some demolition work. The ventilation pipe connections, which were constructed of a steel core concrete pipe linking the two nuclear facilities located near the stack, were dismantled. This operation was particularly important because the connections weighed up to 13 and 5 t, respectively (Fig. I.G–2).

I.G–4.2. Preparatory work

The preparatory work authorized by the ASN involved provision of access to the stack prior to the start of preliminary work for the toppling, and prior to the start of work for the implementation of the provisional ventilation outlets.

The work carried out on the stack during this phase included disconnecting the flues on the base plate of the stack, dismantling the internal metallic structures and removing the concrete filling between the feet (Fig. I.G–3).

I.G–4.3. Preconditioning work for the demolition

The preconditioning work phase covered all the actions to control the fall of the stack and the consequences of deviation from the plan. These were

FIG. I.G–2. Removal of the ventilation piping.

FIG. I.G–3. Demolition of the filling between the stack feet.

critically important to the success of the project. All operations linked to the toppling of the stack had been authorized by the ASN.

The role of the bearing device of the stack was to control the angle of fall of the stack. The selected approach employed a hinge made up of two lower cradles and a steel axis as a pivot. The cradles were placed respectively underneath the south-west and the south-east tympanums (supporting concrete facades of the stack base). The positioning of this hinge and the mechanical properties of the installations and equipment involved in the toppling formed the essential elements controlling the success of the operation. The work required on the hinge (Fig. I.G–4) involved:

— Consolidation of a solid mass of coarse concrete at the foot of the stack;
— Reinforcement of the concrete with 17 micro-piles;
— Creation of the two lower solid support masses for the hinge and a longitudinal connecting beam;
— Fitting of the pivot;
— Creation of the upper masses and reinforcement of the two stack tympanums;

FIG. I.G–4. Consolidation of the foot of the stack with a solid mass of coarse concrete, support masses and hinges.

— Fitting of metallic support beams to reinforce the base plate of the stack;
— Drilling of the feet for placement of explosives (Fig. I.G–5);
— Creation of a ‘mattress’ (shock absorber) (Fig. I.G–6).

The details of the hinge construction are provided in Ref. [I.G–1].

I.G–4.4. Pre-demolition actions

I.G–4.4.1. Organizing the toppling

It was decided to create an operations and command unit jointly run by COGEMA and the CEA whose general role was to organize the follow-up of the preparatory phase, the demolition phase and the post-demolition actions, including the safe startup of the facilities.

I.G–4.4.2. Actions prior to demolition

The operations and command unit managed the interfaces of all actions preceding the demolition. The critical steps in the pre-demolition activity were as follows:

— Receipt of explosives;
— Securing the zones;

FIG. I.G–5. Drilling of the stack feet before blasting.

FIG. I.G–6. Construction of the mattress (shock absorber).

— Following weather reports;
— Installation of explosives and protecting the charged supports;
— Implementation of protection for neighbouring installations and equipment;
— Sensor fitting of installations and equipment;
— Cutting of the south foot (Fig. I.G–7).

I.G–4.5. Execution of the demolition

Figure I.G–8 shows the breaking of the stack during toppling. Figure I.G–9 shows the site and the stack after the fall.

I.G–4.6. Post-demolition actions

The post-demolition actions consisted of:

— Verifying that the stack had been toppled in accordance with the plan;
— Confirming that facilities and support networks had not been damaged;
— Restarting the various facilities and installations.

FIG. I.G–7. Sawing of the south foot.

FIG. I.G–8. Felling of the stack.

FIG. I.G–9. Stack and site after the fall.

I.G–5. TOPPLING FEEDBACK

I.G–5.1. Pre-toppling

I.G–5.1.1. Fall of the stack

It was important to guarantee the angle of the stack fall, and also to limit the breaking of the barrel during the toppling in order to limit the risk of impacts on neighboring facilities. Preliminary analyses demonstrated that ring 15 (level 63.8 m) was likely to burst owing to the cylinder's being bent during the toppling. In addition, a headwind of 10 m/s at the time of the toppling had to be taken into account.

The stack's predicted path during the toppling was studied in order to determine the best trade-off between the cylinders' rigidity during the fall and the risk of reverse movements due to a headwind.

The analysis allowed the pivot's position to be defined. It was installed at 1.5 m on the stack. With this configuration the rigidity of the cylinder was ensured until an angle of 21° was reached.

I.G–5.1.2. Cutting the south foot of the stack

This operation was considered the most delicate and critical of all operations during the toppling of the G1 stack. Indeed, it was an irreversible operation, since once the foot had been cut, the stack would be in a weakened state (with the prestressed cables cut). For this reason, it was envisaged that the south foot would be cut at the last moment, meteorological conditions permitting (wind speed lower than 10 m/s and assurance of stable weather conditions).

Work proceeded very well. At the end of the first cutting phases, a loud sound was noted that was probably due to the transfer of the load to the hinge. The cutting was completed in 8 hours to meet the ASN time limit of 12 hours between the start of the cutting of the south foot and the toppling.

I.G–5.2. Verification of the fall

The kinetics of the toppling of the G1 stack were recorded on the basis of a signal from the acoustic and vibration sensors.

Photographs were taken every 0.5 s and a video cassette was prepared as well [I.G–2].

During toppling the cylinder split into two distinct parts below ring 15 as envisioned. The angle at which the cylinder broke could be observed fairly accurately. The analysis thus demonstrated that the stack's path during toppling corresponded to predictions. The movement kinetics and the rupture mode of the barrel concurred with the results of the simulation calculations.

I.G–5.3. Vibrations

The vibrations and earth movements generated by the impact of the stack were weaker than the simulation study values by a factor of 2 to 4. No damage was noted at the end of the toppling operation.

I.G–5.4. Detonation effects

As indicated by detonation studies, there was no damage to windows.

I.G–5.5. Results of radiological measurements

During the two hours following the demolition, the radiological protection service carried out radiological measurements. The measurements confirmed that there were no detectable levels of radioactivity, and access to the site was reopened.

I.G–5.6. Meteorology

The radiological protection service observed Metéo France data for one month preceding the demolition. The data for the three days before the demolition and on the day of the demolition provided some assurance that there would be no change in wind speed and direction. The analysis consisted of defining the procedures for the toppling operation and of ensuring the coherence of these procedures with the data actually collected on the Marcoule site. These elements were presented to the ASN.

The meteorological data conformed to the planning criteria for cutting operations of the south foot. The forecasts established on 18 July 2003 for the following day predicted anticyclonic conditions with a weak gradient with gentle breezes resulting in a weak northerly wind of 4 to 10 km/h between 5.00 and 8.00 a.m.

I.G–6. WASTE MANAGEMENT

The CEA initially intended to store the waste in the flues of the G1 back end circuit. However, with the opening of the new storage centre for very low level waste at the Centre de stockage des déchets très faiblement actifs (CS TFA), concrete waste from the G1 stack was authorized for transport to the new centre.

The removal pathways were as follows:

- Concrete rubble to the CS TFA beginning in October 2003;
- Conventional waste to the centre for separation (concrete, metal, prestressing cables, geotextiles);
- Metal waste to the CS TFA in 2004 (piping, deflector, internal steel components).

I.G–7. CONCLUSIONS

This annex has presented the main stages of the demolition of the G1 stack by toppling.

The initial proposal to the regulatory authorities was to demolish the stack by segmentation using cranes and work platforms. The review process resulted in an alternative proposal to remove the stack by toppling, which was the method ultimately selected.

The demolition project for the toppling of the G1 stack was started in 2001 with the presentation of selected safety options documents to the ASN, which were subsequently approved. On 19 July 2003 at 7.05 a.m., the G1 stack was successfully brought down by toppling in accordance with the demolition plan.

REFERENCES TO ANNEX I.G

[I.G–1] BECKER, C., SOUBIROU, P., GENELOT, G., Demolition of the G1 Chimney at Marcoule by Toppling, Technical Note, Rep. CEA/DDCO/SPRO 2003/001, CEA, Paris (2003).

[I.G–2] COGEMA–CEA, La disparition d'un symbole, video cassette, CEA, Paris (2003).

Annex I.H

OPTION FOR THE TEMPORARY REPLACEMENT OF THE GÖSGEN NPP STACK TO ACCOMMODATE CONSTRUCTION OF THE WET STORAGE BUILDING FOR SPENT FUEL

I.H–1. INTRODUCTION

Gösgen NPP in Switzerland decided to construct a separate building on the site of the NPP to house a pool for the storage of spent MOX and high burnup fuel. The construction area adjacent to the auxiliary building offers limited space in a triangular shape, owing to the location of the plant ventilation exhaust stack (Fig. I.H–1) relative to the plant fence.

It was anticipated that these geometric conditions could complicate foundation work for the new storage building. Vibrations arising from insertion of in-ground steel slit walls (required to stabilize the excavation for the new building foundation) were expected to impact the stack foundations.

I.H–2. PROPOSED SOLUTION

During the conceptual design of the storage facility one solution proposed to avoid these potential impacts was to replace the stack with a temporary structure in a new location for the construction phase of the storage building. This would then allow the building to be enlarged, simplifying its structure and layout and facilitating the foundation work. Ultimately the permanent stack would then be constructed on top of the new storage building.

I.H–2.1. Stack dismantling proposal

(a) Stack dimensions and features

The Gösgen NPP stack is a 99 m high concrete construction of cylindrical shape reinforced with about 75 t of rebar. The mean inner diameter is 5 m, with a wall thickness of 40 cm and an inner surface area of about 1500 m^2. The total mass of concrete is 800 t.

(b) Dismantling method

The basic approach proposed for the dismantling is a proven method frequently applied to conventional stack demolition. It comprises locating a caterpillar on top of the stack equipped with concrete fragmentation tools which permit fragmentation of the stack walls. The resulting debris is allowed to fall into the interior of the stack.

Taking into account the fact that the demolition work was to be performed on a site with an NPP under full power, several measures were

FIG. I.H–1. Plan view of Gösgen NPP.

necessary to convert the conventional dismantling approach to one which could accommodate the enhanced safety requirements of an NPP site (for example, avoiding the spread of debris outside the stack is achieved by arranging the caterpillar in a tent sliding down the outside of the stack as the work proceeds).

In addition, the interior of the stack was to be maintained at below atmospheric pressure. To minimize the amount of radioactive waste, the potentially contaminated inner walls of the stack would be decontaminated by concrete milling prior to the demolition of the stack. The plan included collection of fragmentation debris in the base of the stack.

(c) Cost estimates

The dismantling costs were estimated at €250 000 over a project duration of eight weeks. The new concrete stack located on top of the new storage building was estimated to cost €1 200 000, including €250 000 for the temporary steel stack.

I.H–3. LICENSING

The advantages of this proposal were recognized by the engineers proposing the solution as well as by the utility. Informal discussions with the licensing authority revealed that this approach would not be approved. The reason was that the time period of one year during which the temporary stack would operate under full power of the reactor was considered to be too long. The authority also indicated concern over the lack of experience with stack dismantling in the vicinity of the reactor building, and the plans were therefore dropped.

I.H–4. PROGRESS OF STACK DISMANTLING TECHNOLOGIES

In the meantime, foundation work for the wet storage building has been in progress. The original plant stack remains in position but is carefully scrutinized with respect to its stability. Any stack deviation from the vertical axis towards the excavation area of the new building would be a reason to reconsider the proposal, which is considered by the utility as the backup solution.

The state of the art of dismantling of conventional stacks was reviewed, looking for applications in the nuclear area. It was recognized that there have been remarkable advances in facilitating demolition of stacks which reduce risks to adjacent facilities and which are more reliable and more efficient than was the case in the past.

A German enterprise [I.H–1] is now offering demolition services for reinforced concrete stacks based on top-down segmenting through the use of diamond circular saws.

The new approach uses a self-climbing device carrying the sawing machine; the device is capable of climbing down the inside of the stack stepwise after cutting each segment. Thus at the end of the whole procedure the climbing saw has arrived at the bottom of the stack and all segments of the stack have been removed.

The operation is either crane or helicopter supported. It results in dismantling that is much cleaner and nearly noiseless compared with fragmenting the concrete through top-down breaking.

The climbing machine comprises a lower and an upper platform connected by a vertical mast along which the platforms can slide. Each of the platforms is equipped with four drilling machines capable of drilling holes into the wall of the stack. Both platforms have four hydraulically driven bolts which are anchored into the holes. The upper platform carries two sawing machines.

The climbing machine is inserted into the stack from above by a crane or a helicopter. The lower platform drills four holes and fixes itself to the walls of the stack. Then the same procedure is repeated at the upper platform. The upper stack section is attached to the crane. The circular saws then cut the wall of the stack, producing one cylindrical section which is removed from its position by the crane.

The climbing down operation continues by shifting the lower platform downward along the mast, drilling new holes and reattaching the platform to the stack wall. The upper platform moves downward in the same way, fixing itself to the stack wall. The cutting procedure is then repeated.

The size and weight of the stack rings removed depend on the carrying capacity of the crane or helicopter.

The principle of the sequence of these operations is shown in Fig. I.H–2.

Figure I.H–3 and Fig. 16 of the main text show the application of the climbing saw for the demolition of a non-nuclear stack at a local district heating plant.

To apply the method to contaminated stacks of nuclear facilities, the workplace can be housed in a tent migrating downward with the climbing machine to control any environmental releases.

The section of stack to be removed can be wrapped in plastic sheeting prior to removal, preventing the spread of contamination. Further size

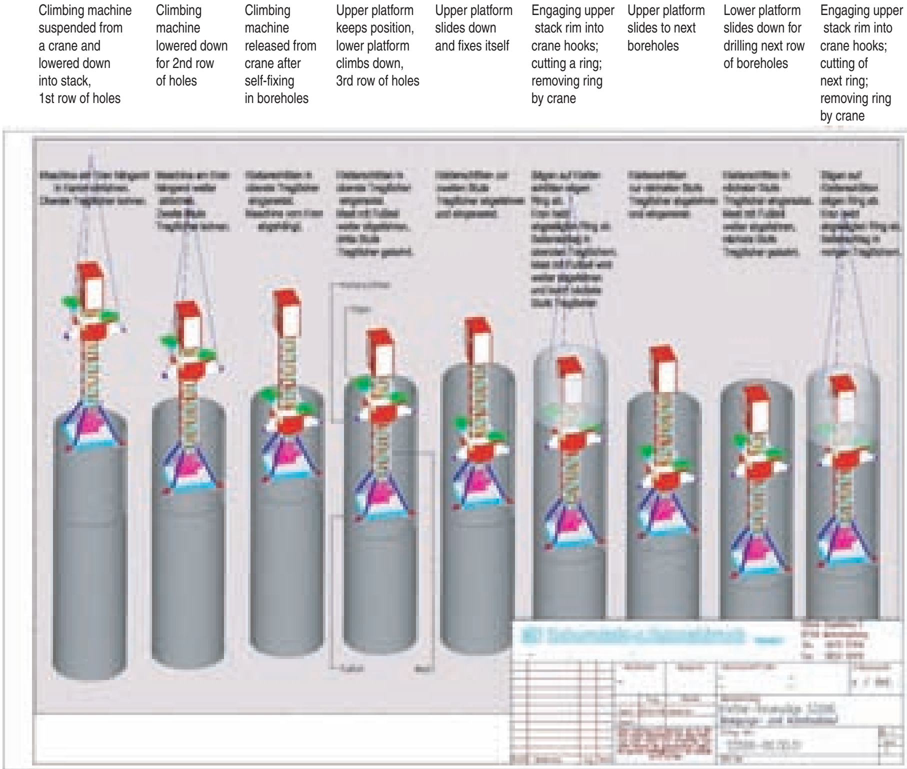

FIG. I.H–2. Working principle of the climbing saw carrier.

reduction and/or decontamination of the cut sections can be conducted in an area suited for this purpose.

REFERENCE TO ANNEX I.H

[I.H–1] MB SCHORNSTEIN & BETONABBRUCH GmbH & Co., www.mb-abbruchtechnik.de

FIG. I.H–3. View of the climbing sawing machine.

Annex II

LESSONS LEARNED

The following examples present lessons learned, some brief technical details of each decommissioning project and a description of the problems encountered. The situations described illustrate typical difficulties that arise in the planning or implementing of a stack decommissioning project. The information presented is not intended to be exhaustive. The reader is encouraged to evaluate the applicability of the lessons learned to his or her specific decommissioning project.

II–1. STRUCTURAL STABILITY

Problem

Preparation of the WR-1 ventilation stack for a lengthy (50 year) decommissioning deferment period included financial considerations relating to the emergency core cooling water storage tank located at the top of the structure. Winter heating costs alone added a significant burden to the maintenance costs of the deferment period.

Accordingly, a decision was made to empty the tank but to retain the stack in operation to meet the reactor building ventilation control requirements. However, soon after removal of the water, it was noted that the structure swayed visibly during high wind conditions. A review of the design records revealed that the mass of water in the tank was integral to maintaining the structural stability of the stack. Therefore the tank was refilled with water and the increased operating cost remained a project issue.

Solution

An analysis of ventilation requirements for the WR-1 reactor building for the deferment period showed that the original stack height of 46 m was not necessary to meet environmental release requirements. Plans were developed to assess the impact of removing the storage tank from the stack, which resulted in tank removal and elimination of future water management costs.

Lesson learned

The simple approach to managing deferment period costs indicated that simply removing the water from the tank provided an inadequate solution. In fact a more detailed assessment of the stack design was necessary to ensure that the operational safety of the structure could be maintained for the overall deferment period.

II–2. ASBESTOS GASKETS IN PIPING[1]

Problem

The unexpected discovery of asbestos in gasket material in the facility piping highlighted a serious problem during the recent decommissioning of a reactor facility at the Idaho National Engineering and Environmental Laboratory. Fortunately, the problem was discovered before the building was dismantled, and corrective actions were taken.

As the Experimental Organic Cooled Reactor (EOCR) building was being prepared for decommissioning, an investigation/characterization was conducted to determine the amount and location of all asbestos-containing materials within the facility. After identifying the location and amounts of this material, it was removed and disposed of in preparation for the explosive demolition of the building. The building had also been previously radiologically decontaminated. The plan was to use explosives to dismantle the extensive piping system at the same time that the building itself was dismantled. During the asbestos removal process it was discovered that many of the pipes contained asbestos type gaskets, which would have been subjected to high explosives during the demolition process. This could potentially have resulted in the release of airborne asbestos fibers, which would have resulted in an unacceptable environmental impact.

Solution

The dismantling schedule was delayed while all flanges were disassembled and the gasket material was removed.

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[1] Although not directly relevant to stack dismantling, this example proves that insufficient characterization of asbestos can be a serious problem in stack dismantling (see also Section II–3).

Lesson learned

Asbestos-containing materials can occur in unexpected places and a great deal of care must be exercised to identify all sources of this material before planning demolition projects to avoid undue delay.

II–3. STACK CHARACTERIZATION PLANNING

Problem

There was uncertainty concerning the possibility of asbestos being present in the gilsonite coating on the interior of the Mound facility stack. The original characterization included specific metals, pesticides and herbicides, and volatile and semivolatile organic analytes. Asbestos sampling was not included in the original characterization. The presence of asbestos would have complicated the stack demolition and required significant additional safety management.

Solution

An additional asbestos sampling and analysis campaign was required that entailed additional cost and delay. However, the absence of asbestos was confirmed.

Lesson learned

When planning stack characterization, it should be ensured that all potential contaminants and hazardous materials are considered in the sampling campaign. Overlooking key materials can lead to significant additional cost and delay.

II–4. PERSONNEL CONSIDERATIONS

Problem

The in-house labour force at the Mound facility stack resisted working in the base of the stack to clear contaminated debris. Working within the confined space and less controlled environment of the stack was new to the workforce.

Workers used sick and vacation leave to avoid the work and the one-day task took two weeks to complete.

Solution

Supervisory personnel, through employee communications and accompaniment of workers into the stack, successfully identified a team of workers to complete the task.

Lesson learned

It should not be assumed that existing decommissioning labour teams will readily adapt to new or changing working environments.

II–5. STACK CHARACTERIZATION ANALYSIS

Problem

In characterizing the Mound facility stack, the assumption was that the highest contamination would be found at the ventilation impingement point. Accordingly, representative sampling was carried out by selecting four sample areas and identifying only the impingement point sample for full, detailed isotopic analysis. Analysis proved the assumption false.

Solution

Fortunately the analysis data were adequate to make the argument that isotopic ratios were consistent throughout the stack, allowing scaling of the data to support the demolition and compliance with the waste acceptance criteria for the site.

Lesson learned

Assumptions for selecting the highest contamination area in difficult stack access areas can lead to unexpected problems. Ideally the highest contamination area would be confirmed by internal screening or, as a minimum, by screening the collected samples prior to conducting detailed analysis. Screening is a relatively quick and inexpensive way of verifying assumptions.

II–6. PUBLIC ISSUES AND CONCERNS

Problem

The removal of site stacks that have become historic landmarks can cause heightened public concern from several perspectives. One is resistance to the removal of an object that has become historically significant or that has socioeconomic implications. A second concern focuses on the safety and environmental impacts of the actual demolition.

Solution

Generally public concerns can be mitigated by an early public consultation programme. It is important to carry out comprehensive communication on the reasons for removal and on how safety to local residents and the environment will be maintained.

Lesson learned

Projects like stack demolition that are highly visible should establish early and comprehensive public communications to manage, and hopefully alleviate, public concerns.

II–7. DISMANTLING EQUIPMENT

Problem

For any nuclear decommissioning project, the required equipment is not always readily available. To design and manufacture bespoke, custom equipment is costly, time consuming and not always successful.

Solution

The solution is to adapt standard, off-the-shelf equipment to nuclear applications. For the Windscale Pile stack decommissioning, using a fork-lift truck on its side was considered to remove insulation boxes from the inside of the stack. Although this was not directly applied, it promoted the idea of using fork-lift truck forks mounted on a mobile excavator to carry out this task.

Lesson learned

The nuclear decommissioning industry can benefit from looking to other industrial applications to adapt existing proven technology to nuclear applications.

II-8. STACK DECONTAMINATION

Problem

Manual scabbling techniques were employed to remove small areas of contamination during decontamination of the Windscale Pile stacks. Because contamination cannot be seen, this often led to arguments between health physics technicians and decommissioning operatives, and to rework.

Solution

Health physics technicians used spray paint to identify areas to be scabbled to make an area of contamination visible. Once the paint had been removed, the area had demonstrably been decontaminated. A final radiological survey confirmed successful decontamination.

Lesson learned

Simple ideas and solutions are often the most effective. In this case applying paint identified the work area and provided demonstrable completion of the work.

II–9. PROTECTION OF ADJACENT FACILITIES

Problem

Many sensitive buildings that are occupied and that contain nuclear and process plant are located below the Windscale Pile stacks. Debris or equipment dropped from the stack could penetrate the roof and cause serious injury or catastrophic damage.

Solution

It was recognized that it would be impossible to make the buildings impenetrable for all objects. It was therefore decided to limit the weight of items used outside the edge of the stack to 25 kg (the weight of a 21 ft (7 m) scaffold tube), and a protective cover of timber decking was placed above the buildings to limit damage potential.

Lesson learned

It is not always possible to remove a hazard or problem completely, but a compromise can often be found through a combination of protection and limiting hazard potential.

II–10. SCAFFOLD ACCESS

Problem

Because of the size of the Windscale Pile stacks, it was considered that conventional scaffolding would not meet access requirements and that a structural access system was required, but because of a 25 kg weight limit imposed owing to the proximity of adjacent facilities (see Section II–9), this solution was not possible.

Solution

Pressed steel lightweight sections of scaffolding equipment, often used in civil engineering construction for temporary works, were evaluated and found to meet project access and weight restrictions.

Lesson learned

Risk mitigation strategies can have significant effects on other parts of the project and may require a degree of ingenuity to overcome problems effectively.

II–11. HIGH ALPHA SURFACE CONTAMINATION

Problem

Areas of high alpha contamination create personnel hazards and can make disassembly solutions cumbersome.

Solution

At the Mound facility stack, a specialist contractor, Encapsulation Technologies, developed a fogging technology to apply an aerosol coating uniformly over the contaminated surface. The application was achieved without invasively entering the contaminated zone. Loose surface contamination was reduced by a factor of over 1000.

Lesson learned

New technologies should be considered while a project is in the design phase. The act of disassembling the stack plenum was greatly simplified, with minimal personal protective equipment required for the workers.

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Nearly all nuclear installations utilize stacks to discharge ventilation air, as well as gases and fumes, from contaminated areas to the environment. Over a service lifetime that can span decades, stacks may become contaminated as a result of the deposition of radioactive substances, e.g. aerosols, on stack surfaces. In the longer term, this is a serious decommissioning issue. The contamination may be difficult to remove, depending on the operating conditions and the chemical and physical environment over time. In addition, the physical logistics of stack dismantling may be complex, for example the difficulty of severing concrete at height. Relevant aspects of stack dismantling include project planning and management, health and safety, and the management and disposal of the resulting waste. It can be assumed that generic decontamination/ dismantling technologies would also apply to these bulky components, but such treatment disregards a number of specific physical and radiological characteristics that make stack decommissioning a unique project. This report reviews and consolidates the worldwide experience available on the technical and planning aspects of stack decommissioning.

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